Diagnosis and Management of Poor Quality Water and Salt Affected Soils

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Preface

In the past, the increasing needs of expanding population for food, fuel and fiber were met from cultivating progressively larger areas of land and by intensifying the use of existing cultivated land. Under the circumstances when no more additional good quality land is available and the crop yields are stagnated, the food requirement of added population in future has to come from the reclamation and management of degraded lands which include salt affected ones also. India has world's 2.4 % of land and 4% of fresh water resources of which nearly 6.73 million hectares lands are salt affected and a sizeable area is underlain by poor quality water. With these limited resources we have to support 16% of the global population. Owing to higher allocation of good quality water to other remunerative sectors the availability of fresh water to agriculture which is the largest user, is diminishing rapidly and has to largely depend upon the low quality water resources. Therefore, another important component to achieve higher productivity could be the optimum utilization of surface waters as well as low quality groundwater and wastewaters which are still usable. The injudicious use of water is oftenly associated with the development of waterlogging, salinity, sodicity and many other environmental problems. Adequate knowledge in diagnosis and management technologies for saline and alkali lands/waters and wastewater generated from municipalities and industries is essential to obtain maximum crop production from these resources.

Central Soil salinity Research Institute, Karnal since its inception has been in the forefront to develop technologies for diagnosis, reclamation and management of salt affected soils and judicious use of poor quality waters. By executing technologies developed by the Institute, about 1.3 million hectare salt affected soils have been reclaimed which are contributing 8 to 10 million tones of food grains in the national kitty. The capacity building is another aspect of the Institute activities.

Keeping in view the technologies developed and expertise available in the field of soil salinity and water quality, Central Soil salinity Research Institute, Karnal was assigned to organize a summer/winter school on 'Recent Advances in Diagnostic Technologies and Management of Poor Quality Water/Soils' by the Indian Council of Agricultural Research, New Delhi. The school was organized at the Institute from 18 November – 08 December, 2008 in which 21 Scientists or equivalent officers from ICAR Institutes and State Agricultural Universities participated. The lectures delivered during the training are compiled and brought out in the form of a book titled 'Diagnosis and Management of Poor Quality Water and Salt Affected Soils'. The emphasis on characterization, reclamation and management technologies of salt affected soils, efficient use of groundwater including saline/sodic water, drainage effluents and wastewater for supplementing the canal water for achieving higher crop productivity was given in the course curriculum. It also covers topic related to modern methods of irrigation, salt tolerance, groundwater recharge and use of remote sensing and Geographic Information System, biodrainage, cultivation of industrial crops for the better management and higher returns from these valuable resources.

This publication has come to the reality because of financial support from ICAR, New and efforts made by the contributors who supplied the lecture notes and agreed to share their valuable experiences and thoughts. The editors of this book wish to place on record their heartiest thanks to the DDG (NRM), DDG (Education) for providing the opportunity in organizing the summer/winter school and publication of this book. The editors have special words of appreciation for all in the last but not the least to one and all that helped directly or indirectly in organization of this training programme and publication of this book.

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Salinity in Agriculture: An Overview

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Introduction

Salinity related land degradation is becoming a serious challenge for food and nutritional security in the developing world. As per FAO/UNESCO soil map of the world, a total of 953 m ha covering about 8 per cent of the land surface is suffering from salinity/sodicity (Szabolcs, 1979). The salt affected soils are reported to occupy 42.3% of the land area of Australia, 21.0% of Asia, 7.6% of South America, 4.6% of Europe, 3.5% of Africa, 0.9% of North America and 0.7% of Central America (El-Mowelhey, 1998). Australia has the world's largest area under salinity which is equivalent to about one third of the total area of the continent (Rangasamy and Olasson, 1991). Recent estimates indicate that 6.74 m ha (NRSA, CSSRI, NBSSLUP, 2006) area in India is affected by soil salinity and alkalinity with state-wise distribution of salt- affected soils.

The first approximation of ground water quality map of the country has been prepared and found that about 25% of ground waters are sodic and/or saline in the country. More than 80% of the ground water resources are of poor quality in the state of Rajasthan located in the Thar desert and are unfit for irrigation to agricultural crops. Continuous use of such waters over longer period for irrigation of field crops is resulting in large scale salinization leading to desertification in several regions of the country.

The salinity problem is becoming more serious with expanding irrigation in arid and semi-arid regions without adequate provision for drainage. Already a sizable area in the country is waterlogged and salinized in almost all the canal commands. In several irrigation commands, the water table is rising at the rate of 30 to 100 cm per year. The nature and severity of the problem varies from region to region depending upon the topographical situation, hydrological and climatic conditions, drainage availability, land use and cultural practices. A detailed review of salinity related desertification in the country and strategies to cope up with salinity has been discussed in this paper.

Characteristics of Salt-Affected Soils

Salt-affected soils in India are broadly placed into two broad groups; sodic (alkali) soils and saline soils. There are certain specific situations where saline-sodic soils also do exist. Since the management of saline sodic soils will be more similar to that of the sodic soils, they are generally grouped with the sodic soil category. The only management difference for their reclamation is that such soil needs extra water for leaching of soluble salts before amendment application. The sodic soils have higher proportion of sodium in relation to other cations in soil solution and on the exchange complex. Growth of most crop plants on sodic soils is adversely affected because of impairment of physical conditions, disorder in nutrient availability and suppression of biological activity due to high pH, exceeding even 10 in severe cases, and exchangeable sodium percentage of up to 90% or so (Kanwar and Bhumbla, 1969). Salt solutions contain preponderance of sodium carbonates and bicarbonates capable of alkaline hydrolysis, thereby saturating the absorbing complex with sodium. The sodic soils of the Indo-Gangetic plain are generally gypsum ($CaSO_4 \cdot 2H_2O$) free but are calcareous, with $CaCO_3$ increasing with depth, which is present in amorphous form, in concretionary form, or even as an indurate bed at about 1 m depth (Table 1). The accumulation of $CaCO_3$ generally occurs within the zone of fluctuating water table. The dominant clay mineral is illite. The processes which target the dissolution of $CaCO_3$ have significant role in reclamation of alkali or sodic soils. Crops like rice helps in reclaiming sodic soils (Chhabra and Abrol, 1977). These soils are deficient in organic matter, available N, Ca, and Zn. Certain micro-nutrients present problems of either deficiency or toxicity. Toxicities of Al, Mn, and Fe sometimes pose problems for wheat when over- irrigated and results in yellowing of the crop. The major factors responsible for formation of alkali soils in the Indo-Gangetic region include: irrigation with ground waters containing excessive quantities of carbonate and bicarbonate ions, rise in groundwater due to introduction of canal irrigation and salt laden runoff from the adjoining areas and undrained basins.

The inland saline lands are widespread in the canal irrigated, arid and semi-arid regions. These soils are characterized by the presence of excess neutral soluble salts like chlorides and sulphates of sodium, calcium and magnesium (Table 2). Sodium chloride is the dominant salt. High soil salinity is often accompanied by high water table, often within 2 m of soil surface. Sub soil waters are generally salty and, therefore, their use for irrigation presents major constraints to crop production. In general, these soils have good physical properties but poor natural drainage. The formation of saline soils is generally associated with the rise in water table due to introduction of irrigation and inadequate drainage.

Table 1. Some important properties of an alkali soil of Indo-Gangetic plain

Depth cm	Horizon	ECe, dS/m	pHs	$CaCO_3$% <2mm	Sand %	Silt %	Clay %	CEC cmolc/kg soil	ESP
0-10	Ap	22.34	10.6	5.1	67.5	17.6	12.2	5.4	90.7
10-48	B21	6.28	10.2	8.9	55.8	23.4	18.5	9.3	87.1
48-76	B22	4.19	9.8	9.4	46.0	29.5	22.2	9.4	88.3
76-104	B2 ca	2.34	9.5	12.6	36.2	28.4	29.3	12.6	84.9
104-163	C ca	1.31	9.6	13.8	27.4	38.4	30.7	13.8	68.8

Table 2. Physico-chemical characteristics of a saline soil from Sampla site in Haryana

Depth	Horizon	pHs	ECe dS/m	Gypsum %	$CaCO_3$ % < 2mm	Sand %	Silt %	Clay %	CEC cmolc/ kg	ESP
0-17	Ap	7.15	42.3	1.20	Nil	66.4	19.2	14.4	10.2	4.3
17-48	8B21	7.20	30.3	Tr.	Nil	60.0	20.0	19.2	16.6	6.6
48-81	1B22	7.15	24.1	Tr.	Nil	48.8	25.6	25.6	18.9	4.7
81-122	B2C	7.20	22.6	Nil	0.85	0.4	22.4	27.2	20.4	5.3
122-140	C	7.15	22.9	Nil	2.1	60.0	27.02	12.8	16.2	4.9

Salinity Related Degradation: Case Studies

Sharda Sahayak canal command area

Sharda Sahayak canal was initiated in 1978 to provide irrigation in 1.67 m ha area in 21 districts of Uttar Pradesh in north India. After the introduction of the canal, agriculture productivity markedly increased in the command area. However, non-provision of drainage and continuous seepage from the canal resulted in rise in water table and subsequent upward flux of salts to the surface soil layers. In a span of about three decades nearly 3.73 lakh ha area is inflicted with salts and rendered barren. Out of this, nearly 1.5 lakh ha area has been estimated as sodic soil with shallow water table. The present scenario is that more than 1 km area adjacent to both sides of the canal has gone out of cultivation and the farmers have almost abandoned their lands. In extreme cases more than 20 years old mango plantations started withering and drying. The Regional Research Station of this institute at Lucknow tried several options to reclaim these lands for successful agriculture. The options tried included (a) installation of an interceptor drain at a depth of about one metre to take out excess seepage water from the canal for disposal elsewhere, (b) bio-drainage to achieve higher transpiration rates by trees to lower the water table and to intercept the seepage and also (c) options of intercept drain and biodrainage. Four years results of this experiment indicated that none of these options worked satisfactorily at the site. The intercepted drain did not work because there was no outlet to take the drained water out of the affected area. After working satisfactorily for initial few years, the drain got almost choked. About a kilometer belt around the canal bank was planted with Eucalyptus trees known for very high transpiration rates. Because of very high salt concentration in the root zone soil, the species failed to yield reasonable leaf area for effective transpiration. After about three years, many of the trees look like as if they are just one year old plantation.

To solve waterlogging problem in sodic areas, a new innovation involving multiple use of water for multi-enterprise agriculture was tried on a farmer's field having one ha land holding at a distance of about 50 m from the Sharda Sahayak Canal. The options tried included digging of a pond 1.75 m deep in an area of 0.33 ha for raising fishery, 0.23 ha for growing crops and 0.22 ha for growing fruit trees mainly on the dykes of the pond. The fruit trees planted included banana, guava and amla (*Emblica officinalis*). The system is working very well and during first 7-8 months, the farmer could get Rs. 7,000/- from the sale of agricultural produce. The pond remained almost full with water for most of the time because of seepage from the canal. The fish in the pond has a weight in the range 150 to 350 grams in about 4-5 months.

Indira Gandhi Nahar Project (IGNP)

Indira Gandhi Nahar Project, earlier known as Rajasthan Canal Project, was launched to provide irrigation and drinking facilities in the arid north-west tract of Rajasthan. The project was undertaken to irrigate about 1.79 m ha area in the districts of Ganganagar, Hanumangarh, Bikaner, Jaiselmer, Jodhpur, Barmer and Churu in Rajasthan. The IGNP command area receives an annual rainfall of 300 mm in feeder canal area to less than 120 mm in Jaiselmer area. The potential evaporation varies from 1600 to 2000 mm per annum. The region can be divided into the flood plain soils (54% of the area) and aeolian soils (46% of the area). The flood plain soils are mainly fine sandy loams, deep calcareous, highly stratified with good water holding capacity. Roughly 10% soils are saline or moderately alkaline. The aeolian soils in general, are coarse textured, deep and calcareous with low fertility and are highly succeptible to wind erosion. Soils in Jamsar, Lunkaransar, Soorsar, Dattor, Sallor distributory and Khusar minor and Mohangarh are gypsiferous. The gypsiferous soils are in general shallow and found in intra-dunal flats at low lying areas. Due to the presence of hard and impervious layer, its management is little difficult.

The introduction of irrigation in desert area brought about a mini green revolution and considerable prosperity to the farmers. Some of the positive impacts of introduction of irrigation in the desert include improvement in micro climate, change in land use/ in cropping pattern, improvement of soil and moisture conditions and associated biological activities in the soils. However, after few years of the introduction of irrigation, several negative effects emerged such as rise in the water table, waterlogging, formation of marshy lands, increased soil salinity and decreased biodiversity. The current estimates indicate that about 0.18 m ha land is already affected by salinity and sodicity in the IGNP command (Table 3). The salt affected soils in this command are mainly located in Anupgarh branch, Suratgarh branch and Eastern block. The maximum area under salinity/sodicity is in the Anupgarh branch because of poor infiltration rate, high bulk density, poorly developed structure, stratification and hard crust formation in the soil. The soils are predominately clay to silty clay with medium sub angular blocky structure. They are difficult to cultivate when dry and remain wet for longer time than normal soils. Electrical conductivity in these soils varies from 0.50 to 55.0 dSm^{-1} and pH from 8.5 to 9.0. It has been observed that on both North and South sides of IGNP canal feeder (Badopal, Dabli, Seelwala and Tibi areas), the water table is within 2 m. In between Rawatsar and Maseetawali head, the problem is mainly due to seepage of canal water whereas in Lunkaransar lift canal area, the problem is of perched water table. Similarly, in part of Ghaggar flood area, the problem has developed due to water stagnation in the depressions. Fluctuations in ground water table from 1996-97 to 2004-05 were recorded. There is decline in the waterlogged area during last 5-6 years mainly due to subdued rainfall and decreased availability of water in canal.

Table 3: Area (ha) of salt-affected soils in IGNP

Salt affected class	Anupgarh Branch		Suratgarh Branch		Eastern Block	
	Area (ha)	% of area	Area (ha)	% of area	Area (ha)	% of area
Highly	73850	27.2	19930	17.1	37230	23.7
Moderately	34580	12.7	7830	6.7	--	--
Total	108430	39.9	27760	23.8	37230	23.7

Source: UNDP, F.A.O. (1971)

In sizable part of IGNP, the ground water quality is saline. The EC of ground water varies between 0.4 to 39.6 dSm^{-1}. However, development of a fresh cushion of good quality water is observed in the Ghaggar plain area. This good quality water has tremendous scope for exploitation for irrigation. Similarly, the chemical composition quality of water in the vicinity of canals is better with EC values of about 3.0 dSm^{-1}. This indicates that a fresh water quality zone is developing gradually and floating over the poor quality ground water.

Since, there is no natural drainage system, more and more areas are getting waterlogged and salinized resulting in desertification. A sizable area has already gone out of cultivation and several villages have been abandoned. In some of the extreme cases, people feel that they were better when the irrigation was not introduced in the desert area. Some of the techniques which need to be adopted for reverting desertification include adoption of better techniques of water management such as drip and sprinkler irrigation, bio-drainage to lower the water table, fixing water allowance as per irrigation capacity of land and soil profile, lining of unlined water courses including personal fields, conjunctive use of surface and ground water resources, capacity building of farmers and large scale adoption of multiple use of water for multi-enterprise agriculture with major emphasis on saline aquaculture in already waterlogged areas. Areas where water remains stagnated on the surface throughout the year can be developed as marine eco-system or as a bird sanctuary. There seems ample scope for promotion of bio-saline agriculture including cultivation of highly salt tolerant trees, bushes, grasses, aromatic and medicinal crops in this command.

Saline Aquaculture Induced Soil And Water Degradation In South Coastal Belt

In coastal areas of Andhra Pradesh many rice fields are being converted into brackish water fish farms due to high remuneration from aquaculture for more than the last decade. Farmers draw brackish water from the sea through creeks and drains into the land and store millions of gallons of this salt laden sea water on surface in big tanks. This activity is practiced upto 10 km distance along the sea coast. The stored sea water in ponds is used for raising high value prawns. Almost all the small and marginal farmers and also the progressive and big farmers are engaged in this practice as livelihood source. It is reported that nearly 2 lakh ha area is under saline aquaculture in the coastal districts of Andhra Pradesh. The pumped sea water into the fish tanks having salinity in the range of 35-40 dS/m is blended with canal or ground water to lower its salinity level to 18-20 dS/m which is suitable for cultivation of prawns. The farmers generally take two crops of prawns in a year. Initial investment for undertaking this activity is around Rs. 74-99 thousand per hectare. Each crop of prawn matures in about 4 months and yields about 2.5-3.3 tonnes per hectare of produce which gives a profit of nearly Rs. 2.53 to 3.63 lakhs per hectare. A discussion with the farmers at the site revealed that many of the small and marginal farmers are abandoning this activity and more than 50% of the farmers already abandoned their prawn ponds. They revert back to rice cultivation but are unable to grow a successful crop because of severe salinity problem in the pond soils. Probable reason advocated by the farmers for abandoning this activity is the contamination of pond waters with some fatal virus due to its mixing with drain, canal or creek water. The farmers further revealed that the whole crop of prawns is finished within few days of viral infection. As such there is no treatment for the control of this virus once it infects the prawns.

Continuous cultivation of prawns in the coastal belt for about a decade now has resulted into the serious problems of environmental degradation, deterioration in the soil and water quality and associated socio-economic concerns. Recent studies conducted by the scientists at Baptala centre of CSSRI indicated that the adjoining cultivated fields are also affected severely due to salinization leading to reduction in crop yield. A survey conducted in the adjacent fields on soils, waters and plant samples revealed that the presence of brackish water fish ponds resulted in build-up of soil salinity in nearby fields in comparison to the fields away from saline aquaculture ponds. Many of the farmers after abandoning their ponds are migrating to other areas for employment and livelihood earning. The water samples collected in Guntur, Prakasam and Nellore districts indicated values of pH, EC and SAR in the range of 7.1-9.0, 0.58-34.0 dS/m and 0.76-39.9 $(m.mole/l)^{1/2}$, respectively. In most of the cases, the ground water quality is changing into the saline water. Similarly, the analysis of soil samples collected in the adjoining fields of prawn culture ponds at a distance of 10 m and 20 m showed ECe and pH values in the range of 0.8 -19.5 dS/m, 7.4-10.2, 0.5-15.6 dS/m, 6.5-8.9 and 3.8-66 dS/m and 7.2 to 8.5, respectively, in the districts of Guntur, Prakasam and Nellore.

Salinity in Vertisols

Vertisols and associates cover nearly 257 m ha of the earth's surface (Dudal and Bramao, 1965) of which about 72 m ha occur in India. This shows that nearly 22% of total geographical area of the country is occupied by vertisols. In the central region of India known as the Deccan Plateau, the soils are derived from weathered basalts mixed to some extent with detritus from other rocks. In other areas, particularly in the south, the soils are also derived from basic metamorphic rocks and calcareous clays. Similarly, in the western region, these are derived from marine alluvium that account for nearly 19.6 m ha. Of this about 1.12 m ha are affected by salinity and waterlogging problems. These soils are generally deep to very deep heavy textured with clay content varying from 40-70%. Further, these are also low in organic carbon content, high in cation exchange capacity, slight to moderate in soil reaction and are generally calcareous in nature. Vertisols, when kept fallow during Kharif season are exposed to soil erosion hazards. Because of their inherent physico-chemical characteristics such as poor hydraulic conductivity, low infiltration rates, narrow workable moisture range, deep and wide cracks pose serious problems even at low salinity level. However, the vertisols of Bara tract in Gujarat are generally very deep (150 to 200 cm), fine textured with clay content ranging from 45 to 68% with montmorillonite dominant clay minerals. The soils exhibit high shrink and swell potential and develop wide cracks of 4-6 cm extending upto 100 cm depth. The soils are calcareous in nature having calcium carbonate ranging from 2 to 12% in the form of nodules, *kankar* and powdery form. In general, they exhibit alkaline reaction. In the recent past, Sardar Sarovar Irrigation Project with a target to provide irrigation for about 1.8 m ha of command in Gujarat has been established. The ground water quality in this region is highly saline in about 90% area. The salinity varies from 2 to 117 dS/m with a mean of 30.7 dS/m. The use of such high salinity water either directly or in conjunction with canal water for crop production is thus limited. The salts in the sub-soil are prone to mobilize to upper surface with rising ground water table. Conditions are very favourable for secondary salinization if irrigation is practiced in traditional way. The major approach for salinity management in this region will require for prevention of rise of salinity rather than salinity reduction alone. Rainfed farming systems with *in-situ* and *ex-situ* rain water conservation, harvesting, storage, recycling and tapping of perennial flows and augmentation of ground water for supplemental irrigation are some of the strategies for boosting the agricultural productivity of vertisols in arid and semi-arid regions. Another option is to go for bio saline agriculture in these soils. A large number of medicinal, aromatic, oil yielding and petro crops have been identified which can be cultivated with saline water irrigation (Singh & Singh, 1993; Singh *et al.,* 1993). Some of the promising crops included *Salvadora, Matricaria, dill (Anethum graveolens)* and *grasses* like Aeloroups and Dicanthium. More vigorous efforts are required to prevent irrigation induced salinity in the vertisols. Once such soils are salinized, these will require huge investment for reclamation.

Use of Poor Quality Waters In Agriculture

India with its 4.2% share of global water resources is supporting 16.7 per cent of global population. Nearly 85% of India's fresh water resources are being utilized in agriculture and the balance 15% in domestic and industrial sectors. Quantity and quality of ground waters are most important factors of high productivity and production. In general, the areas demarcated by water scarcity situation are also usually underlain by poor quality ground water resources. The maximum area under saline and brackish ground waters in India occurs in the arid and semi-arid regions of Rajasthan, Haryana, Delhi, Punjab and Uttar Pradesh (Minhas and Tyagi, 1998; Minhas and Samra, 2003). Percentage use of poor quality ground water resources in different States is given in Table 4. Because of scarcity of good quality water and increasing pumping cost, brackish ground waters are being increasingly utilized for irrigated agriculture. Because of more pumping of the ground water, many areas which were underlain with good quality aquifers are being contaminated in several parts of the country. Indiscriminate use of poor quality waters in the absence of proper soil-water-crop-livestock management practices is posing a serious threat to soil, animal, human and environment health. Build-up of salinity, sodicity and toxicity problems in soils with increased use of poor quality waters not only reduces crop productivity but many times effects become so severe that lands even go out of cultivation. Based on the research and experience in different agro-ecological regions of India, irrigation water resources were grouped into the good, saline and alkali waters Gupta *et al., 1994*). Based upon the degree of restrictions, two poor quality water classes were further sub-divided each into three sub groups. Since each sub group needs specific treatments and practices, this classification also serves the purpose of planning their development and management at micro niche level. Suitable guidelines based on chemical quality of water, soil texture, crop tolerance, rainfall, concentration of solutions due to evapotranspiration for using saline and sodic poor quality waters to monsoonal agriculture have been developed.

Table 4. Percentage of use of poor quality waters in different states

State	% (estimated values)	State	% (estimated values)
Andhra Pradesh	32	Gujarat	30
Haryana	62	Karnataka	38
Madhya Pradesh	25	Rajasthan	84
Uttar Pradesh	47		

Reclamation and Management Strategies

Strategies to Manage Sodic (Alkali) Soils: The chemical amendment based technology has been developed to reclaim the alkali/sodic soils (Singh *et al.*, 2003). Various components of this technology includes; field leveling, bunding, soil sampling to know the sodicity status for working out amendment dose, application of gypsum/pyrite as per requirement of the soil and its mixing in upper 10 cm soil, keeping water ponding for 5-7 days, following rice-wheat rotation for the first 3 to 4 years and growing *sesbania* during summer as green manure crop after wheat harvest in April. By adopting this technology about 1.3 m ha area has been reclaimed in the states of Punjab, Haryana and western UP (Singh *et al., 2007*). The reclaimed area is contributing 8-10 m tonnes additional food grains to the national foodgrains pool. The sodicity/alkali soil reclamation technology gives a benefit cost ratio varying from 1.29 to 2.30 and an internal rate of return 22 to 56% depending upon the level of subsidy provided by the government. In addition to food production and employment generation, the reclamation programmes have helped in minimizing flood hazards, increasing ground water recharge, reducing incidence of malaria and water borne diseases, growth in agro-based and auxiliary industries and increasing forest cover. Some of the constraints being experienced in further adoption of this technology includes; increased cost of amendments and withdrawal of subsidy, requirement of repeat application of gypsum in areas with high residual sodium carbonate waters or with shallow brackish water. Crops differ in their tolerance to soil sodicity (Abrol & Bhumbla, 1979). The relative tolerance of crops and grasses to soil exchangeable sodium per cent (ESP) is given in Table 5.

Table 5. Relative tolerance of crops and grasses to soil ESP

Tolerant (ESP: 35-50)	Moderately tolerant (ESP: 15-35)	Sensitive (ESP: < 15)
Karnal grass (*Leptochloa fusca*)	Wheat (*Triticum aestivum*)	Gram (*Cicer arietium*)
Rhodes grass (*Chloris gayana*)	Barley (*Hordeum vulgare*)	Mash (*Phaseolus mungo*)
Para grass (*Brachiaria mutica*)	Oat (*Avena sativa*)	Chickpea (*Cicer arietinum*)
Bermuda grass(*Cynodon dactylon*)	Shaftal (*Trifolium resupinatum*)	Lentil (*Lens esculenta*)
Rice (*Oryza sativa*)	Lucerne (*Medicago sativa*)	Soyabean (*Glycine max)*
Dhaincha (*Sesbania aculeata*)	Turnip (*Brassica rapa*)	Groundnut (*Arachis hypogea*)
Sugarbeet (*Beta vulgaris*)	Sunflower (*Helianthus annus*)	Sesamum (*Sesamum oriental*)
Teosinte (*Euchlaena maxicana*)	Safflower (*Carthamus tinctorius*)	Mung (*Phaseolus aureus*)
	Berseen (*Trifolium alexandrinum*)	Pea (*Pisum sativum*)
	Linseed (*Linum usitatissimum*)	Cowpea (*Vigna unguiculata*)
	Onion (*Allium cepa*)	Maize (*Zea mays*)
	Gralic (*Allium sativum*)	Cotton (*Gossypium hirsutum*)
	Pearl millet (*Pennisetum typhoides*)	

Salt Tolerant Varieties: A sizable part of the salt-affected area in India is in possession of small and marginal farmers who are themselves poor. Under such situations, chemical amendments based reclamation technology without government subsidy is not sustainable. Development of salt tolerant varieties of important field crops is an option of great promise for utilization of such areas. As most of these varieties gives significant yield without or with little application of chemical amendments. Several varieties of field crops like rice, wheat and mustard have been developed which have potential to yield reasonable economic return both in high pH alkali soils and also in saline soils (Singh & Sharma*, 2006*). In case of rice, the most promising varieties include CSR10, CSR13, CSR19, CSR23, CSR27, CSR30 and CSR36. These varieties can be cultivated in soils with pH and EC range from 9.4 to 9.8 and 6-11 dS/m. A list of salt tolerant varieties along with their level of tolerance to soil salinity and alkalinity is given in Table 6.

Reclamation of Saline Waterlogged Soils

Sub-surface drainage technology has been developed to lower the water table in saline waterlogged areas (Datta *et al., 2000*). The system consists of a network of concrete or rigid PVC pipes alongwith filter installed manually or mechanically at a designed spacing and depth below soil surface to control water table depth by draining excess water and disposing it out of the area by gravity or by pumping from an open well, called sump. The first approximation covered under subsurface drainage in India is given in Table 7.

Table 6. Recommended salt tolerant varieties

Crop	Tolerant varieties	Adaptability		
		Sodic pH_2	Saline ECe, dS/m	Coastal saline ECe, dS/m
Rice	CSR 10*, CSR 11, CSR 12, CSR 13*	9.8 -10.2	6-11	-
	CSR19, CSR23*, CSR27*, CSR30*, CSR36*	9.4-9.8	6.11	-
	CSR1, CSR2, CSR3, CSR4*, CST7-1*, SR26B, Sumati*	-	6-9	4
Wheat	KRL 1-4*, WH157	<9.3	6-10	-
	Raj3077, KRL19*	<9.3	6-10	
Barley	DL200, Ratna, BH97, DL348	8.8-9.3		
Indian mustard (Raya)	Pusa Bold, Varuna	8.8-9.2	6-8	-
	Kranti, CS52*, CSTR330-1,	8.8-9.3	6-9	-
	CST609-B 10, CS54*	8.8-9.3	6-9	-
Gram	Karnal Chana 1	<9.0	<6.0	-
Sugarbeet	Ramonskaaya 06, Maribo Resistapoly	9.5-10	<6.5	-
Sugarcane	Co453, Co1341	<9.0	ECe – 10	-

**Institute varieties released by Central Varietal Release Committee*

The socio-economic analysis of sub-surface drainage indicates that 128 mandays of employment are generated per hectare with a benefit cost ratio of 1.26 to 1.49. The internal rate of return varies from 13.3 to 14.75%. The large scale adoption of this technology has not taken place because of cost factors, difficulty in maintenance of drainage system, need of community participation, highly skilled manpower, environmental problems of drainage effluent disposal and requirement of continuous energy to pump out the drainage effluent. To address these issues involvement of farmers, sharing of construction and operating cost and government subsidy seems vital for success of sub-surface drainage technology.

Table 7. First approximation of the area covered under sub surface drainage projects

State	Name of command	Area covered, ha*
Rajasthan	Chambal	15,700
	Indira Gandhi Nahar Pariyojana	500
	Western Jamuna Canal	1450+3000*
	Bhakra Canal	1300+1000*
Punjab	South West Punjab	30+2000*
Karnataka	Upper Krishna	30
	Tungabhadra	200
	Malparbha/Ghatparbha	20
Andhra Pradesh	Nagarjuna Sagar	50
	Krishana Western Delta	50
Madhya Pradesh	Unspecified	50
Maharashtra	Uncommanded/Neera canal Command/Others	1000+1000*
Gujarat	Mahi-Kadana	150
	Ukai-kakrapar	80

Alternate Land Use Systems: A sizable part of the salt-affected soils in India is constituted by the village community lands, lands along the roads, railway tracks and other government lands reserved for specific purposes. Reclamation of such area for crop production is posing problems because of community rights on such land resources. These sites offer ample opportunities to raise salt tolerant trees, bushes and grasses to produce fuelwood, fodder and energy. An alternate technology of raising multipurpose forest tree plantation, fruit trees, agroforestry systems and other high value medicinal and aromatic crops seems quite feasible. Several salt tolerant forest and fruit species have been identified which can be grown in highly sodic and saline soils (*Singh et al., 1994; Minhas et al., 1997; Tomar et al., 2003*). The promising forest species include *Prosopis juliflora, Acacia nilotica, Tamarix articulata and Casuarina equisetifolia.* Long term field trials in a highly sodic soil revealed that *Emblica officinalis, Psydium guajava and Carissa carandus* proved highly promising in terms of growth performance and fruit production (*Singh et al., 1997*). Ten years financial analysis indicated that benefit - cost (B: C) ratio in case of Emblica was highest 2.79 followed by Carissa 1.62 and Guava 1.60.

Saline and sodic soils require special site management techniques for growing deep rooted trees. Accordingly, special site preparation techniques for growing forest and fruit trees have been developed and standardized. An augerhole technique has been developed to break the calcium carbonate hard pan present in the profile of a sodic soil at a depth of about 1 m from the surface (*Singh, 1996*). In this technique, a hole of 20-25 cm diameter and 100 to 120 cm deep is dug out with a tractor mounted augerbore. The dug out holes are refilled back with a mixture of original alkali soil blended with 3-4 kg of gypsum, 8-10 kg of FYM and about 10 kg silt (river sand). This technique ensures more than 90% tree survival in soils of pH 10.4 even after 8-10 years of planting. A number of village community lands were planted with this technique under the social forestry project funded by European Union and implemented by the state forest departments. For raising forest trees in saline soils, trench method proves better than planting either on surface or on ridges (*Tomar and Gupta, 1985*). The sub-surface planting ensures better survival and growth of trees in saline soils as the soluble salts move away from the roots of sapling and get deposited on the ridges with evaporation. Further, irrigation to saplings in trenches provides less salty soil and water regime, which favours survival and growth during the establishment stage.

For raising fruit trees, the augerhole technique has been further modified to facilitate root growth both in horizontal and vertical direction (*Singh et al., 1997*). The devised technique called pit-cum-augerhole method involves two phases of operations. In the first phase, a pit of 45 cm x 45 cm x 45 cm dimensions is dug manually and in the second phase, in the center of this pit, an augerbore of 20-25 cm diameter and 120-140 cm deep is made to facilitate root spread both in horizontal and vertical directions. The dug out pit-cum-augerbores are refilled back with original soil plus 8-10 kg gypsum, 20 kg FYM and 20 kg river sand. This technique ensures more than 80% survival of fruit trees in a soil of pH around 10. By adopting this technique several fruit species have survived and identified for highly sodic soil.

***Agroforestry*:** Several grass species have mechanism to tolerate high salt concentration in the root zone soil. Some of these highly tolerant grasses either exclude the absorption of salts from the soil and/or deposit the absorbed/translocated salts at points within the plant system which do not allow them to interfere in matabolic processes. Grasses like *Leptochloa fusca* has the potential to yield high biomass even at pH level of 10.4 and more. Similarly, *Bricharia mutica* is another salt tolerant grass, which can be grown even under prolonged waterlogged and salt situation.

Several experiments have been conducted at CSSRI, Karnal and elsewhere to study the performance of these grasses in association with salt tolerant trees like *Prosopis juliflora* and *Acacia nilotica* in a unified agroforestry system (*Singh et al., 1988; Singh, 1995*). A field study conducted at Gudha experimental farm for six years indicated that *Leptochloa fusca* has the potential to yield about 20 tonnes/ha of green biomass per annum when planted with *Prosopis juliflora* in a soil having pH of 10.4. *Leptochloa* grass has a special characterstic that it starts disappearing when sodicity level in the soil decreases. Thus, allowing the regeneration of other moderately salt tolerant grasses and other annuals. The results of this experiment clearly indicated that sodic soils can be reclaimed by growing *Prosopis juliflora* and *Leptochloa fusca* for five years. During this period, the surface soil is reclaimed and salt tolerant crops like Berseem (*Trifolium alexendrinum*), Egyption clover, oats and senji can be grown without the application of amendments. Various components of this agroforestry system are enumerated in Fig. 1.

Medicinal and Aromatic Crops: A number of medicinal and aromatic crops have been screened for salinity and sodicity tolerance in India. Crops like Isabgol (*Plantago ovata*) and Matricaria can be successfully cultivated in soils having pH of 9.5 and EC between 8-10 dS/m (*Dagar et al., 2004; Dagar et al., 2006*). Similarly, dill (*Anethum graveolens*), a spice crop and Salvadora, a non-edible oil tree can be grown in salt-affected vertisols very successfully. Industrial species like *Euphorbia* and *mulethi* (*Glycyrrhiza glabra*) also have good scope for cultivation in salty environments.

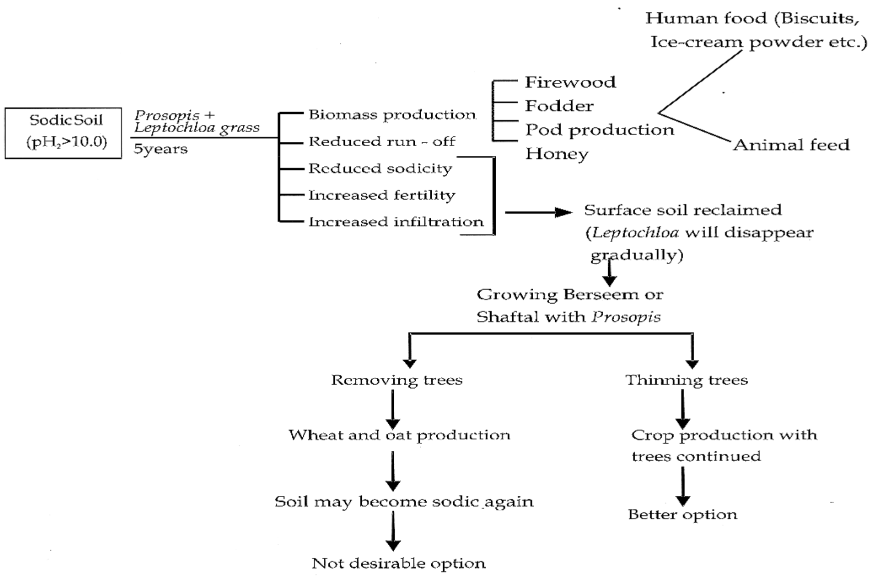

Fig. 1. Silvi-pastoral model for reclamation of sodic soils.

Soil Reclamation: Salt tolerant trees and grasses when planted either in association or as sole plantations reclaim the sodic soils over a considerable period of time. The mechanism for sodic soil reclamation by trees involves; a) dissolution of native calcium carbonate present in precipitated form in sodic soils by the biological activity of tree, grass roots, b) addition of leaf litter and turn over of old roots which increase organic carbon in the soil, c) penetration of water into the otherwise impermeable soil through the holes created by the decayed roots which facilitates reaction with CO_2 evolved from root respiration and thus producing carbonic acid. This acid, though weak in reaction initiates the process of dissolution of native $CaCO_3$. The free Ca in the soil solution available through this reaction replaces the Na ions on the exchange complex and d) initiation of biological activity in the soil due to improved organic matter contents, moisture and fertility regime. The degree of reclamation depends upon the kind of tree species, planting density, the adopted management practices and fencing provided to the plantation to check encroachment by humans and animals. Several experiments have been conducted in the past to study the reclamation effects of trees on physical, chemical and biological properties of sodic soils (*Kaur et al.,2000; 2001a ; 2001b*). The results of a long term field experiment after 20 years (planted in 1970) in a soil having pH of 10.3 indicated that *Prosopis juliflora* has the maximum impact on reducing soil pH and EC and improvement in soil organic carbon and plant nutrients. The comparative effect of different tree species on soil properties is given in Table 8.

Table 8. Ameliorating effects of tree plantation on alkali soils

Species	Original		After 20 years of planting	
	pH_2	Organic C (%)	pH_2	Organic C (%)
Eucalyptus tereticornis	10.3	0.12	9.18	0.33
Acacia nilotica	10.3	0.12	9.03	0.55
Albizia lebbeck	10.3	0.12	8.67	0.47
Terminalia arjuna	10.3	0.12	8.15	0.58
Prosopis juliflora	10.3	0.12	8.03	0.58

When salt tolerant grasses are associated with trees, the reclaiming effect becomes much faster. It has been proved that crops like gram, oats and wheat can be successfully grown on sodic soils reclaimed by tree plantations (Fig. 3). Experimental evidences indicated that productivity of these crops was much higher when soils reclaimed by trees were used in pots to raise these crops as compared to sodic soils reclaimed by gypsum application (Bhojvaid *et al*., 1996; Singh *et al*.1998).

Bio-drainage: Biodrainage refers to a technique of lowering ground water table in waterlogged areas through the use of raising tree plantations. This technique removes excess soil water through the process of transpiration by trees using solar radiation energy. It is a kind of preventive technique to avoid the development of salinity and waterlogging problem in canal command areas. The technique is highly useful when the soils are still in the process of salinization due to rise in ground water level. However, if the soils are already salinized it has limited scope. Several species of trees have been screened to study their capacity to transpire water from different salinity and water table depths. The most promising species identified for bio-drainage include *Eucalyptus*, *Populus, Casurania* and *Bambusa*. Several programmes are in progress throughout the country to reclaim waterlogged areas in canal commands through biodrainage.

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Nature and Extent of Salt-Affected Soils in India

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Introduction

Salt affected soils differ from arable soils with respect to two important properties, namely, the soluble salts and the soil reaction. A build-up of soluble salts in the soil may influence its behaviour for crop production through changes in the proportions of exchangeable cations, soil reaction, the physical properties and the effects of osmotic and specific ion toxicity. Salt- related properties of soils are subject to rapid change. Therefore, to facilitate discussion on soil management and the influence of the two common kinds of salts (neutrals and alkali salts) on soil properties and plant growth, salt affected soils are broadly grouped as either saline or alkali soils (Szabolcs, 1974; Abrol and Bhumbla, 1978; Bhumbla and Abrol, 1979).

Saline Soils

Saline soils are oftenly recognised by the presence of white salt encrustation on the surface and have predominance of chloride and sulphate of Na, Ca and Mg. in quantities sufficient to interfere with growth of most crop plants. Soil with neutral soluble salts has saturation paste pH less than 8.5. The electrical conductance of saturation extract of saline soils is more than 4 dSm^{-1} at 25^{o} C and exchangeable sodium percentage (ESP) less than 15. The sodium adsorption ratio SAR of the soil solution is generally less than 15. However, soil salinisation with neutral soluble salts of Na invariably result in soil solution SAR greater than 15. Such soils are termed Saline-Sodic (U.S.Salinity Laboratory Staff, 1954). Results of several field experiments in India and Iraq on sandy loam soils suggest a limited value of amendments in the reclamation of saline-sodic soils. However, significant responses to application of amendments can be expected in soil with inherent low permeability. When salinity and sodicity occur together, limited evidence suggests that the effect of the two factors on plant growth is nonadditive and noninteractive, and primarily salinity effects limit the growth. Many saline-sodic soils contain soluble carbonates besides the excess of neutral salts. Such soils manifest alkali soil properties. It is, therefore prudent that the saline-sodic soils that do not contain soluble carbonates be grouped and managed as saline soils and the rest of them grouped and managed like alkali soils. Due to the presence of excess salts saline soils remain flocculated and their hydraulic conductivity is equal to or slightly more than that of similar non-saline soils. Poor plant growth in saline soils results from high osmotic pressure of soil solution causing low physiological availability of water to the plant and direct toxic effects of individual ions.

Alkali Soils

Soils containing excessive salts of sodium carbonate and sodium bicarbonate and having sufficient exchangeable sodium to interfere with growth of most crops plants are called alkali. These have pH of the soil saturated paste more than 8.5, ESP 15 or more and ECe limitless if resulting from salts capable of alkaline hydrolysis.

How Alkali Soils are Formed?

The alluvium (parent material) rich in plagioclase feldspars under hydrolytic dissolution release high amount of sodium. Weathering of alumino-silicate minerals through carbonation yields solutions of bicarbonates and carbonates of alkali in addition to silica and alumina. The bicarbonates and carbonates migrate with the subterranean and surface waters and accumulate in undrained areas under arid and semi-arid conditions to form (Na_2CO_3) alkali soils.

$$\text{Na-Primary mineral} + HOH \rightarrow \text{H-silicate clay} + NaOH$$
$$\text{H-silicate clay} + HOH \rightarrow Al_2O_3.H_2O + H_2SiO_3$$
$$NaOH + CO_2\ (\text{air}) \rightarrow NaHCO_3$$
$$2\ NaHCO_3 \rightarrow Na_2CO_3\ _{(\text{leachable})}$$

Limitation of Alkali Soils for Plant Growth

Management of alkali soils present difficulties due to their physical, chemical and hydrological properties, which affect the field preparation, irrigation practices, drainage and choice of crops. Major limitations of alkali soils are:

Physical Properties

Most alkali soil exhibit impervious characteristics with slow to nil infiltration rates. The surface horizon with the highest pH, ESP, high content of sodium carbonate and platy structure is the limiting horizon. At about 1m depth 30-60 percent calcium carbonate concretion 30 to 70 cm thick layer is invariably found. Roots have to wind their way through the nodules and, therefore, find less space for growth total nutrient reserve in this horizon is accordingly low. The underground water in most of the alkali soils is non-saline and non-sodic.

Chemical and Nutritional Properties

In alkali soils chemical environment is unfavorable for plant growth. Crop failures on alkali soil results largely from toxicity of sodium carbonate and bicarbonate and osmotic effects of other salts present. Soluble and exchangeable calcium and magnesium precipitate as calcium carbonate rendering soil deficient in these elements. Availability of trace elements except molybdenum and boron decreases due to reduced solubility. Weathering under alkaline conditions results in the release of high quantities of potassium, silica and iron.

Hydrological Properties

Alkali soils have flat, very gently sloping surface and negligible infiltration rates in the surface horizon. Surface soil reclamation through application of amendments improves infiltration rates leading to reduced surface run-off losses and increased ground water recharge. Drainage of excess water accumulating on surface is accomplished through shallow ditches dug along the natural slope gradients. In those areas where water table prevails within 1 to 2m depths and is not utilised noticeably for irrigation, vertical drainage through a net work of deep tubewells is necessary. The physico- chemical characteristics of a typical alkali soil are presented in Table-1.

Table 1. Physico-chemical characteristics of a typical alkali soil from Etah (U.P.)

Depth (cm)	pHs	ECe (dS $m^{-1)}$	Particle size (%)			Inoic Compsition (me/l)						CaCO$_3$ (%)	CEC [cmol(p +)kg-1]	ESP
			Sand	Silt	Clay	Ca	Mg	Na	HCO$_3$	CO$_3$	SO$_4$			
0-16	10.2	13.84	62.0	24.0	14.0	0.6	1.6	210.0	28.0	151.0	21.0	1.9	6.7	88
16-27	10.1	12.50	57.0	25.5	17.5	1.1	1.4	190.0	20.0	129.0	13.0	4.0	7.3	87
27-64	9.7	4.60	45.0	22.0	33.0	0.5	0.8	45.0	10.0	32.0	3.0	3.8	15.9	67
64-81	9.8	1.92	38.0	35.0	27.0	1.0	1.5	19.0	13.0	4.0	1.0	2.7	13.9	78
81-108	9.4	1.88	34.0	34.0	32.0	0.5	1.5	16.0	9.0	4.0	1.0	12.0	12.9	24
108-127	9.1	2.35	39.5	33.0	27.0	0.5	0.5	21.0	10.0	7.0	1.0	23.8	12.0	31
127-148	8.6	1.40	65.0	18.0	17.0	1.3	1.4	13.0	6.0	2.0	1.0	25.0	8.0	22

Other Categories of Alkali Soils in the Indo Gangetic Plains

Some other categories of alkali soils differing slightly from the above do exist in different parts of the country. They are briefly described below:

Alkali soils with Shallow Calcic Horizon

They occasionally have a calcic horizon within 50 cm from the soil surface. The occurrence of a shallow calcic horizon is caused either by removal of the top soil by excessive erosion or accumulation of dolomitic material at reduced depths due to inadequate leaching. The main characteristics, limitations and ameliorative requirements of these are similar to soils with a calcic horizon at depths of 1m or more. A shallow calcic horizon reduces soil depth for root spread and has low nutrient reserve and water storage capacity.

Alkali Soil with a Saline Groundwater

Also exists in narrow bands in states of Punjab, Haryana and Uttar Pradesh in area having 500-700 mm annual rainfall. A shallow saline or sodic ground water when rises to within 1m depth aggravates the existing sodic conditions.

Alkali Soils Occurring in Black Soil Region (Deccan Plateau)

Due to high coefficient of swelling and shrinkage of montmorilconitic clays, black soils (vertisols) on drying develop deep cracks. Introduction of canal irrigation has rendered them either sodic or saline. At certain places even irrigation with saline water has brought about such deterioration.

Soil Characteristics

Soil matrix colours vary from grey to very dark grey, dark greyish brown and very dark greyish brown in the surface horizons and black to dark grey and dark greyish brown in the subsurface. Soil texture remain mainly clay or clay loam with major parts remaining subangular blocky in structure. With high stickiness, plasticity and cohesiveness remain workable only within a narrow range of moisture content. On drying these turn extremely hard rendering tillage impossible and so does excessive stickiness when wet. Severe limitation in alkali vertisols is the extremely slow permeability and infiltration. Montmorillonitic particles get deflocculated faster under high pH and high degree of sodium saturation resulting in disintegration of soil aggregates and sealing of pores. Under a build up of shallow water table, high capillary conductivity facilitates rise of water to the surface rendering it excessively moist, saline and unworkable. High pH adversely affects solubility and availability of iron and trace elements causing serious nutritional disorders. Molybdenum, however, may become toxic due to increased solubility at very high pH. Phosphorus deficiency is unlikely because of enhanced solubility of sodium phosphate at high pH. Unlike alkali soils of the Indo-Gangetic alluvial plains, pH and electrical conductance vary irregularly indicating different stages of alkalisation and salinisation. These differences are associated with rising water table. When the surface horizons have a high pH and high salt content the magnitude of problem becomes more serious than when such situations are confined to deeper horizons. In the latter a shallow surface soil strate may remain fit for cultivation while the deeper horizons turn unfit and threaten alkalisation of upper strata too. In these circumstances an effective depth of soil for root growth decreases accordingly.

Alkali vertisols are associated with shallow water table and impeded subsurface drainage. Due to high capillary conductivity water may rise to the surface even from 5m depth. Prevention of soil alkalisation, therefore, necessitates keeping the water table under check in deep black soils. Because of very poor infiltration, surplus rain water escapes through natural drainages, existing within the plateau. While provision of sub surface drainage is necessary for amelioration, its execution is extremely difficult. The factors contributing to low hydraulic conductivity of alkali vertisols are, excessive cohesiveness, pore sealing by sodium saturated deflocculated clay, little porosity and lack of continuous water conducting channels in the substratum. The physico-chemical characteristics of an alkali vertisol are given in Table 2.

Table 2. Physico-chemical characteristics of an alkali soil (vertisol) from district Shajapur, M.P.

Depth (cm)	pHs	ECe (dS m^{-1})	Particle size (%)			Inoic Compsition (me/l)						$CaCO_3$ (%)	ESP
			Sand	Silt	Clay	Ca	Mg	Na	HCO3	Cl	SO4		
0-13	8.3	3.5	15.0	50.0	34.5	52	5.1	26.0	6.3	23.0	2.0	8.0	8.0
13 – 31	8.4	1.7	30.0	45.5	29.5	60	1.0	7.5	9.2	6.0	2.0	7.0	7.0
31 –62	8.2	2.8	3.0	56.0	42.0	65	4.8	14.0	14.2	2.5	2.0	12.8	12.8
62- 94	9.4	1.6	4.0	52.5	43.5	73	4.9	7.8	10.2	5.0	4.0	21.2	21.2
94 –126	9.1	6.5	7.0	46.0	47.0	51	8.8	58.8	87.0	Tr	Tr	21.4	21.4
126 -158	8.7	2.4	3.0	54.0	48.0	56	5.1	17.8	8.8	1.0	0.5	18.7	18.7

Saline Soils

Due to the presence of excess salts saline soils remain flocculated and their hydraulic conductivity is equal to or slightly more than that of similar non-saline soils.Poor plant growth in saline soils results from high osmotic pressure of soil solution causing low physiological availavility of water to the plant, direct toxic effects of individual ions and complex interaction between sodium, calcium and magnesium leading to disturbed equilibrium of these ions in the plant's ability to absorb water and nutrients in required amounts. Characteristics of atypical inland saline soil of IGP are presented in table 3. In India saline soils occur under three broad groups namely; inland, coastal and delatic saline soils**.**

Table 3. Saline soil from Kalayat, Haryana

Depth (cm)	pHs	ECe (dS m^{-1})	Ca+Mg	Na	CO_3	Cl	ESP
			me l^{-1}				
0-15	7.8	61.7	87	516	2	580	7
15-31	7.7	20.2	47	147	1.5	137	8
31-68	7.6	10.4	22	86	1.3	102	8
68-103	7.7	9.4	37	50	1.6	72	7
103-145	7.6	5.7	17	36	2.0	48	8

Inland Saline Soils of the Arid and Semi-arid Regions

Highly saline soils enriched with neutral salts are wide spread in the arid to semi arid parts of Haryana, Punjab and Rajasthan states. These occur in regions with less than 550 mm mean annual rainfall. Neutral salts abound in these and maximum salt accumulation under excessively desiccating conditions happens to be in the surface horizon. These have a shallow saline water table and often remain waterlogged or even submerged for some duration each year.

Saline-Alkali Soils of the Indo-Gangetic Alluvium

These are mostly confined to regions with around 550 mm mean annual rainfall in the form of a narrow band separating the alkali and saline soils. These have a preponderance of neutral salts but contain sizeable quantities of sodium carbonates and bicarbonates. These generally have sandy to loam textural gradation and may have a calcic or a petrocalcic horizon in the substratum thereby resulting in reduced water intake.

Inland Saline Soils of the Sub-Humid Region

Sizeable area in the sub-humid parts of north Bihar has undergone secondary salinisation under the impact of operating Continental and Anthropogenic cycles.Widespread in parts of East Champaran, West Champaran, Muzaffarpur,Saron and Saharsa districts. These are unique in having developed on dolomitic alluvium containing 23 to 40 percent calcium and magnesium carbonates in fine powdery form. Although neutral salts predominate in these soils, some soils containing sizeable quantities of sodium carbonate and bicarbonate present saline-alkali nature.

Inland Salt Affected Medium and Deep Black Soils (Vertisols)

The medium and deep black soils (Vertisol) are extensive in part of Madhya Pradesh, Maharashtra,Rajasthan, Andhra Pradesh, Gujarat and Karnataka states. All vertisols have the potential to turn saline, alkali or saline-alkali and all the three situation may exist within a small geographical area. Salinisation/ alkalisation processes are associated with rising water table subsequent to introduction of canal irrigation on vertisols. Montmorillonitic (smectitic) clay minerology and high clay content (sometimes as high as 70 to 80 percent) impart unfavourable physical characteristics to these soils.The inland vertisols initially have deep water table with low degree of mineralisation.

Medium to Deep Black Saline Soils of the Deltaic and Coastal Semi-arid Region

In the deltas of the Godavari and Krishna rivers and along the Saurashtra coast in the Gujarat state saline vertisols with shallow water table prevailing mostly within 1 meter depth occur. These generally contain only neutral salts with traces of bicarbonates. With smectitic mineralogy and high clay content these pose problems similar to the inland saline vertisols. The operating marine and delta cyles however cause salinisation.

Saline Micaceous Deltaic Alluvium of the Humid Region

The deep micaceous,fine textured soils of the Ganges delta in the humid subtropical climatic region are saline to varying degrees with a perpetual shallow saline water table. These have neutral salts which owe their origin to saline substratum and saline water innundations during marine cycles and also during the origin of delta. Salt accumulation happens to be the maximum in the surface.

Saline-Humic and Acid Sulphate Soils of Humid Tropical Regions

These occur along the Malabar coast, humus rich,distinctly saline soils occupying marshy situations and undergoing seasonal periodic flooding and innundations.

Saline Marsh of the Rann of Kutch

The great Rann of kutch constitute the vast saline marsh and contains a variety of saline soil types. The process of accretion is continuing and textural stratifications are interspersed with bands of gypsum, calcium carbonate and hydrated iron oxide accumulation thus facilitating identification of separate texonomic units.

Extent of Salt Affected Soils In India

Systematic Survey Using Remote Sensing and Ground Truth

The first systematic attempt to map salt affected soils (SAS) of entire country was made in 1996 by NRSA in association with other National and State level organizations like CSSRI, Karnal; NBSS & LUP, Nagpur; AIS & LUS, Delhi; and State Government Agencies. A total of 125 false colour composite (FCC) prints of the Landsat TM satellite were used in mapping salt affected soils at 1:250,000 scale. The methodology consisted of, development of nation-wide mapping legend, interpretation of satellite data, ground truth collection, analysis of soil samples, post-field interpretation and reconciliation and area estimation. A common legend was evolved after extensive discussions with the collaborating partners engaged in either conventional or remote sensing based soil surveys. Satellite images were interpreted for broad categorisation of different types of salt-affected soils, sample areas for field verification were identified and surveyed for soil sampling and characterization The salt affected soils were classified according to norms for pH, electrical conductivity (EC) and exchangeable sodium percentage (ESP). The salt affected soil boundaries drawn earlier were modified, wherever needed, and were transferred onto base maps prepared from Survey of India topographical sheets at 1:250,000 scale. The distribution and mapping legend of salt affected soils of 15 states is shown in 125 map sheets, which are available with NRSA Hyderabad. The statewide extent is given in Table 4. It shows that maximum area of salt affected soils occur in Gujarat followed by Uttar Pradesh, Maharashtra, West Bengal, Rajasthan, Tamil Nadu, Andhra Pradesh, Haryana, Bihar, Punjab, Karnataka, Orissa, Madhya Pradesh, Andaman & Nicobar Islands and Kerala. Due to the limitation of small scale some very small and isolated patches of salt affected soils occurring in the states of Delhi and Himachal Pradesh could not be detected. The salt affected soils accounts for 67.27-lakh hectares equivalent to 2.1 per cent of the geographical area of the country. 194 out of 584 districts have salt affected soils. 4 districts, 3 distributed in Uttar Pradesh and 1 in West Bengal have more than 20 per cent of geographical area under these soils. Out of the total 67.27-lakh hectares of salt affected soils, 29.56 lakh hectares are saline and the rest 37.71-lakh hectares are sodic. Out of the total 23.47-lakh hectares salt affected soils in the IGP, 5.60-lakh hectares are saline and 17.87-lakh hectares are sodic.

Table 4. Extent of salt-affected soils India (ha)

State	Saline	Sodic	Total
Andhra Pradesh	77598	196609	274207
Andaman & Nicobar Island	77000	0	77000
Bihar	47301	105852	153153
Gujarat	1680570	541430	2222000
Haryana	49157	183399	232556
Karnataka	1893	148136	150029
Kerala	20000	0	20000
Madhya Pradesh	0	139720	139720
Maharastra	184089	422670	606759
Orissa	147138	0	147138
Punjab	0	151717	151717
Rajasthan	195571	179371	374942
Tamil Nadu	13231	354784	368015
Uttar Pradesh	21989	1346971	1368960
West Bengal	441272	0	441272
Total	2956809	3770659	6727468

The 67.27-lakh hectares area of salt affected soils reported by the NRSA and Associates (1996) did not give the split up under saline and sodic classes. This was reckoned by abstracting information from the mapping legend, kind of soils, clay minerals, climatic conditions and physiographic setting of various regions. The mapping legend prefixed with letter F represents medium and deep black soils, the letters s, n and sn denote saline, sodic and saline-sodic respectively. As per discussion on the threshold value of ESP for sodic soils in black soils region the entire mapping units prefixed with letter F (black soils) were classed as sodic. Thus most of the salt affected soils occurring in Penninsula India were sodic in nature. Further, all the mapping units denoting saline-sodic conditions in physiographic regions A, B, E and H were classed under sodic. The mapping units of salt affected soils falling in physiographic regions C, D and G were classed under saline. In Uttar Pradesh, salt affected soils occurring in Agra and Mathura districts were classed as saline while the others under sodic. In Bihar, as per the recent appraisal of Sharma and Bhargava (2002), the salt affected soils falling in Gandak command were classed as sodic.

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Recent Advances in Diagnosis of Salt-affected Soils

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Introduction

All soils contain some amount of soluble salts. Many of these act as a source of essential nutrients for the healthy growth of plants. However, when quantity and quality of salts in the soil (active root zone) exceeds a particular value, growth, yield and / or quality of most crops is adversely affected. Soil that contains excess salts which impairs its productivity is called salt-affected. The degree of adverse effects depends upon the type and quantity of salts, type of crop, variety, stage of growth, cultural practices, and environmental factors (temperature, relative humidity, and rainfall *etc.*). Development of salinity and waterlogging is a serious problem in arid and semi-arid regions of the world and threatening the sustainability of irrigated agriculture. According to Dudal and Purnell (1986), salt-affected soils occupy nearly 7 % of the world land area.

Based on pH of the saturation paste (pHs), electrical conductivity of the saturation extract (ECe) and exchangeable sodium percentage (ESP), USDA (Richard, 1954) classified these soils into three categories *viz.* saline, alkali and saline–alkali soils (Table 1). Russian scientists (Kovda,1965) have classified these soils into solonchak (based on % soluble salts) and solonetz (based on ESP) soils. Australian scientists (McIntyre, 1979) have classified these soils into three categories *viz.* saline (based on soluble salts), sodic (based on ESP) and alkaline (based on pHs). Saline soils refer to soils that contain sufficient soluble salts to impair their productivity. Alkali soils are defined in term of productivity as influenced by exchangeable sodium. Saline-alkali soils contain both excess of soluble salts and exchangeable sodium. This definition was adopted from the work of Sigmond (1938). Direct toxic effect of Na^+ and other cations and anions was not considered in their definitions.

Table 1. USDA classification of salt-affected soils

Type of soil	ECe, dSm^{-1}	ESP	pHs
Saline soils	>4.0	<15	<8.5
Alkali soils	<4.0	>15	>8.5
Saline-alkali soils	>4.0	>15	>8.5

Saline Soils

Saline soils, also known as solonchaks are those, which contain appreciable amounts of soluble salts, so as to interfere with plant growth. ECe of the soil is > 4 dSm^{-1}, pHs < 8.5, and ESP < 15. Chemical characteristics of some of the saline soils are given in Table 2 (Chhabra, 1996).

Table 2. Chemical properties of some saline soils

pHs	ECe (dSm^{-})	SAR	Concentration of ions in the saturation extract, $meqL^{-1}$							
			Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	CO_3^{2-}	Cl^-	SO_4^{2-}
7.30	2.2	4.14	11	2.2	6.9	7.2	2.9	Nil	12	13
7.60	26.6	54.42	260	5.5	16.1	24.0	4.2	Nil	110	249
7.20	32.3	37.75	252	6.1	36.6	62.8	3.8	Nil	285	114
7.45	27.9	22.76	174	17.3	44.9	72.0	4.8	Nil	224	104

Alkali Soils

Alkali soils also known as sodic or solonetz are those which have high pH, high ESP and contain low concentration of soluble salts. These soils have pHs > 8.5, ESP >15 and ECe < 4 dSm^{-1}. Chemical characteristics of a typical alkali soil of the Indo-Gangetic plains of India are given in Table 3. Due to these characteristics, alkali soils are highly dispersed and have poor physical properties. Some times distinction is made between alkali and sodic soils especially for the Vertisols where the term sodic is preferred because in those soils in contrast to the alfisols, pHs increases slowly with increase in ESP.

Table 3. Chemical characteristics of surface15 soil of a typical alkali soil of Indo-Gangetic alluvial plain.

pHs	ECe (dSm^{-})	SAR	Concentration of ions in the saturation extract, $meqL^{-1}$							
			Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	CO_3^{2-}	Cl^-	SO_4^{2-}
10.6	22.34	96.0	248.3	0.70	0.20	0.40	141.6	136.2	6.60	3.90

Type of Salt-Affected Soils and Method of Their Reclamation

Reclamation of saline soils involves removing excess soluble salts from the root zone through leaching and lowering of the water table by providing surface and subsurface drainage. While reclamation of alkali soils involves application of chemical amendments to lower down ESP and pH and to leach the reaction products below the root zone. In case of saline-alkali soils both leaching of excess soluble salts and lowering of high ESP are required for successful crop production. Since in nature, most of the salt-affected soils of Indo-Gangetic plains of India and else where in the world are high in pH, have high ESP and contain high amounts of soluble salts (Table 4), these have been classified as saline-sodic/alkali as per the criteria proposed by USDA (Bhargava, 1972; Bhumbla *et al*.,1973; Bhargava and Abrol, 1978). However, large-scale reclamation of such soils has been achieved through application of chemical amendments like gypsum to lower down ESP and pH of the soil (Chhabra, 1996). Excess soluble salts present originally in those soils got leached down slowly and slowly along with the reaction product and moved out of the root zone. In these soils conventional sub-surface drainage was neither necessary nor feasible because of their low hydraulic conductivity. Hence such soils were reclaimed by treating those as alkali soils only.

Considering these points Abrol *et al.* (1980) pointed out that level of ECe should not be criteria for classifying a soil as alkali soil. Based on the chemical composition of the saturation extract, they observed that instead of total salt concentration as measured through ECe, nature of the soluble salts should be stronger and reliable index for distinguishing alkali soils from the saline soils. They observed that alkali soils contain soluble salts capable of alkaline hydrolysis and are predominately CO_3^{2-} and HCO_3^- of Na^+. While saline soils contain neutral soluble salts of Cl^-, SO_4^{2-} of Na^+, Ca^{2+} and Mg^{2+}. CO_3^{2-} are absent from saline soils. They also lowered the limit of pHs from 8.5 to 8.2 because the precipitation of $CaCO_3$ which is a prerequisite for the formation of alkali soils, starts at that pHs. Further, for alluvial soils of the Indo-Gangetic plains, the ESP of 15 corresponded to pHs of 8.2. Using these criteria most of the soils which were earlier classified as saline-alkali should be classified as alkali soils (Table 4 & 5) and reclaimed by application of chemical amendments.

Table 4. Composition of saturation extract of alluvial salt-affected soils of Indo-Gangetic plains of India

Location of profile	Concentration of ions in the saturated extract, $meqL^{-1}$							
	Na^+	Ca^{2+}	Mg^{2+}	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}
CSSRI Farm, Karnal, Haryana	248.3	0.70	0.20	0.40	141.6	136.2	6.6	3.9
CSSRI Farm, Karnal, Haryana	1084.3	0.80	0.40	3.60	560.0	236.0	273.6	19.6
Guda, Karnal, Haryana	39.6	Tr.	0.25	2.30	138.0	47.6	38.0	21.5
Kurwal, Etah, U.P.	14.0	0.50	1.70	0.20	149.0	27.5	13.7	22.4
Dhadha, Partapgarh, U.P.	70.0	Tr.	0.50	0.10	392.0	63.5	12.0	25.0
Nauner, Mianpuri,U.P.	70.2	0.40	1.20	0.10	105.0	182.0	74.5	29.5
Hirapur, Aligarh, U.P.	74.0	1.70	2.20	0.40	132.0	21.0	19.0	3.0

Solution of Saline-Alkali Soils

Theoretically, soils having pHs > 8.2, ESP > 15 and ECe > 4 dSm^{-1} are referred to as saline-alkali soils. When cropped directly *i.e.* without adopting any soil amelioration measures, plants in these soils suffers due to adverse effects of high pH, high ESP/SAR and high concentration of soluble salts. Such soils are formed under a situation when irrigation is given with high RSC water leading to precipitation of soluble and exchangeable-Ca^{2+} of the soil as $CaCO_3$. This enables Na^+ to enter exchange complex leading to increase in ESP and rise in pH, especially of the surface layers. Mostly such soils occur in the geographically transitional zone of alkali and saline soils. Further, soils having high pH and high ECe as in alkali soils formed in *situ*; soils having high pH and high ECe formed due to use of high RSC waters and soils with moderate pH but high SAR and high EC formed due to shallow saline water table high in SAR are all classified as saline-alkali soils. While all the three categories need different reclamation measures. This creates a lot of confusion in the mind of soil survey officials, planners and developing authorities.

Table 5. Classification of salt-affected soils of Indo-Gangetic plains based on pH, EC, ESP & nature of soluble salts

Location of profile	pHs	ECe, dSm^{-1}	ESP	SAR	Old Soil classi-fication	CO_3^{2-} + HCO_3^-/ Cl^-+ SO_4^{2-}	Na^+ / Cl^-+ SO_4^{2-}
CSSRI Farm, Karnal	10.6	22.3	96.0	370	Saline-sodic	26.46	Alkali soil
CSSRI Farm, Karnal.	9.0	102.3	95.5	1400	Saline- sodic	2.72	Alkali soil
Guda,Karnal, Haryana	10.3	22.6	92.4	678	Saline-Alkali	3.12	Alkali soil
Khiranwali Kapurthala Punjab	9.5	4.8	69.3	21	Saline-Alkali	0.66	Saline-Alkali soil
Kurwal, Etah, U.P.	10.5	14.4	89.4	204	Saline- sodic	5.68	Alkali soil
Dhadha, Partapgarh, U.P.	9.8	30.4	92.5	940	Saline-sodic	12.31	Alkali soil
Nauner, Mianpuri, U.P.	10.4	29.3	95.4	414	Saline-sodici	2.76	Alkali soil
Hirapur, Aligarh, U.P.	10.7	12.4	93.0	125	Saline-sodic	3.83	Alkali soil

An examination of the composition of saturation extract of these soils shows that these are either to be treated as saline or alkali for the purpose of adopting a reclamation technique. In contrast to saline soils, these contain sufficient amount of CO_3^{2-} and in contrast to alkali soils their saturation extract contains high amounts of Cl^- and SO_4^{2-} . Chhabra (2003), proposed that when these soils have either $(CO_3^{2-} + HCO_3^-) / (Cl^- + SO_4^{2-}) > 1$ and / or $Na^+/ (Cl^- + SO_4^{2-}) > 1$ then these are to be treated as alkali soils. But when such soils have both $Na^+/ (Cl^- + SO_4^{2-})$ and $(CO_3^{2-} + HCO_3^-) / (Cl^- + SO_4^{2-}) < 1$, then irrespective of their pH and SAR, these soils are to be treated as saline soils (Table 6).

Table 6. Criteria for classification of salt-affected soils as applicable to alluvial Indo- Gangetic plains

Soil properties	Saline soils	Alkali soils
pHs	< 8.2	> 8.2
ESP	< 15	>15 > 5 for Vertisols. EMgP should also be considered along with ESP for Mg rich soils.
ECe	>4 dSm^{-1}	Variable, mostly < 4 dSm^{-1}
Nature of soluble salts	Neutral, mostly Cl^- and SO_4^{2-} of Na^+,Ca^{2+}& Mg^{2+}. HCO_3^- may be present but CO_3^{2-} are absent. $(CO_3^{2-} + HCO_3^-) / (Cl^- + SO_4^{2-}) <1$ $Na^+/ (Cl^- + SO_4^{2-}) <1$.	Capable of alkaline hydrolysis, preponderance of HCO_3^-,CO_3^{2-} & silicates of Na^+. $(CO_3^{2-} + HCO_3^-) / (Cl^- + SO_4^{2-}) >1$ $Na^+/ (Cl^- + SO_4^{2-}) >1$.
Nature of insoluble salts	May contain gypsum.	Always contain free calcium carbonate.

Considering this, soil of Khiranwali, Kapurthala, Punjab in the Table 5 is to be classified as alkali soil and reclaimed through application of chemical amendments. Further, in Mg-rich soils, in addition of ESP, exchangeable magnesium percentage (EMgP) should also be considered as an index of soil physical problems. Because it has been observed that Mg^{2+} behaves like Na^+ when it is in excess over Ca^{2+} is soil exchange complex. Based on these criteria soils of various irrigation commands of Bihar, India which were earlier classified as saline-alkali soils (Pandey, 1986) are to be classified as alkali soils (Table 7 A & B).

Table 7. Chemical properties of salt-affected soils of Bihar, India and their classification based on pH, EC, ESP/ SAR and nature of soluble salts as per the criteria of Chhabra (2003).

(A) Composition of saturation extract

Location of profile	Concentration of ions in the saturated extract, $meqL^{-1}$							
	Na^+	Ca^{2+}	Mg^{2+}	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}
Bijaipur, Gandak ommand	1480.0	4.01	4.52	5.50	125.0	80.0	70.0	360.6
Bangaon, Kosi Command	78.5	0.25	0.75	0.20	19.0	12.5	22.0	22.8
Garhani, Sone Command	70.0	0.21	1.80	0.03	7.5	8.5	22.2	30.3

(B) Chemical properties and classification

Location of profile	pHs	ECe, dSm^{-1}	ESP	SAR	Old Soil classi-fication	CO_3^{2-} + HCO_3^-/ Cl^- + SO_4^{2-}	Na^+ / Cl^-+ SO_4^{2-}	Present Soil classi-fication
Bijaipur, Gandak Command	10.3	36.8	91.4	717	Saline-sodic	0.48	3.44	Alkali soil
Bangaon, Kosi Command	10.2	4.6	61.9	111	Saline-sodic	0.70	1.75	Alkali soil
Garhani, Sone Command	10.1	3.0	50.5	70	Saline-sodic	0.31	1.33	Alkali soil

Table 8. Characteristics of salt-affected soils of village Subhankarpur, district Madhubani, Bihar, India

Soil depth, cm	pH_2	ECe, dSm^{-1}	SAR	Concentration of ions in the saturated extract, $meqL^{-1}$						
				Na^+	$[Ca^{2+}+ Mg^{2+}]$	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}
Profile 1										
0 – 9	9.6	3.8	28.2	31.3	3.5	0.1	7.0	9.0	3.0	2.0
9 - 40	9.0	0.9	5.7	5.9	3.0	0.2	nil	6.0	3.0	2.0
40 - 76	8.6	0.5	1.7	2.2	3.5	0.1	nil	3.0	2.0	1.5
76 - 140	9.1	0.9	4.1	5.0	3.0	0.1	nil	6.8	2.0	1.0
+ 140	8.8	0.8	2.1	3.5	6.0	0.1	nil	4.0	4.0	5.0
Profile 2										
0 - 12	8.5	1.1	8.1	8.1	2.0	1.6	nil	4.0	7.0	5.0
12 - 30	9.0	1.6	14.3	14.3	2.0	2.6	5.0	10.5	2.0	3.3
30 - 85	8.5	0.7	6.1	4.3	1.0	1.1	nil	5.0	7.0	2.5
85 -124	10.1	8.0	74.4	74.4	2.0	3.2	8.0	41.0	6.0	3.0
+124	8.9	6.2	87.3	61.7	1.0	1.4	7.0	40.0	4.0	7.0

Similarly, because of their high pH and high SAR, Sharma and Jha (1989) classified salt-affected soils of Madhubani, district of Bihar, India (Table 8) as saline-alkali soils. But these soils which have been formed due to irrigation with high RSC waters and their $(CO_3^{2-} + HCO_3^-) / (Cl^- + SO_4^{2-}) > 1$ and $Na^+/(Cl^- + SO_4^{2-}) > 1$. When an attempt is made to leach excess soluble salts from these soils their pH and ESP increases and there is a decrease in infiltration rate. Such soils can not be reclaimed without the application of chemical amendments, which is required to lower their ESP and pH. Alternatively when gypsum is added to treat high RSC of irrigation waters, which is the cause of formation of such soils, these get reclaimed with out provision of extra leaching and drainage. However, when such soils have both $Na^+/(Cl^- + SO_4^{2-})$ and $(CO_3^{2-} + HCO_3^-) / (Cl^- + SO_4^{2-}) < 1$, then irrespective of their pH and ESP / SAR, these are to be treated as saline soils (Table 9 & 10).

Table 9. Chemical properties of salt-affected soils of Gohana (Haryana) and their classification based on pH, EC, ESP/SAR and nature of soluble salts as per the criteria of Chhabra (2003).

(A) Composition of saturation extract

Location of profile	Concentration of ions in the saturated extract, $meqL^{-1}$						
	Na^+	$[Ca^{2+} + Mg^{2+}]$	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}
Bali	43.3	30.0	0.27	0.93	3.03	54.1	ND
Imoi	22.3	10.2	0.27	0.94	8.02	28.6	ND
Katwa,	38.1	34.1	0.21	0.90	4.21	40.4	ND
Riwara	49.0	48.8	0.28	2.27	8.90	67.1	ND
Lath	125.1	58.8	0.31	0.56	3.75	149.0	ND

(B) Chemical properties and classification

Location of profile	pHs	ECe, dSm^{-1}	SAR	Old Soil classi-fication	$[CO_3^{2-} + HCO_3^-] / [Cl^- + SO_4^{2-}]$	Na / $Cl^- + SO_4^{2-}$	Present Soil Classification
Bali	8.12	5.85	11.2	Saline-alkali	0.80	0.066	Saline
Imoi	8.34	2.51	9.9	Saline-alkali	0.78	0.313	Saline
Katwal	8.20	4.68	9.2	Saline-alkali	0.94	0.126	Saline
Riwara	8.00	6.84	9.9	Saline-alkali	0.73	0.167	Saline
Lath	8.12	12.08	23.1	Saline-alkali	0.84	0.029	Saline

Source of data: Singh (1995)

Table 10. Properties of high-SAR saline soils and their classification as per criteria of Chhabra (2003).

(A) Composition of saturation extract

Location of profile	Concentration of ions in the saturated extract, $meqL^{-1}$								
	Na+	Ca_2^+	Mg_2^+	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	
Sampla, Rohtak, Haryana	102.5	326.4	163.2	ND	Nil		1.3	590.0	ND
Sampla, Rohtak, Haryana	97.5	500.8		2.53		Nil		680.4	60.7
Gohana, Haryana	975.0	125.7		ND	Nil		7.1	645.0	448.7
CIRB,Hisar, Haryana	700.0	64.2	170.7	ND	Nil		2.4	820.0	ND
CIRB,Hisar, Haryana	440.0	283.9	297.2	ND	Nil		10.0	950.0	ND
Lunkarnsar, Rajasthan	2.1	4.50		0.14	Nil		1.8	4.5	ND
Lunkarnsar, Rajasthan	125.0	117.8		0.52	Nil		1.1	268.5	ND

(B) Chemical properties and classification

Location of profile	pHs	ECe, dSm^{-1}	SAR	Old Soil classi-fication	$[CO_3^{2-} + HCO_3^-] / [Cl^- + SO_4^{2-}]$	Na / $Cl^- + SO_4^{2-}$	Present Soil Classi-fication
Sampla Rohtak, Haryana	7.2	42.30	6.6	Saline soil	0.002	0.17	Saline
Sampla, Rohtak, Haryana	7.3	65.97	18.8	Saline-alkali	Nil	0.14	Saline
Gohana, Haryana	8.1	63.8	123.0	Saline-alkali	0.007	0.89	Saline
CIRB, Hisar, Haryana	8.2	66.20	64.6	Saline-alkali	0.003	0.85	Saline
CIRB, Hisar, Haryana	7.5	69.40	25.8	Saline-alkali	0.010	0.46	Saline
Lunkarnsar, Rajasthan	8.2	0.55	1.4	Saline	0.400	0.47	Saline
Lunkarnsar, Rajasthan	8.0	25.10	16.3	Saline-alkali	0.004	0.47	Saline

Source: Rao *et al.,* (1986, 1987 &1991)

It is commonly apprehended that when such soils are leached there is disproportionate reduction in ECe andSAR. That may lead to rise in pH and subsequent dispersion of clay particles making these soils difficult to leach. Their apprehensions are based on the fact that in general on dilution, ECe decreases linearly while the SAR which depends upon the activity ratio of the ions in the soil decreases as a square root function [SAR= $Na^+/\sqrt{(Ca^{+2} + Mg^{+2}/2)}$]. Such phenomenon may lead to the physico-chemical process of alkalinity production during leaching due to hydrolysis of exchangeable sodium leading to increase in soil pH and reduction in soil permeability. But various studies done with soils where $Na^+/(Cl^- + SO_4^{2-})$ ratio is < 1 *i.e.*

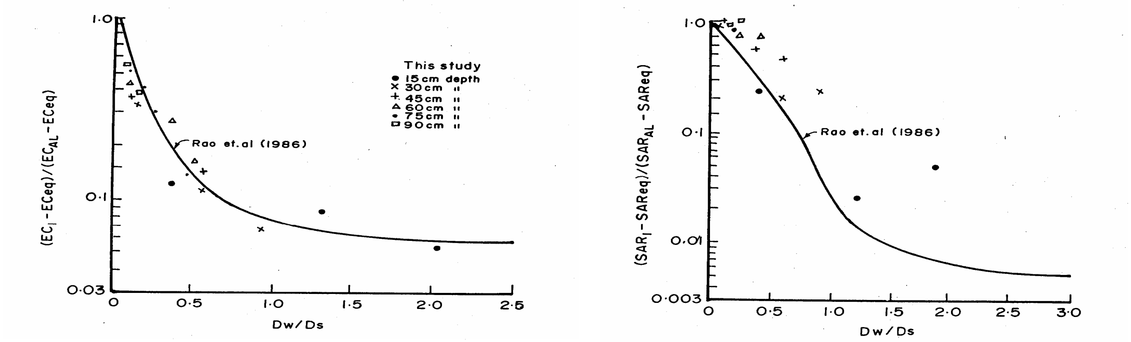

Fig. 1 Changes in salinity and SAR of a saline-sodic soil of Gohana,

when Cl^- and SO_4^{2-} are the dominant anions and are in excess of Na^+, such a hydrolysis is not possible. Their dominance keeps enough Ca^{+2} and Mg^{+2} in the soil solution to prevent hydrolysis of exchangeable-Na. Under such situations, both SAR and ECe decreases with leaching as reported by Khosla *et al.* (1979), Fig.1 and Rao *et al.* (1986, 1987), Fig.2 . Further, there is no need to apply any chemical amendments to improve their physical conditions (Khosla *et al.,*1979). Rao *et al* (1987) found that when leaching such soils, the infiltration rate remained stable and soil pH did not increase above the limiting value of 8.2. Hence based on the composition of their saturation extract and the strategy to be adopted for their reclamation, the soils previously classified as saline-alkali because of their high pH, high ESP/SAR, high ECe are to be treated as either saline or alkali. This will avoid the confusion in the minds of planners and the developing agencies undertaking reclamation and rehabilitation of salt-affected soils.

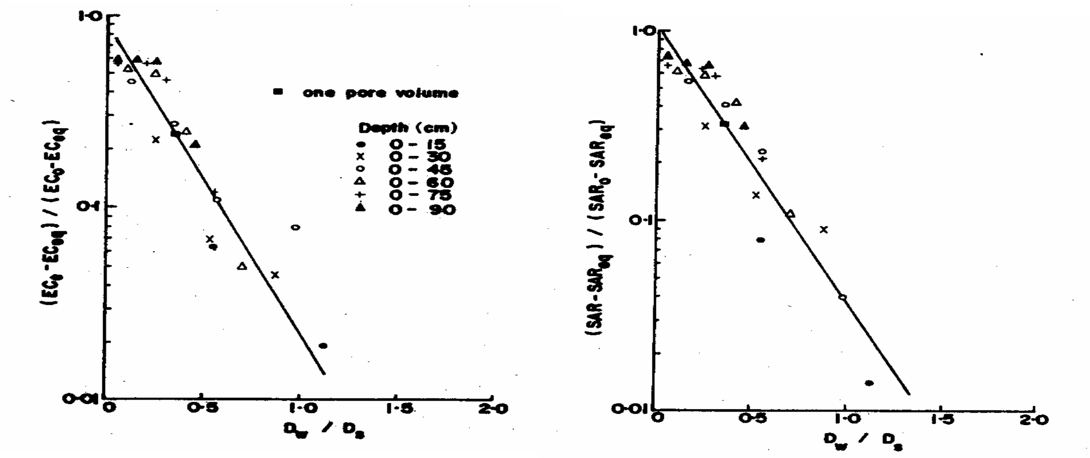

Fig. 2. Leaching and desodication curves of a high-SAR saline soil at CIRB, Hisar

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Reclamation and Management of Alkali Soils

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Introduction

To provide for an increasing population, India would have to increase its grain production multifold. Assured irrigation, increase in use of fertilizers, better varieties and plant protection measures have helped to increase the yield per unit area. Considering its limitations for further increase, and shortage of arable land, efforts have been made to reclaim and bring salt-affected lands under crop production, which were hitherto considered unprofitable.

Salt-affected soils occupy an estimated 952.2 m. ha of land in the world. This constitutes to nearly 7% of the total land area and nearly 33% of the area of potential arable land. As per estimates prepared out of 8.4 million ha of salt-affected soils, 2.4 million ha are alkali, 3.8 million ha are saline while the rest 2.185 million ha are coastal saline soils Singh (1992), These soils are mostly found in the states of U.P., Haryana, Punjab, M. P., Bihar and A. P. In the last 25 years 1.1 million ha of alkali soils have been reclaimed in the states of Haryana, Punjab and U.P. These have contributed to the additional grain production of 10 million tonnes of food grain annually. Reclamation of alkali soils have also decreased the incidents of floods and malaria and increased the groundwater recharge.

Alkali Soils

Alkali soils also known as sodic or solonetz soils, have pH of the saturation paste more than 8.2, exchangeable sodium percentage (ESP) more than 15 and soluble salts, mostly carbonates and bicarbonates of sodium, capable of alkaline hydrolysis. The ratio between soluble Na and Cl + SO_4 is always more than one. The electrical conductivity of saturation extract (ECe) of these soils is variable. Under natural conditions, all alkali soils are calcareous in nature and contain 2 to 4 % amorphous $CaCO_3$ in the surface and a hard kankar pan, mainly dolomite, of variable thickness and depth below the surface. The zone of calcic horizon possibly indicates the zone of shallow water table fluctuations. Physico- chemical characteristics of a representative alluvial alkali soil are given in table 1.

Table 1. Physico-chemical characteristics of an alkali soil in the alluvial region of Karnal Haryana.

Depth (cm)	Clay (<2μ) %	pHs	ECe (dS m^{-1})	ESP	$CaCO_3$ <2 mm) %	O.M., %
0 -10	12.5	10.6	22.3	96.0	5.1	0.25
10 -48	18.9	10.2	6.3	91.0	8.9	0.16
48 – 76	22.7	9.8	4.2	88.2	9.4	0.12
76 – 104	21.2	9.5	2.3	85.0	12.6	0.08
104-163	31.8	9.6	1.3	69.2	13.8	0.06

Source: Bhargava and Abrol (1978)

Factors Affecting Plant Growth in Alkali Soils

Plant growth, yield and quality of crops in alkali soils are affected by the following factors:

i) Poor water and air permeability as a result of high dispersion of soil aggregates and clay particles.
ii) Low water availability due to poor conductance from the lower to the upper soil layers and restricted effective root zone.
iii) Hard crust on the surface layer which greatly hinders the seedling emergence and reduces the germination percentage and thus plant population.
iv) Deficiency of Ca because, soluble and exchangeable Ca is precipitated as in-soluble $CaCO_3$.
v) Excess of Na which is toxic to the plants and causes imbalance due to antagonistic effect on K and Ca nutrition.
vi) Toxic concentration of HCO_3^- and CO_3^{2-} ions.
vii) Decreased solubility and availability of micro-nutrients like Zn, Fe, and Mn due to high pH, $CaCO_3$ and soluble CO_3^{2-} and HCO_3^- ions.
viii) Increased solubility and accumulation of toxic elements like F, Se and Mo in plants that may affect crop yield and/or health of the animals feeding on such crops. Selenium toxicity is quite common among cattle fed on fodder and straw of crops raised on alkali soil.
ix) Difficulties in preparing seedbed as all the soil do not come to proper moisture conditions at the same time. This also results in clod formation and poor tilth of the soil.
x) Low activity of useful microbes due to high pH and excess exchangeable Na.
xi) Presence of hard $CaCO_3$ layer which is a physical barrier for the movement of water, salts and vertical root growth of crops and trees.
xii) Continuous loss of fertile soil due to air and water erosion.

Under field conditions, plant growth is adversely affected due to combination of the above factors. The extent depends upon the amount of exchangeable sodium, pHs, nature and stage of crop growth, environmental conditions and the overall management levels (Table 2).

Table 2. Exchangeable sodium percentage of soil and sodicity hazards to the plants.

Approximate ESP	pHs	Sodicity hazards
<15	8.0-8.2	Non-slight
15-35	8.2-8.4	Slight to moderate
34-50	8.4-8.6	Moderate to high
50-65	8.6-8.8	High to very high
>65	>8.8	Extremely high

Source: Chhabra (1996)

Reclamation of Alkali Soils

Reclamation of alkali soils involves amending their physical, chemical and biological properties that affect the crop production.

On-farm Development

For successful adoption of reclamation technology the farm should be properly developed. The on–farm development activities include land shaping (leveling), bunding and making provisions for irrigation and drainage. To ensure proper water management and uniform leaching of salts, the field should be leveled properly. To avoid major earthwork, the big fields should be divided onto small parcels and leveled. Drastic removal of the surface soil will expose the subsoil containing $CaCO_3$, which can pose difficulties in reclamation, and cropping of the area. Best results are achieved when the moisture level in the field is 12 to16% on dry weight basis. Strong bunds are essential to store rainwater for leaching and irrigation in the field and to prevent its loss through surface runoff. These also prevent the entry of salt rich water from the adjoining areas to avoid resodication. Drainage of excess water may be needed under high rainfall conditions to prevent damage to young rice seedlings and to arable crops like wheat. Provision of good quality irrigation water is a must for successful reclamation of alkali soils. For this a sallow cavity tube well should be installed in the area or supply of canal water may be ensured.

Application of Amendments

To have successful crops, ESP of the soil must be lowered, which can be achieved by application of amendments. Amendments are materials which i) directly supply Ca for the replacement of exchangeable Na or ii) furnish Ca indirectly by dissolving calcite, natively found in the alkali soils due to their acidulating effect and or iii) dissolve native $CaCO_3$ by increasing the partial pressure of CO_2. The Ca so mobilized is used to replace Na from the exchange complex and this reclaims the alkali soil. Based on their nature the amendments have been classified into the following three categories:

a. Chemical Amendments

Amendments like gypsum ($CaSO_4.2H_2O$) and calcium chloride ($CaCl_2.2H_2O$) directly supply Ca to replace exchangeable Na there by lowering ESP and pH. Mine gypsum is the most commonly used amendment for alkali soil reclamation.

$$2Na\text{-soil} + CaSO_4 \text{ ------- } Ca\text{-soil} + Na_2SO_4$$

Pyrites (FeS2) furnishes Ca indirectly by first oxidizing to an acid which in turn reacts with soil lime to furnish soluble calcium.

$$2FeS_2 + 2H_2O + 7O_2 \text{ -------- } 2FeSO_4 + 2H_2SO_4$$
$$CaCO_3 + H_2SO_4 \text{ -------- } CaSO_4 + CO_2 + H_2O$$
$$2Na\text{-soil} + CaSO_4 \text{ ------- } Ca\text{-soil} + Na_2SO_4$$

To have better results from pyrites, following guidelines should be adopted:

a) Encourage maximum oxidation of pyrites before applying it into the alkali field, by storing the freshly mined pyrites for a period of 10-20 days in a well aerated place under moist conditions, approximately at 10% moisture level.
b) Store pyrite under a rain shelter so as not to let H_2SO_4 formed washed away before applying in the field.
c) Best results are obtained when the pyrites contains 4-6% soluble –S and its pH is less that 3.
d) After application in the field instead of continuous ponding of water, giving cycles of alternate wetting and drying helps to increase its oxidation and thus efficiency.

But despite all this, its efficiency is not more that 70 to 80% as compared to gypsum. Similar to pyrites, conversion of mineral sulphur to H_2SO_4 , which also takes place through the biological oxidation is very slow in alkali soils. Due to this reason, the relative efficiency of mineral S is also not high in alkali soil. Sulphuric acid reacts rapidly with soil lime since it does not have to go through the oxidation process. However, it is highly corrosive and dangerous to handle. Theoretical amounts of amendments to supply Ca equivalent to 1 tonne of gypsum is given in table 3. The agricultural grade gypsum is only 75 to 80 % pure.

Table 3. Equivalent amount of various amendments for supplying Ca in terms of pure gypsum.

Amendment	Tonnes equivalent to 1 tonne of 100% gypsum
Gypsum ($CaSO_4.2H_2O$)	1.00
Calcium chloride ($CaCl_2.2.H_2O$)	0.85
Calcium nitrate ($Ca(NO_3)_2.2H_2O$)	1.06
Press mud (Lime-sulphur, 9% Ca, 24%S)	0.78
Sulphuric acid (H_2SO_4)	0.61
Iron sulphate ($FeSO_4.7H_2O$)	1.62
Ferric sulphate ($Fe_2(SO_4)_3.9H_2O$)	1.09
Aluminium sulphate ($AL_2(SO_4)_3.18H_2O$)	1.29
Sulphur (S)*	0.19
Pyrites (FeS_2, 30%S)	0.63

* Hundred per cent oxidation is assumed. In practice this does not happen and thus its effectiveness is much lower than other amendments.

b. Organic Amendments

Alkali soils are generally low in organic matter. Addition of crop residues and other organic materials in the soil is beneficial as these help to improve and maintain soil structure, supply needed plant nutrients, prevent soil erosion and hastens reclamation of alkali soils. Most commonly used organic amendments are materials like straw, rice husk, poultry droppings, groundnut and sunflower hulls, farm yard manure (FYM), compost, green manure, tree leaves, saw dust etc.

Organic amendments on their decomposition produce high partial pressure of carbon dioxide and organic acids, which help in increasing electrolyte concentration and lowering the soil pH. These processes increase the solubility of calcite and thereby lower the ESP. To achieve maximum benefits from organic amendments, submerged conditions should be maintained by continuously ponding water during the course of their decomposition. Activated press mud (APM) obtained from treating press mud, a by product of sugar industry which is rich in organic matter and nutrients, with sulphuric acid is another promising combination of inorganic and organic amendments for reclamation of alkali soils in areas where sugar mills are in abundance.

c. Industrial Byproducts as Amendments

Industrial byproducts like phosphgypsum, pressmud, molasses, acid wash and effluents from milk plants may be used to provide soluble Ca directly or indirectly by dissolving soil lime, for reclamation purposes. As these materials can be cheap and locally available, their use should be encouraged. However, care should be taken not to introduce toxic elements like F, which may be present in large amounts in products like phosphgypsum (Chhabra *et al.*, 1980).

d. Quantity of Amendment

The amount of amendment needed for reclamation depends upon the amount of exchangeable sodium to be replaced, which in turn is governed by the amount of sodium adsorbed on the soil (ESP & CEC), sodicity tolerance and the rooting depth of the crop to be raised. For every one milliequivallent (me) of Na to be replaced one needs one me of Ca. This will amount to 1.72 tonnes of gypsum for 0-15 cm depth of soil. Gypsum requirement (GR) determined by Schoonover (1952) method in the laboratory comes out to be very high, 30 to 60 tonnes/ha, and is beyond the economic means of the farmers. Abrol *et al.*1975) reported that soluble Na_2CO_3 of the soil partially inactivate the added Ca and thus overestimates the GR in the Schoonover's method. They suggested determining GR on salt free soil i.e. after leaching the soil with 60 % alcohol, so as to get realistic estimates.

Extensive work done at the Central Soil Salinity Research Institute, Karnal have shown that 10 to 15 tonnes of gypsum containing 70% $CaSO_4.2H_2O$ which approximates about half of the actual GR determined by Schoonover's method, is sufficient to reclaim the surface 15 cm soil of one hectare if one is to start with rice as the first crop. This is keeping in view the high tolerance of rice to soil ESP, its shallow root system, and its capacity to solubalise soil $CaCO_3$ to further reduce soil ESP. Over the time, ESP of the surface as well as deeper layers gets reduced so as to allow cultivation of other crops. However, to grow sensitive crops like pulses, one needs to add high amounts of amendments right in the initial years of reclamation.

e. pH and Gypsum Requirement

There exists a good relationship between pH of 1:2 soil water suspension (pH_2), pH of the saturation paste(pHs) and ESP of the soil. It has been observed that for the soils of Indo-Gangetic Plains, such a relationship can form a sound basis for estimating gypsum requirement of the soils varying in texture and thus CEC. However, for each type of soil such a relationship should be established separately.

f. Method of Application

Gypsum should be applied after first irrigation to ensure maximum leaching of soluble CO_3^{-2} and HCO_3^- so as to avoid its precipitation and to increase efficiency. Amendment should normally be broadcasted and then mixed in only shallow depths to achieve better results. Field studies (Khosla *et al*., 1973) have shown that mixing limited quantities of gypsum in deeper layers results in its dilution and higher inactivation due to the soluble salts. To ensure proper dissolution of gypsum and leaching of replaced Na, water is to be ponded on the soil. Normally 10 to 80 % of the applied gypsum gets dissolved with in 7 to 10 days of continuous ponding and leaching. However, when rice is to be taken as the first crop, which is recommended, post-application leaching is not needed and rice can be transplanted immediately after gypsum application.

h. Fineness of Amendment

At the mine site gypsum is obtained in the form of lumps which need to be ground before application. Finer gypsum particles require less amount of water for their dissolution nd react faster. Chawla and Abrol (1982) have shown that gypsum lumps when ground to pass through 2 mm sieve contain sufficient fine sized particles to effectively reclaim alkali soil. Increasing the fineness of pyrites increases the specific surface area and results in better autooxidation of sulphur. Singh *et al.* (1981) observed an increase in water-soluble S content with increase in fineness of pyrites.

i. Frequency of Amendment Application

Alkali soils once reclaimed do not need repeated application of amendments provided these are continuously cropped. This is due to the fact that these soils contain high amounts of $CaCO_3$, which together with Ca added through fertilizers like CAN and SSP, and irrigation water is sufficient to meet the Ca needs of the plants and to keep Na out of the exchange complex. However, the following conditions result in resodication of the reclaimed soil and may warrant repeated application of amendments:

i) When large amounts of soluble Na is added from outside through the flood waters from the adjoining un-reclaimed alkali fields.
ii) Irrigation water has a problem of high RSC.
iii) There exists a shallow water table with high RSC or and high EC.
iv) The area experiences prolonged dry fallow periods causing precipitation of soluble Ca.
v) Initial incomplete reclamation because of low levels of amendments than the recommended dose coupled with poor leaching causing incomplete removal of reaction products.
vi) Change from high water to low water requiring crops resulting in upward flux of the reaction products.

Crops and Cropping Pattern

Different crops vary widely in their tolerance to soil exchangeable sodium. In general, cereal like rice is more tolerant than legumes as they require less Ca, availability of which is a limiting factor in alkali soils. Crops which can stand withstand excess moisture conditions are generally more tolerant to alkali conditions. Among the cultivated crops, rice is most tolerant to soil sodicity. It can with stand an ESP of 50 without any significant reduction in yield. It is followed by sugar beet ant teosinte. Crops like wheat, barley and oats etc. are moderately tolerant. Legumes like gram, mash and lentil, chickpea and pea etc. are very sensitive and their yield decreases significantly even when the soil ESP is leas than 15. *Sesbania* is an exception among the leguminous crops as it can grow at ESP up to 50 without any reduction in yield. Due to this it is an excellent crop for green manuring in alkali soils. Some of the natural grasses like Karnal grass and Rhodes grass are very tolerant to soil sodicity, and in fact grow normally under high alkali conditions. Karnal grass likes both waterlogging and high ESP in its growing environment.

Nutrient Management

High exchangeable Na, high pH, $CaCO_3$ content and high concentration of soluble CO_3^{-2} and HCO_3^- present in alkali soils, adversely affect the transformation and availability of several essential plant nutrients. Almost all crops grown in alkali soils respond both to the application of different fertilizer nutrients and to methods of their application. In general alkali soils are deficient in Ca, N and Zn (Chhabra and Abrol, 1983).

a. Calcium

Alkali soils are deficient both in soluble and exchangeable Ca. Though these soils contain $CaCO_3$, ranging from traces to 40% and more, the availability of Ca from it is insufficient to meet the plant needs because of its low solubility at high pH. Therefore plants growing in alkali soil may more often succumb to Ca deficiency than the toxic effects of Na (Chhabra and Abrol, 1983). Moreover, because of the antagonistic effect of Na on Ca, increasing soil sodicity nearly always results in decreasing uptake of ca by plants. Calcium amendments are direct sources of Ca to the plants. Hence application of adequate amounts of amendments is a prerequisite both for decreasing the soil ESP and meeting the Ca needs of the crop. Decomposing organic matter and growing roots may also mobilize Ca from the native $CaCO_3$ through their biological action and thus meet the Ca needs of the growing plants.

b. Nitrogen

Alkali soils are low in organic matter and hence poor in total and available N content. Alkalinity and high pH adversely affect the biological transformation from amide to ammonia and of the later to nitrite. Nitant and Bhumbla (1974) reported that complete hydrolysis of urea in a sodic soil with pH10.3 was delayed by 4 days compared with that in normal soil. Bhardwaj and Abrol (1978) observed that nearly 32 to 52 % of the applied N is lost through volatilization. Because of low availability and low efficiency of the applied fertilizer, it is recommended that in general crops grown in alkali soils should be fertilized with 25% more N over the rates recommended for normal soils. When adequate amounts of amendments are applied both urea and ammonium sulphate showed equal response. Efficiency of applied N can be increased by split application (Dargan *et al.,*1973, Singh *et al.*,1983) and its application before puddling which decreases the losses due to volatilization. Based on a number of field experiments it is recommended that 33% of the total N applied as basal and the rest split in two equal parts after 21 and 45 days of transplanting/sowing gives best results for rice and wheat grown in alkali soils.

c. Phosphorus

Alkali soils contain high amounts of extractable phosphorus (Chhabra *et al*., 1980). The sodium carbonate and bicarbonate of alkali soils reacts with insoluble calcium phosphate forming soluble sodium phosphate with a sharp increase in Olsen's extractable–P. The sodium phosphate formed is highly mobile and through mass flow with water moves to plant roots where it is converted into Ca $(H_2PO_4)_2$ and is made available to the plant. This form is also liable to leaching. In a long term experiment conducted at the Central Soil Salinity Research Institute, Karnal, the surface 15 cm soil lost 24 kg/ha of soluble P in the initial year of cropping (Chhabra, 1985). Owing to inherent high soluble P content of these soils, rice and wheat grown in rotation in these soils do not respond to the application of phosphatic fertilizers during the initial 3-5 years of cropping (Table 4). After that due to decrease in P status of the surface soil as a result of leaching, immobilization due to added gypsum and, decrease in soil pH resulting in more fixation of applied P, crops start responding to application of fertilizer P (Chhabra *et al.,*1981). However, the wheat crop being deep rooted and of long duration do not respond to application of fertilizer P for a long time since it can mine the leached P from the lower layers. Hence, the response of the crops in alkali soils depends upon the P status of the surface as well as of the sub surface soil layers. Hence in alkali soils P fertilization should be done based on the soil test value. When the crops grown on alkali soils start responding to fertilizer P then single super-phosphate and diammonium phophate are better sources that nitrophosphate.

d. Potassium

In general increasing soil ESP decreases the K and increases the Na content of the plants. Due to high Na and deficiency of Ca, many studies have shown reduced uptake of K by plants raised in alkali soil (Chhabra *et al*.,1979). However, its absolute concentration in the plant tissue is nearly always above the lower critical limit. In the field, crop responses to applied K fertilizer have not been observed, possibly because of the presence on micaeceous minerals and illite, which are capable of releasing sufficient K to meet the crop needs. For correcting Na induced K deficiency in plants grown on alkali soils with medium to high amounts of exchangeable K, instead of applying K fertilizers, it is suggested that a proper amount of amendment should be added so as to correct Ca:Na balance which in turn improves the K status of the plants (Chhabra and Abrol,1975).

e. Zinc

Alkali soils contain medium to high amounts of total Zn (40 to 100 mg/kg soil), which is comparable with the amount found in non-alkali soils. But due to high pH, presence of $CaCO_3$, high soluble P, toxic concentration of CO_3^{-2} and HCO_3^- and low organic matter, alkali soils often contain less than o.6 ppm DTPA-extractable Zn and the plants grown there in suffer severe Zn deficiency symptoms. Rice crop, though tolerant to soil sodicity is sensitive to Zn deficiency which appears 15 to 21 days after transplanting, causing stunted growth, poor tillering with rusty brown spots on fully matured leaves. Commonly known as *Khaira* disease it delays maturity and severely affects yields.

Table 4. Effect of N and P application on the yield, t/ha, of rice and wheat in a gypsum amended alkali soils.

Treatment	Years after reclamation										
	1	2	3	4	5	6	7	8	9	10	11
						Rice					
R0w0	6.58	7.24	6.65	7.31	5.90	5.89	5.27	3.68	4.27	3.88	5.03
R11W0	7.29	6.89	6.81	7.45	6.31	6.29	6.57	5.13	5.82	5.47	5.52
R22W0	6.78	7.08	7.18	8.24	7.30	7.01	7.48	5.70	5.83	6.05	6.92
R0W11	6.87	7.32	6.87	8.02	6.92	6.73	6.89	4.12	4.84	4.76	5.57
R0W22	6.11	7.23	6.92	8.04	6.74	6.66	7.04	4.64	5.48	5.34	6.41
R11W11	6.91	7.09	6.95	8.32	6.93	7.30	7.86	5.76	5.48	5.86	6.80
R22W22	6.69	7.02	6.83	7.97	6.75	6.82	7.74	5.98	6.17	5.90	7.59
N0P0K0	3.94	3.39	2.43	2.67	2.69	2.63	2.11	1.77	2.30	2.59	2.14
LSD at P=0.05 for P levels	NS	NS	NS	0.60	0.55	0.74	1.00	0.76	0.85	0.94	0.76
						Wheat					
R0w0	4.35	3.71	3.63	5.04	4.74	4.83	5.55	4.88	5.66	4.32	4.35
R11W0	4.62	3.99	3.46	4.99	4.70	5.04	5.48	5.03	5.62	4.44	4.53
R22W0	4.38	4.02	3.72	5.25	4.86	5.04	5.95	5.37	5.98	4.57	4.55
R0W11	4.25	3.80	3.62	5.10	4.75	4.88	5.56	5.33	5.55	4.44	4.29
R0W22	4.34	3.82	3.53	5.17	4.79	4.93	5.49	5.19	5.85	4.74	4.39
R11W11	4.49	3.86	3.63	5.27	4.87	497	5.74	5.33	5.90	469	4.51
R22W22	4.45	3.87	3.45	5.16	4.59	4.80	5.51	5.17	5.84	4.83	4.41
N0P0K0	0.83	0.85	0.50	0.89	0.92	1.13	1.01	0.91	1.07	0.95	0.82
LSD (0.05) for P levels	NS	NS	NS	NS	NS	NS	NS	NS	NS		

Source: Chhabra (1987)

From a series of field trials, it ahs been reported that when adequate amounts of amendments (10 to15 MG/ha) is added, 10 to 20 kg Zinc sulphate /ha is enough to meet the Zn requirement of rice and wheat. At low levels of gypsum application and moderate dose of applied Zn, the plants suffer more from sodium toxicity and calcium deficiency than from Zn availability. It is further observed that on continuous application of zinc sulphate there is built up of soil available Zn and the farmers may skip its application for a year or so (Chhabra *et al.*, 1982).

g. Iron

Next to Zn, iron is the most common deficient micronutrient in alkali soils. Due to high pH and excess of CO_3^{-2} and HCO_3^{-}, iron chlorosis often appears in rice nurseries, sugarcane, soybean, tomato and many other crops raised on calcareous alkali soils. Correction of Fe deficiency using soluble salts such as $FeSO_4$ is generally not found useful unless it is accompanied by changes in the oxidation status of the soil brought about by prolonged submergence and easily decomposable organic matter. Pretreatment of nursery beds after incorporation of green manure, FYM or compost helps in creating reduced conditions and mobilizing soil iron to meet the plant needs. It is advisable to flood the rice nurseries with water and apply pyrites when they show iron deficiency. Since iron is an immobile nutrient in the plant, foliar application of Fe (3 % solution of $FeSO_4$) gives limited relief to the suffering crop and should be used to supplement the improvement in reduction status of the soil.

h. Managnese

Soil pH and $CaCO_3$ affect the availability of Mn. However, Mn is seldom a problem for wetland rice in alkali soils but is increasing becoming a limiting factor for wheat following it. It is because on submergence, Mn solublises on reduction and is leached down to the lower layers especially in the coarse textured soils. Mn deficiency symptoms come after the first irrigation in the form of white spots in the center of the leaf blade. As a consequence of that the leaf breaks from that point and dies. At maturity Mn-deficient plants experience difficulties in ear emergence as the flag leaf does not open and curls around the ear head. This also leads to improper grain formation.

Due to auto-oxidation of Mn, it is very difficult to correct Mn deficiency by soil application of $MnSO_4$. Repeated sprays of $MnSO_4$ are needed to make up the deficiency. Deep ploughing so as to mix subsoil with the surface layers generally helps in re-distribution of soil Mn and increase its availability.

Other Cultural Practices

To ensure successful reclamation of alkali soils following practices should be adopted:

a. Plant population

Due to hard crust on the surface, germination percentage is often low in alkali soils. Plant population further decreases due to high rate of mortality especially during early stages of plant growth. This together with poor tillering can reduce the yield of crops. Crop stand in alkali soils can be improved by increasing the seed rate and reducing the planting distance. In case of better plant population is achieved by increasing the number of seedlings per hill and by gap filling so as to replace the dead plants.

b. Age of seedlings

Generally, the tolerance of crop increases with age. In rice older seedlings (40-45 days) have been found to establish better than the younger seedlings (25-30 days). Similarly, for establishing tree species, planting old seedlings have been proved to be beneficial.

c. Green manuring

Application of green manuring can help to enhance O.M. content, increase partial pressure of CO_2, lower pH, enhance solubility of native $CaCO_3$ and add considerable amount of plant nutrients in the soil. For this *Sesbania* which is tolerant to both high ESP and waterlogging is an ideal crop. As it grows during summer month (May-June), a lean period for rice and wheat, this also fits into the cropping pattern of the crops to be followed in alkali soils.

Normally 45 days old *Sesbania* crop which attains a height of 1.5 to 1.8 m is ideal for incorporation as green manure crop. Being succulent and having a narrow C-N ratio (about 25), it decomposes very easily and quickly. The standing water in rice fields hastens the decay without any harm to rice crop. So there is no need to allow any time for the decomposition of the organic matter and rice seedlings can be transplanted immediately after the incorporation of *Sesbania* in the soil. Since about 50 per cent of the organic nitrogen content in the green manured crop is converted into the readily available ammonical form with in 4-6 days and the rest with in 10 to 20 days of incorporation (under the temperature conditions prevailing in the main rice growing season), it helps in ensuring steady supply of N to the rice crop.

d. Continuous cropping

On application of amendment, leaching (especially during growth of rice) and cropping, replaced Na keeps on mowing downward and there is continuous reduction in the exchangeable sodium of the soil through out the soil profile. Including *Egyptian clover* or other green fodder crop in the crop production, those require frequent irrigations, one can further hasten this process. However, the land should be continuously cropped to keep downward movement of the repulsed Na and soluble salts. Fallowing will encourage upward flux of salts and therefore reverse the process of reclamation.

Water Management

a. Drainage

As the alkali soils basically have low infiltration rate, even a low intensity shower or a normal irrigation may create temporary waterlogging and anaerobic conditions. Due to this, upland plants normally suffer oxygen stress in alkali soils. To avoid this, surface drainage especially during the rainy season is a must. During early stage of reclamation, surface runoff water which contains high concentration of soluble Na_2CO_3 and $NaHCO_3$ should not be allowed to pass on to the adjacent fields otherwise this can cause sodication of the good quality land. If water table is high which is the case in most soils then subsurface drainage is to be installed. However, due to low hydraulic conductivity, conventional subsurface drainage to lower the water table is neither possible nor required in these soils. Normally, in alkali soils, the groundwater is of good quality and can be exploited for irrigation. For this maximum number of shallow cavity tube wells should be installed to act both as a source of irrigation and to provide vertical drainage. This has proved to be most effective and economical way of controlling water table and providing an assured source of irrigation for crop production in alkali soils.

b. Irrigation

Irrigation management in alkali soils poses peculiar problems due to clogging action of dispersed soil particles and low stability of soil aggregates, which limit the water and air permeability of these soils. Because of this restricted entry from the surface, enough recharge of the depleted soil moisture does not take place during irrigation of alkali soils. Further, the amount of available water held by the soil as defined by the moisture content between field capacity i.e. 0.1 bar to wilting point i.e.15 bars suction, is significantly reduced with increasing ESP (Abrol and Acharya, 1975). Thus the total water storage capacity of the soil decreases with increase in exchangeable sodium. Further, during the post-irrigation period, the water transmission from the lower layers to the upper layers to meet the evapotranspiration need of the crop is severely restricted due to low hydraulic conductivity of the soil.

As the depth of irrigation water and interval between two irrigations depends upon the climate i.e. evaporative demand, nature of plant response to soil water stress, depth of root development and the water storage and transmission characteristics of the soil, it is found that light but frequent irrigations should be applied in alkali soils. Heavy irrigations which will supply water in excess of what can be absorbed by the soils in a few hours can result in temporary waterlogging and in an oxygen stress in the root zone, which can affect the crop growth/yield adversely. This means that the total amount of irrigation water remaining the same, it should be supplied in small quantities but quite frequently. Generally, 4-6 irrigation of 5 cm will be required for wheat crop. To facilitate this, big fields should be divided into small irrigation blocks.

Normally, surface method of irrigation like furrow or basin type flood method is applied for irrigating alkali soils. However, keeping in view their susceptibility to surface waterlogging, sprinkler method can be promising because of its ability to supply water uniformly and in small quantities.

Post-Reclamation Management of Alkali Soils

Reclaiming alkali soils consists in replacing Na on the exchange complex with and leaching sodium salt down the root zone. Depending upon the amount of water that passes through the root zone and internal drainage of the soil, the washed down salts reside at different soil depth before being finally pushed to the groundwater. Moreover, only surface soil is reclaimed through this technology and the soil immediately below may still be highly deteriorated even a couple of years after reclamation. Prolonged fallowing, changing to low water requiring crops, poor land management, rise in water table and use of shallow groundwater, for irrigation can cause the return or rise of salts to the surface soil. These factors along with accumulation of salt through weathering of soil minerals, outside sources like run off waters, subsurface intrusion of salts from neighboring lands or ground waters in the system have rendered many reclaimed lands less productive than before. Consequently farmers have been repeating the application of gypsum. In fact a large part of gypsum sale with the Land Reclamation & Development Corporations is meant for repeat application to already reclaimed lands and for treatments of soils irrigated with sodic waters.

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Integrating Cartography, Remote Sensing and GIS for Diagnosis and Prognosis of Salt Affected and Waterlogged Lands

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Introduction

The collection and analysis of data concerning spatial distribution of relevant characteristics of the earth's surface have long been an important part of the activities of organized societies. From the earliest civilizations to modern times spatial data have been acquired and rendered into pictorial maps to accomplish the many activities that include navigation, land survey and military operations. In the last decades the development of earth sciences disciplines geography geology, hydrology soil sciences etc. have greatly enhanced the collection and of spatial georeferenced data along with the production of a variety of general purpose (topographic) and special purpose thematic maps. Maps indeed are the best method for reducing very large –scale spatial relations so they can be easily perceived and analysed. During the 1960's the advent and dissemination of high speed computers and of data capture / display electronic devices have profoundly influenced methods and techniques. New sensors provided enhanced remotely sensed data for earth resources studies while cartography took a new turn to complement remote sensing in the geographical information system.

Remote sensing is a technology used for obtaining information about a target through the analysis of data acquired from the target at a distance. It is composed of three parts, the targets - objects or phenomena in an area; the data acquisition - through certain instruments; and the data analysis - again by some devices. This definition is so broad that the vision system of human eyes, sonar sounding of the sea floor, ultrasound and x-rays used in medical sciences, laser probing of atmospheric particles, are all included. The target can be as big as the earth, the moon and other planets, or as small as biological cells that can only be seen through microscopes. Remote sensing data acquisition can be conducted on such platforms as aircraft, satellites, balloons, rockets, space shuttles, etc. Inside or on-board these platforms, we use sensors to collect data. Sensors include aerial photographic cameras and non-photographic instruments, such as radiometers, electro-optical scanners, radar systems, etc. Electro-magnetic energy is reflected, transmitted or emitted by the target and recorded by the sensor. Because energy travels through the medium of the earth's atmosphere, it is modified such that signal between the target and the sensor may differ. The effects of the atmosphere on remote sensing can be examined later. Methods are introduced to reduce such atmospheric effects.

Once image data are acquired, we need methods for interpreting and analyzing images. By knowing "what" information we expect to derive from remote sensing, we will examine methods that can be used to obtain the desirable information. We are interested in "how" various methods of remote sensing data analysis can be used. In summary, electromagnetic energy is recorded as remotely sensed data, and such data are transformed into valuable information about the earth.

Imagery

Remotely sensed data are digital representations of the earth. Remote sensing is the measurement or acquisition of data about an object or scene by satellite or other instruments above or far from the object (Colwell 1984). In general terms, *an image is a digital picture or representation of the earth's surface*. Image data are stored in a data file also called an *Image file* and may be available on magnetic tape, computer disk or optical media. The data consists only of numbers, whose representation form images when they are displayed on a screen or output to hardcopy. There are many data ranges available as photographic products or digital products. Digital products are more sophisticated and are easily processed by the computer. Photographic hardcopy products are however more useful in the field.

Bands

The data are detected in different parts of the electromagnetic spectrum ranging from the visible to the infrared. These range from 0.5 to 1.0 μm in LANDSAT MSS to 0.1 to 12.0 μm in LANDSAT TM and NOAA, AVHRR. In IRS, the range lies between 0.5 to 1.70 μm and is divided into 5 bands. Image data may include several bands of information. Each band is a set of data file values for the specific portion of the electromagnetic spectrum of reflected light or emitted heat (red, green, blue, near infrared, infrared, thermal etc.) or some other user defined information created by combining or enhancing the original bands. All image data is available in raster format.

Cartography and GIS

For map production a new discipline has been set up - computer assisted (automated /modern) cartography. Meanwhile scientists and planners and policy makers have increasingly become aware of the importance of acquiring and using computer based systems that enable any type of environmental data to be efficiently and cost effectively handled, analysed, and displayed. Consequently, public and private agencies and scientific institutions made several attempts to extend to the realm of geographical data and the methods used in the processing of tabular (non spatial) data through database management systems (DBMS).

As a result, data base systems for spatial data commonly named Geographical Information Systems (GIS) were designed and developed which enable the acquisition, compilation, storage, updating, processing and display of spatial data traditionally represented in the form of topographic or thematic maps. Hence the main and unique features of a GIS consist in it’s ability of

- capturing, handling and portraying the spatial characteristics of objects geographical -entities
- collecting and processing the non spatial characteristics (attributes) associated to these objects,
- identifying, analyzing and displaying the topological and geometrical interrelations existing between spatial and non spatial properties of an object or different objects

In the strictest sense, it is any information system capable of integrating, storing, editing, analyzing, sharing, and displaying geographically referenced information. In a more generic sense, GIS applications are tools that allow users to create interactive queries (user created searches), analyze spatial information, edit data, maps, and present the results of all these operations. It is apparent that the accomplishment of almost any project aimed at evaluating environmental resources and constraints may be greatly facilitated by the use of an efficient geographical information system. This is particularly true when conducting a resource assessment and the risk benefit analysis that constitutes the primary concern of an investigation.

Data Representation

Remote sensing and GIS data represent real world objects (roads, land use, elevation, rivers, waterlogged areas, degraded lands etc.) with digital data (Fig.1, a). Real world objects can be divided into two abstractions: discrete objects (a house) and continuous fields (rain fall amount or elevation). There are two broad methods used to store data in a GIS for both abstractions: Raster and Vector.

Raster

A raster data type is, in essence, any type of digital image (from a standard file-based structure of TIF, JPEG, etc. to binary large object (BLOB) data stored directly in a relational database management system). Raster data types consist of rows and columns of cells, with each cell storing a single value. Raster data can be images (raster images) with each pixel (or cell) containing a color value (Fig.1, b). Additional values recorded for each cell may be a discrete value, such as salinity, a continuous value, such as temperature, or a null value if no data is available. While a raster cell stores a single value, it can be extended by using raster bands to represent RGB (red, green, blue) colors, colormaps (a mapping between a thematic code and RGB value), or an extended attribute table with one row for each unique cell value. The resolution of the raster data set is its cell width in ground units. Remotely sensed data are essentially raster in character. Database storage, when properly indexed, typically allows for quicker retrieval of the raster data but can require storage of millions of significantly-sized records.

Vector

In a GIS, geographical features are often expressed as vectors, by considering those features as geometrical shapes as points, lines or polygon (Fig.1, c).

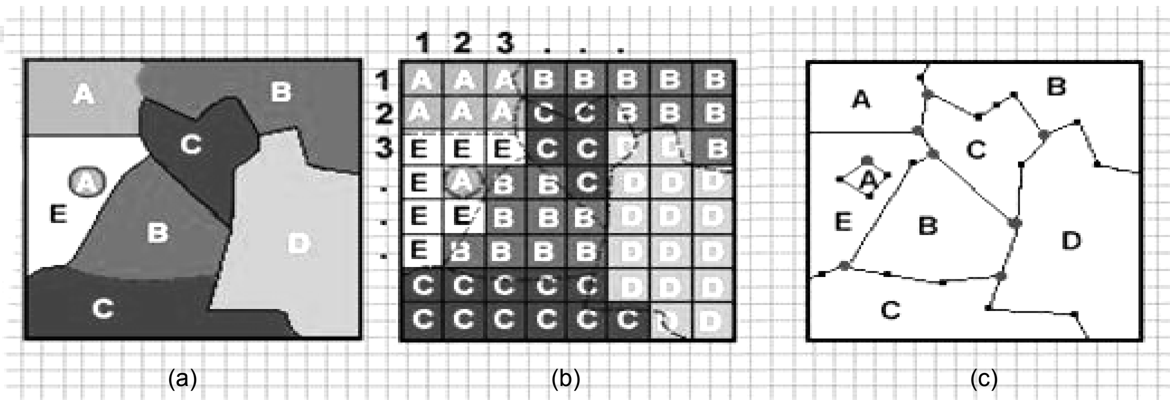

Fig.1. Simple map (a), raster data representation (b) and vector data representation (c)

Points

Zero-dimensional points are used for geographical features that can best be expressed by a single point reference; in other words, simple location. For example, the locations of Salt affected soils, waterlooged lands, wells, peak elevations, features of interest or trailheads. Points convey the least amount of information of these file types. Points can also be used to represent areas when displayed at a small scale. For example, cities on a map of the world would be represented by points rather than polygons. No measurements are possible with point features.

Lines or polylines

One-dimensional lines or polylines are used for linear features such as rivers, roads, railroads, trails, and topographic lines. Again, as with point features, linear features displayed at a small scale will be represented as linear features rather than as a polygon. Line features can measure distance.

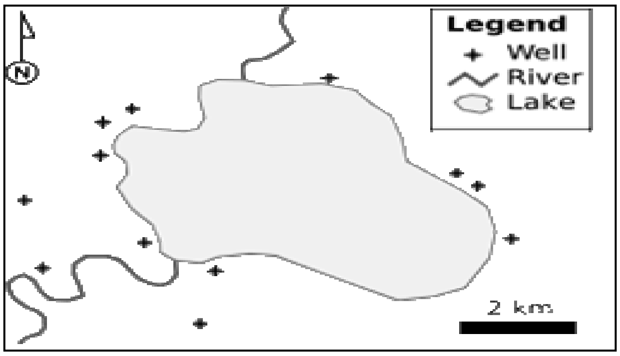

Fig.2. A sample vector map showing the vector elements - points for wells, lines for rivers, and a polygon for the lake

Polygons

Two-dimensional polygons are used for geographical features that cover a particular area of the earth's surface. Such features may include salt affected areas, field boundaries or land uses. Polygons convey the most amount of information of the file types. Polygon features can measure perimeter and area.

Each of these geometries is linked to a row in a database that describes their attributes. For example, a database that describes salinity may contain information on the ph, EC, water quality, pollution level etc. This information can be used to make a map to describe a particular attribute of the dataset. For example, salinity could be coloured in shades of yellow depending on level of degradation. Different geometries can also be compared. For example, the GIS could be used to identify all wells (point geometry) that are within 1-mile (1.6 km) of a saline patch (polygon geometry) that has a high level of degradation.

Vector features can be made to respect spatial integrity through the application of topology rules such as 'polygons must not overlap'. Vector data can also be used to represent continuously varying phenomena. Contour lines and triangulated irregular networks (TIN) are used to represent elevation or other continuously changing values. TINs record values at point locations, which are connected by lines to form an irregular mesh of triangles. The face of the triangles represent the terrain surface.

Delineation and Mapping of Salt-Affected Waterlogged Soils

Image interpretation of remotely sensed data can be attempted either by visual or digital techniques of analysis. The purpose of applying either of the above two techniques is for feature identification and classification. The methodology for conducting visual interpretation of multi-date satellite imageries comprises the following six major steps.

- **Selection and acquisition of data**: Standard FCC imagery or raw imagery of IRS data of *Kharif* and *Rabi* seasons.
- **Preliminary visual interpretation**: IRS FCC's of *Kharif* and *Rabi* seasons are interpreted individually making use of the interpretation keys. The boundaries of land use/land cover classes are plotted onto transparent overlay, such as artian or polyester tracing sheets.
- **Ground data collection and verification**: Following the previously drawn scheme and transverse plan, ground truth information is collected as per specific performa to cover at least 80 percent of the district as a reconnaissance initially in areas where no mapping has been conducted before. 10 percent once the mapping has been established. Areas of doubtful preliminary interpretation are particularly verified.
- **Final interpretation and modification**: Based on the ground truth data, modifications are effected and classes as well as their boundaries refined.

- **Area estimation**: Areas under different classes are estimated by computer for digital data/or planimeteric measurements for analog maps to complete district land use statistics.
- **Final cartographic map preparation and reproduction:** Fair drawings of originals are made as per pre-designed specifications and cartographic symbols on the computer or manually.

Land use/land cover maps have been completed following the visual interpretation approach for a large part of the country.

A number of factors determine the vulnerability of sites to salinization and are as follows:

- the position of a site within a landscape – generally the lower it is, the more likely it is that the water table will reach the surface and cause salinization
- soil type
- management – such as the extent of clearing
- rainfall

Combining information on these and other factors could allow the prediction of sites vulnerable to the saline menace. This is where a geographic information system (GIS) takes on an important role because the data are stored in digital form they can be analysed readily by computer. In the case of salinity, scientists can use data on rainfall, topography, soil type-indeed, any spatial information that is available electronically – to first determine the combinations most susceptible to salinization, and then to predict similar regions that may be at risk. CSSRI has carried out the important tasks of collection of database, inventory and information gathering for updating the status of salt-affected waterlogged soils. Using multi-date images, image processing techniques, GIS and ground truth data, there is a continuous effort to add to the detailed information on the status of salt affected soils.

Applying Remote Sensing, GIS, GPS Technologies

The only known way then to start prognosing soil water management domains is to resort to quick and efficient technologies for management. Remote Sensing, GIS and GPS are the effective and accurate methodologies for identifying, diagnosing and prognosing problems of land and water and their management. An integrated approach using Remote Sensing offers technologically the appropriate method of analyzing land and water resources, characterizing coherent agricultural zones and identifying constraints for natural resource management. A lack of data and information prevents management indicators to be evolved both at the regional and farm level.

The existing resource constraints in rice wheat systems include salinity, alkalinity, high water tables, on set of water logging and nutrient deficiencies. These domains require targeting for both technology and for the development of a decision support system employing remote sensing, GIS and GPS technologies. Each specific domain would require besides remotely sensed biophysical information and cropping system database, generation of socio-economic and ancillary information for assessing the status of the site-specific adoption of resource conserving technologies. Therefore the specific technology to manage it would have to be put into place taking into consideration different parameters in different agro-ecological zones but first we must understand site-specific problems.

The specific problem of increasing salinity in command areas for instance has been widely diagnosed by different organizations. IRS-1B LISS II data were used for mapping and monitoring salt-affected soils in Nagajunsagar right bank canal command areas, in Andhra Pradesh, and Periyar-Vaigai command area in Tamil nadu (National Remote Sensing Agency, 1995, 1996 and 1997) Dubey *et al*., (1995) mapped the salt affected soils of all of the state of Gujarat using IRS IB data on 1:1 m scale. This study was based on visual interpretation and Ground truth. The salt waterlogged soils were mapped by Sethi *et al*., (1996) in the Ukai-Karapar command area using visual interpretation and Ground truth. The salt affected soils of Kanpur district were mapped using IRS IB imagery on 1:50,000 scale by Sethi *et al*. (2001) digital analysis showed the area affected to be 11.9 percent of the total district. Although the attempts at mapping have brought forth varying levels of accuracy the attempts to appraise salt affected soils more accurately are continuing. Prognosis is a much harder assignment and researchers need to build up skills to predict salinity. In a recent prognostic study, rising water tables are bringing on secondary salinization in South West Punjab. There is a drastic change in cropping patterns from wheat-cotton to rice- wheat-sugarcane after the cotton crop failed. Using multitasking and multitemporal remotely sensed data of 1997and 2001 it was found that in an area covering 2000 sq kms almost 40 percent of the areas would degrade into salty lands if remedies were not put into place (Sethi *et al*. 2005). Using such site-specific data and modeling would aid in understanding the problems and help in providing technologies for improvement. In fact, remote sensing and GIS will provide the essential ingredients for evolving management strategies for different soils/water/cropping systems and aid in accurate implementation. More recently Chandna *et al.* (2004) successfully tested a suite of resource conserving technologies and disseminated it through the Rice Wheat Consortium and its regional partners in the five transects of the Indo-Gangetic Plains. Similar studies have been carried out where remote sensing has proved invaluable in diagnosing. Providing a prognosis requires greater understanding and use of modeling techniques in remote sensing and GIS. Sethi *et al.* (2006) mapped salty lands of Shorapur Taluka in Gulbarga district using IRS data highlighting the effect of irrigation on secondary salinisation.

Important Considerations for Implementation

A major fear is that the remote sensing technology might be over sold. Caution must be excercised in what expectations we raise and the ability/constraints of the remote sensing/GIS/GPS technologies. This happened in the 1970s when people were told that they would be able to detect diseases, nitrogen deficiencies, and many other stresses--all which proved false or inconsistent. But the conditions for applying remote sensing to natural resource management are now greatly improved. The improvements have come through advances in sensor technology; as well as dramatic improvements in computer hardware and software, and the ability to rapidly transfer data between remote locations. We must realize however, that we are dealing with complex technologies that require specialized training

It is true that voluminous data gathered with the help of remote sensing techniques are better handled and utilized with the help of Geographical Information Systems (GIS). GIS functionality can be extensively utilized in the preparation of erosion and natural resources inventory and their analysis for assessing soil erosion and soil conservation planning. The methodology needs to be further developed to provide more precise evaluations and decision support at sub-national and local level, e.g., by identification of socio-economically defined resource management domains; by characterization of zones for land development and natural conservation, land management and research planning, and by assessing land degradation. Activities should also focus on improvement of computerized geo-referenced databases combining information on terrain, soils, climate, crops/production systems, land uses and socio-economic factors such as land tenure, markets and prices; dissemination of computerized models, software packages, reports and training materials for land resources analysis, land resources optimization and decision support systems. It is important to encourage and expand applications of new geographic information technologies and newly available geographically referenced data; and introduce the next generation of scholars to this integrated approach to increase collaborative interdisciplinary networks that address core issues.

Remote sensing can provide data on agricultural activities in inaccessible areas, or simply obtain more accurate information than otherwise available. This information can be obtained from radar images, and interpreted using machine vision techniques to identify different agricultural regions or crop types.

Over the last two decades, the role and impact of Geo-Information and Communication Technologies has significantly changed. It is evolving toward a `strategic` role with the potential not only to support chosen agricultural advancement strategies, but also to shape new strategies. This addresses, emerging policy links and trends in Geo-Information Management for Land and other domains such as topography, geology, land cover/uses and natural resources at the national and district levels. We need to confront the issues of:

- Data sources, data acquisition, data conversion and processing;
- Data models, process models and databases (central/local);
- Electronic exchange and distribution of geo-information;
- Quality parameters and review procedures;

We must recognize that the use of geo informatics must become an essential ingredient for data base collection and dissemination as well constitutes the basis for diagnosis and prognosis for management. It is of great import that we develop conceptual and logical models of Geo-information systems using system development methodologies focusing on stakeholder's requirements, data sources, and acquisition, maintenance and data models. There is also a need to ensure that those who might benefit most from this kind of information are suitably equipped with the knowledge and equipment to effectively apply it for long-term benefit. This will require investment in capacity building for training and infrastructure projects.

Future Challenges

To completely exploit the capability of technology available, for diagnosis, prognosis and management of soil water domains as also to widen the usage and acceptability and accuracy future challenges need focus on.

- Increased co-ordination between national satellite programmes and their counterpart development assistance programmes including state remote sensing agencies;
- Stronger links between ground observations and related satellite observations by all organizations;
- Better understanding of user needs for earth observation data in the agricultural and rural sectors, certainly more assessments are needed.
- Improvements in product development, validation, and continuity of data sources, in particular of high (5m) and medium (30-40m) resolution satellite systems such as IRS.

- Improved data archiving and access by users. Integration of data collection, management, and assimilation is necessary and integral to any diagnostic procedure for land/water/soil studies
- Current prices of software and output hardware are so high that often even if the data are available the digital analysis cannot be attempted. Ground truth radiometers remain elusive because of prohibitory prices affecting the true.Prices of data available are too high to practically bring in it to use for farmer's fields. Data more than a year old must be sold by the NRSA at highly discounted prices so that the NRSA and the user can both benefit.
- Strengthened links between in-situ data gathering networks and satellite programmes to assist product validation such as land cover, land use, crop production, and cultivated area.
- Imperative that we overcome the impediment of broad band widths to finer and more calibrated spectral ranges similar to those available in Hyperion data, The band widths are dedicated and calibrated to ground data making working simple and accurate. We need to refine and hone the information with ground instruments.
- Create inter-institutional and intra-institutional exchange of information through the internet and greater transparency.

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GPS Technology for Assisting Ground Truth for Salt Affected Soils

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Introduction

The most important attribute of the most GIS (Geographical Information System) approaches is the use of a common coordinate system to represent information. In many GIS implementations, real-world coordinates in the form of latitude and longitude are used, while in others an arbitrary graphic unit is used. Some systems also model height and some can be configured to represent time as a fourth dimension. Data for GIS use must be georeferenced, or registered with the common coordinate system. The accuracy of georeferencing has a significant impact on the validity of the GIS analysis to be performed. While preparing a GIS, data acquisition could be accomplished through digitization of the existing maps, keyboard entry of attribute data, or by the importation of existing data files. In most vector-based systems, points or nodes represent geographic entities with a single position in the common coordinate system. Utility poles, radio transmitters, and customer addresses are some of the examples of point entities. Lines, polylines, arcs, and spans are the terms associated with groups of line segments that are used to generally represent transportation routes, pipelines, or wired networks etc. Zones, polygons, and regions are GIS terms for groups of lines that enclose areas such as state boundaries, property, and soil type delineations.

The Global Positioning System (GPS) is a space-based radio navigation system that provides reliable positioning, navigation, and timing services to civilian users on a freely and continuous basis worldwide. For anyone with a GPS receiver, the system will provide location and time. GPS provides accurate location and time information to an unlimited number of people in all weather, day and night, anywhere in the world. The GPS is made up of three parts: satellites orbiting the Earth; control and monitoring stations on Earth; and the GPS receivers owned by users. GPS satellites broadcast signals from space that are picked up and identified by GPS receivers. Each GPS receiver then provides three-dimensional location (latitude, longitude, and altitude) plus the time. Individuals may acquire GPS handsets that are readily available through commercial retailers. Equipped with these GPS receivers, users can accurately locate where they are and easily navigate to where they want to go, whether walking, driving, flying, or boating. Farmers, surveyors, geologists and countless others perform their work more efficiently, safely, economically and accurately using open GPS signals. The GPS technology has tremendous amount of applications in GIS data collection, surveying, and mappingGPS is also widely used in transportation systems worldwide. By positioning we understand the determination of stationary or moving objects. These can be determined as follows:

- In relation to a well-defined coordinate system, usually by three coordinate values and
- In relation to other point, taking one point as the origin of a local coordinate system.

The first mode of positioning is known as point positioning, the second as relative positioning. If the object to be positioned is stationary, we term it as static positioning. When the object is moving, we call it kinematic positioning. Usually, the static positioning is used in surveying and the kinematic position in navigation (Fig. 1).

GPS - Components and Basic Facts

GPS uses satellites and computers to compute positions anywhere on earth. The GPS is based on satellite ranging. That means the position on the earth is determined by measuring the distance from a group of satellites in space. The basic principle for global positioning is simple, though the system employs some of the most high-tech equipment ever developed. In order to understand GPS basics, the system can be categorised into five logical steps.

- Triangulation from the satellites is the basis of the system.
- GPS measures the distance using the travel time of the radio message for triangulation.
- GPS uses a very accurate clock to measure travel time.
- Once the distance to a satellite is known, then we need to know where the satellite is in space.
- As the GPS signal travels through the ionosphere and the earth's atmosphere, the signal is delayed.

To compute positions in three dimensions, four satellite measurements are required. The GPS uses a trigonometric approach to calculate the positions, The GPS satellites are so high up that their orbits are very predictable and each of the satellites is equipped with a very accurate atomic clock. The Global Positioning System is divided into following three major components.

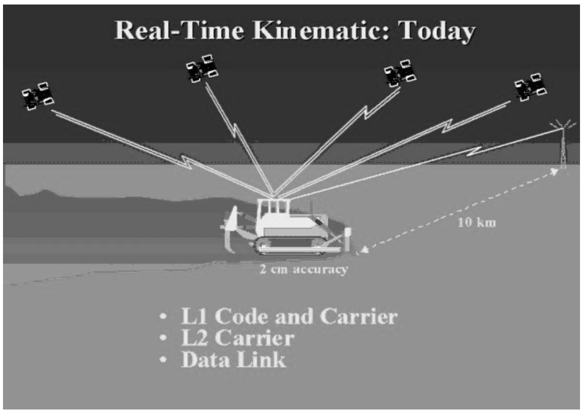

Fig.1. Kinematic positioning of an object

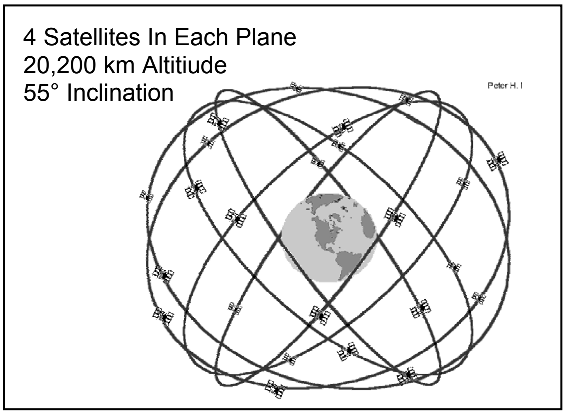

Fig.2. Constellation of 24 GPS Satellites in 6 orbits

Space Segment

The Space Segment consists of the Constellation of NAVASTAR earth orbiting satellites. The current Defence Department plan calls for a full constellation of 24 Block II satellites (21 operational and 3 in-orbit spares). The satellites are arrayed in 6 orbital planes, inclined 55 degrees to the equator (Fig. 2). They orbit at altitudes of about 12000, miles each, with orbital periods of 12 sidereal hours (i.e., determined by or from the stars), or approximately one half of the earth's periods, approximately 12 hours of 3-D position fixes. The next block of satellites is called Block IIR, and they will provide improved reliability and have a capacity of ranging between satellites, which will increase the orbital accuracy. Each satellite contains four precise atomic clocks (Rubidium and Cesium standards) and has a microprocessor on board for limited self-monitoring and data processing. The satellites are equipped with thrusters which can be used to maintain or modify their orbits.

Control Segment

The Control Segment consists of five monitoring stations (Colorado Springs, Ascesion Island, Diego Garcia, Hawaii, and Kwajalein Island). Three of the stations (Ascension, Diego Garcia, and Kwajalein) serve as uplink installations, capable of transmitting data to the satellites, including new ephemerides (satellite positions as a function of time), clock corrections, and other broadcast message data, while Colorado Springs serves as the master control station. The Control Segment is the sole responsibility of the DOD (Department of Defence) who undertakes construction, launching, maintenance, and virtually constant performance monitoring of all GPS satellites. The DOD monitoring stations track all GPS signals for use in controlling the satellites and predicting their orbits. Meteorological data also are collected at the monitoring stations, permitting the most accurate evaluation of tropospheric delays of GPS signals. Satellite tracking data from the monitoring stations are transmitted to the master control station for processing. This processing involves the computation of satellite ephemerides and satellite clock corrections. The master station controls orbital corrections, when any satellite strays too far from its assigned position, and necessary repositioning to compensate for unhealthy (not fully functioning) satellites.

User Segment

The user segment is a total user and supplier community, both civilian and military. The User Segment consists of all earth-based GPS receivers. Receivers vary greatly in size and complexity, though the basic design is rather simple. The typical receiver is composed of an antenna and preamplifier, radio signal microprocessor, control and display device, data recording unit, and power supply. The GPS receiver decodes the timing signals from the 'visible' satellites (four or more) and, having calculated their distances, computes its own latitude, longitude, elevation, and time. This is a continuous process and generally the position is updated on a second-by-second basis, output to the receiver display device and, if the receiver display device and, if the receiver provides data capture capabilities, stored by the receiver-logging unit.

GPS Positioning Types

Absolute Positioning

The mode of positioning relies upon a single receiver station. It is also referred to as 'stand-alone' GPS, because, unlike differential positioning, ranging is carried out strictly between the satellite and the receiver station, not on a ground-based reference station that assists with the computation of error corrections. As a result, the positions derived in absolute mode are subject to the unmitigated errors inherent in satellite positioning (Fig.3).

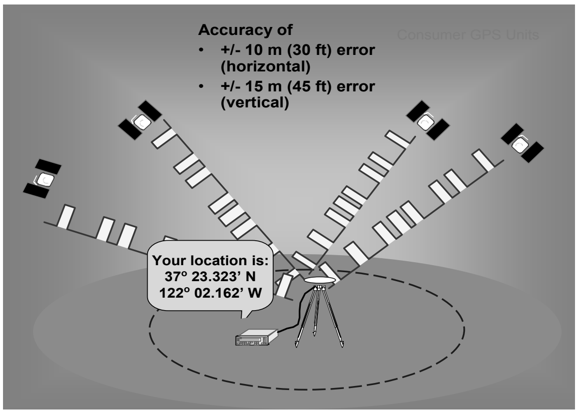

Fig.3. Absolute positioning

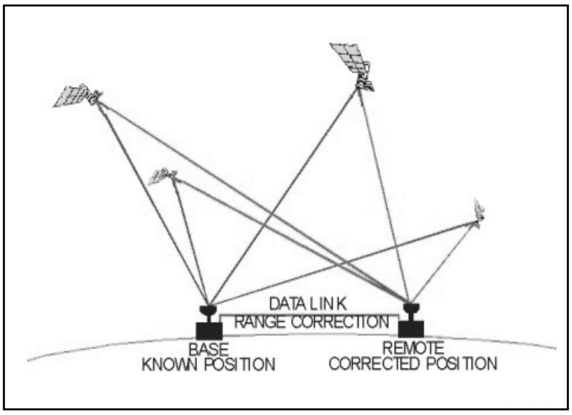

Fig.4. Differential positioning

Differential Positioning

Relative or Differential GPS carries the triangulation principles one step further, with a second receiver at a known reference point. To further facilitate determination of a point's position, relative to the known earth surface point, this configuration demands collection of an error-correcting message from the reference receiver (Fig.4).

Differential-mode positioning relies upon an established control point. The reference station is placed on the control point, a triangulated position, the control point coordinate. This allows for a correction factor to be calculated and applied to other roving GPS units used in the same area and in the same time series. Inaccuracies in the control point's coordinate are directly additive to errors inherent in the satellite positioning process. Error corrections derived by the reference station vary rapidly, as the factors propagating position errors are not static over time. This error correction allows for a considerable amount of error of error to be negated, potentially as much as 90 percent.

Accuracy of GPS

There are four basic levels of accuracy (Table 1) which can be with your real-time GPS system:

Table 1: Accuracy of GPS system

Mode	Accuracy
Autonomous	15 - 100 meters
Differential GPS (DGPS)	0.5 - 5 meters
Real-Time Kinematic Float (RTK Float)	20cm - 1 meter
Real-Time Kinematic Fixed (RTK Fixed)	1cm - 5 cm

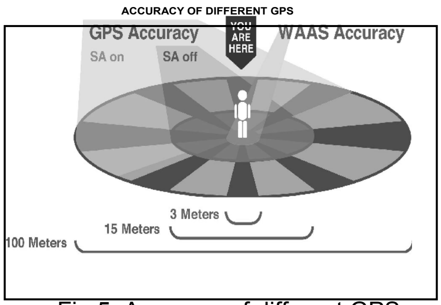

Fig.5. Accuracy of different GPSs

Factors Affecting GPS Accuracy

There are a number of potential error sources or factors that affect either the GPS signal directly or your ability to produce optimal results.

Number of Satellites Required

You must track atleast four common satellites - the same four satellites - at both the reference receiver and rover for either DGPS or RTK solutions. Also to achieve centimeter -level accuracy, remember you must have a fifth satellite for on-the fly RTK initialization. This extra satellite adds a check on the internal calculation. Any additional satellites beyond five provide even more checks, which is always useful.

Ionosphere

Before GPS signals reach antenna on the earth, they pass through charged particles zone called the ionosphere, which changes the speed of the signal. If your reference and rover receivers are relatively close together, the effect of ionosphere tends to be minimal. And if you are working with the lower range of GPS precisions, the ionosphere is not a major consideration. However if your rover is working too far from the reference station, you may experience problems, particularly with initializing your RTK fixed solution.

Multipath

Multipath is simply reflection of signals similar to the phenomenon of ghosting on our television screen. GPS signals may be reflected by surfaces near the antennae, causing error in the travel time and therefore error in the GPS positions.

Troposphere

Troposphere is essentially the weather zone of our atmosphere, and droplets of water vapour in it can effect the speed of the signals. The vertical component of your GPS answer (your elevation) is particularly sensitive to the troposphere.

Satellite Geometry

The satellite geometry or the distribution of satellites in the sky, effects the computation of the position. This is often referred to as Position Dilution of Precision (PDOP). PDOP is expressed as a number, where lower numbers are preferable to higher numbers. The best results are obtained when PDOP is less than about 7. PDOP is determined by your geographic location, the time of day you are working, and any site obstruction, which might block satellites. You can use planning software to help you determine when you'll have the most satellites in a particular area. When satellites are spread out, PDOP is Low (good), and similarly when satellites are closer together, PDOP is High (weak).

Satellite Health

While the satellite systems are robust and dependable, occasionally these satellites could be unhealthy. A satellite broadcasts its health status, based on information from the U.S. Department of Defense. The GPS receivers have safeguards to protect against using data from unhealthy satellites.

Signal Strength

The strength of the satellite signal depends on obstructions and the elevation of the satellites above the horizon. To the extent it is possible, obstructions between your GPS antennae and the sky should be avoided. Satellites which are close to the horizon provide weaker signals.

Distance from the Reference Receiver

The effective range of a rover from a reference station depends primarily on the type of accuracy you aere trying to achieve. For the highest real time accuracy (RTK fixed), roveres should be within about 10-15 Km (about 6-9 miles) of the reference station. As the range exceeds this recommended limit, you may failto initialize and be restricted to RTK float solutions (decimeter accuracy).

Radio frequency (RF) Interference

RF interference may sometimes be a problem both for your GPS reception and your radio system. Some sources of RF interference include:

- Radio towers
- Transmitters
- Satellite dishes
- Generators

One should be particularly careful of sources which transmit either near the GPS frequencies (1227 and 1575 MHz) or near harmonics (multiples) of these frequencies. One should also be aware of the RF generated by his own machines.

Loss of Radio Transmission from Base

If, for any reason, there is an interruption in the radio link between a reference receiver and a rover, then your rover is left with an autonomous position. It is very important to set up a network of radios and repeaters, which can provide the uninterrupted radio link needed for the best GPS results.

GPS Applications in Remote Sensing and GIS

One of the most significant and unique features of the Global Positioning Systems is the fact that the positioning signal is available to users in any position worldwide at any time. With a fully operational GPS system, it can be generated to a large community of likely to grow as there are multiple applications, ranging from surveying, mapping, and navigation to GIS data capture.

It is possible to integrate GPS positioning into remote-sensing methods such as photogrammetry and aerial scanning, magnetometry, and video technology. Using DGPS or kinematic techniques, depending upon the accuracy required, real time or post-processing will provide positions for the sensor which can be projected to the ground, instead of having ground control projected to an image. GPS are becoming very effective tools for GIS data capture. The GIS user community benefits from the use of GPS for locational data capture in various GIS applications. The GPS can easily be linked to a laptop computer in the field, and, with appropriate software, users can also have all their data on a common base with every little distortion. Thus GPS can help in several aspects of construction of accurate and timely GIS databases.

Soil Survey Field Activities

A significant part of the time spent in the production of a soil survey by the soil scientists involved in the project is not in an office but on-site. There are new technological developments that may diminish the necessity for as much on-site work by individuals through predictive models using remote sensing derivatives. As effective as these new tools may prove to be, there will always need to be on-site work performed during the course of a soil survey project, and it is in this area that mobile computing devices are considered to improve production. The two categories of this on-site work are field mapping and supporting documentation.

Advantages of Using Mobile GIS

Real Time Mapping

Considerable production time is saved when the mapper is working on the digital version of the soil map rather than on a hardcopy map that would have to be converted to a digital format. The number of errors that result from processing and converting the hardcopy map to digital are reduced. However, this process needs to be taken out of the office and off the desktop computer and into the field on a mobile computer. Real-time mapping enables the creation or modification of the digital product on-site by the individual who knows the most about that particular soil/landscape model used in the survey. With an application such as ArcPad, that integrates GPS position data into the GIS, the mapper is no longer constantly burdened with having to keep a running count of paces in order to locate the position on the map. The importance of the time savings that occurs cannot be overstated when the location on the aerial photo base can be observed by using GPS integrated with the GIS. The GPS position is viewed on the map display that can include the digital aerial photograph and the location of the soil map unit boundaries. The mapper can actually stand on the map unit boundary as it appears on the map display. Other data layers may also provide the mapper with valuable information while on-site, such as the location ownership boundaries.

On-Site Documentation

Use of a tablet or PDA mobile device would enable more documentation during field mapping. Each location at which an observation is made can be captured as a point feature using the coordinates obtained from the GPS. Attribute information could include how well the predicted map unit corresponded with the observation. This observation database would provide a clear picture of which landscape components needed to be studied more intensely. This spatial database could also be queried and analyzed to determine map unit composition and to provide a record of what areas have had on-site observations. Use of a tablet mobile device would enable the mapper to capture detailed field notes in a digital format using the Windows pedon Program or similar data recording program. This would replace the handwritten form on paper that would have to be input into the computer back in the office. Data entry in the field on a mobile device would save considerable time and reduce possible errors during data entry. An additional function that mobile devices provide is the capability to have digital reference material available in the field. Information such as soil descriptions and standards and methods frequently reviewed, which would require thick cumbersome three-ring binders, can be accessed digitally whenever needed on the mobile device.

Mobile Device Solutions

A number of mobile devices have been examined for their use in soil survey applications and to identify business requirements needed to develop technical specifications. These devices range from handheld PDA to tablet computers. Potential users want a device that is able to withstand exposure to the elements involved in field work, has a large display area viewable in bright sunlight to near darkness, has a long battery life, and is small, lightweight, and easy to carry. A mobile device must have sufficient data storage processing capacity and to handle GIS analysis and editing.

Handheld PDA devices with GPS integration have been successfully used for simple field data collection. A disadvantage of handheld PDA devices is that they are not considered suitable for field soil mapping because of the limited size of the display. There is simply not enough area for the mapper to view the area of interest at a desirable scale. The larger display size on tablet computers is considered to be more suitable. Technology is rapidly changing with new products constantly being released. Even without the optimal display capability, the advantages to using mobile devices in regard to time saved on editing map unit line work, field note collection, and the positioning capability provided by wireless GPS integration, will result in a very effective tool for future soil survey projects.

GPS for Salinity Mapping

The high precision of GPS carrier phase measurements, together with appropriate adjustment algorithms, provide an adequate tool for a variety of tasks for surveying and mapping Mapping of the land damaged due to salinization is a frantic task and requires lot of man power and time since it requires identification, sampling and classifying the land by conventional surveying methods. On the other hand advanced techniques like remote sensing (RS) and GIS can do this task more efficiently. The approach to the problem dealing with salt affected land using RS and GIS has been proved in many recent studies to be the most efficient. Large coverage, good resolution in visible and near visible spectrum and repetitive passes are advantages of Indian Remote Sensing(IRS) satellites and advanced analytical techniques in GIS can be useful in detection and intensity analysis of salt affected land. Applications, such as cadastral mapping, needing a high degree of accuracy also can be carried out using high grade GPS receivers. Continuous kinematic techniques can be used for topographic surveys and accurate linear mapping. Ground truth data collection for delineating salinity/alkalinity as well as water logging are in the forms of sample collection based on GPS, morphological and chemical analysis data for salt affected soil profiles. Soil saturation extracts are prepared to determine ion types and content. The EC and pH values for representative soil samples are kept in the individual salinity/alkalinity classes. Other ancillary data (ground cover type and percentage of organic matter content, crust type and color also recorded. For water logging the ground truth information normally includes extent of surface water logging, type of aquatic vegetation, slope gradient and its direction and depth of standing water above ground surface. Training sets of information classes such as soil salinity/alkalinity or water logging are marked in the false color composite (FCC) of IRS 1C LISS III. In general training set should be homogeneous and composed of many pixels usually an average of 10 pixels of training data are collected for extraction.

Future of GPS Technology in Agriculture

The development and implementation of precision agriculture or site-specific farming has been made possible by combining the Global Positioning System (GPS) and geographic information systems (GIS). These technologies enable the coupling of real-time data collection with accurate position information, leading to the efficient manipulation and analysis of large amounts of geospatial data. GPS based applications in precision farming are being used for farm planning, field mapping, soil sampling, tractor guidance, crop scouting, variable rate applications, and yield mapping. GPS allows farmers to work during low visibility conditions such as rain, dust, fog and darkness.

In the past, it was difficult for farmers to correlate production techniques and crop yields with land variability. This limited their ability to develop the most effective soil/plant treatment strategies that could have enhanced their production. Today, more precise application of pesticides, herbicides, and fertilizers, and better control of the dispersion those chemicals are possible through precision agriculture, thus reducing expenses, producing a higher yield, and creating a more environmentally friendly usage on the farm. By changing the way farmers and agribusinesses view the land through use of GPS in precision agriculture, timely geospatial information on soil-plant-animal requirements and prescribing and applying site-specific treatments to increase agricultural production and protect the environment. Where farmers may have once treated their fields uniformly, they are now seeing benefits from micromanaging their fields. Many of the new innovations rely on the integration of on-board computers, data collection sensors, and GPS time and position reference systems.

Many believe that the benefits of precision agriculture can only be realized on large farms with huge capital investments and experience with information technologies. Such is not the case. There are inexpensive and easy-to-use methods and techniques that can be developed for use by all farmers. Through the use of GPS, GIS, and remote sensing, information needed for improving land and water use can be collected. Farmers can achieve additional benefits by combining better utilization of fertilizers and other soil amendments, determining the economic threshold for treating pest and weed infestations, and protecting the natural resources for future use. GPS equipment manufacturers have developed several tools to help farmers and agribusinesses become more productive and efficient in their precision farming activities. Today, many farmers use GPS derived products to enhance operations in their farming businesses, their information is collected by GPS receivers for mapping field boundaries, roads, irrigation systems, and problem areas in crops such as weeds or disease. The accuracy of GPS allows farmers to create farm maps with precise acreage for field areas, road locations and distances between points of interest. GPS allows farmers to accurately navigate to specific locations in the field, year after year, to collect soil and crop samples.

Crop advisors use rugged data collection devices with GPS for accurate positioning to map pest, insect, and weed infestations in the field. Pest problem areas in crops can be pinpointed and mapped for future management decisions and input recommendations. The same field data can also be used by aircraft sprayers, enabling accurate swathing of fields without use of human “flaggers” to guide them. Crop dusters equipped with GPS are able to fly accurate swaths over the field, applying chemicals only where needed, minimizing chemical drift, reducing the amount of chemicals needed, thereby benefiting the environment. GPS also allows pilots to provide farmers with accurate maps.

Farmers and agriculture service providers can expect even further improvements as GPS continues to modernize. In addition to the current civilian service provided by GPS, the United States is committed to implementing a second and a third civil signal on GPS satellites. The first satellite with the second civilian signal was launched in 2005. The new signals will enhance both the quality and efficiency of agricultural operations in the future.

Useful GPS Terminology

Accuracy – A measure of how close an estimate of a GPS position is to the true location.

Bearing – The compass direction from a position to a destination, (also called an azimuth). In a GPS receiver, bearing usually refers to the direction to a waypoint.

Coordinate Systems – Such as latitude/longitude, represent your position on the earth to a flat surface like a sale map.

Course – The compass direction you are trying to follow from your starting point to the point you are trying to reach.

Course Over Ground – see Track

Declination Setting - GPS units can be adjusted to the amount of magnetic declination in the area of use.

Differential GPS (DGPS) - An extension of the GPS system that uses landbased radio beacons to transmit position corrections to GPS receivers. DGPS reduces the effect of selective availability, propagation delay, etc. and can improve position accuracy to better than 10 meters.

Direction – The direction between two locations is usually called a bearing, azimuth, or course.

Error – Measurement of horizontal position error in feet or meters based on a variety of factors including Dilution of Precision (DOP) and satellite signal quality.

GOTO – The selected point you wish to travel to or find. It may be a position fix or part of a route or track.

Heading - The direction in which you or your vehicle are moving. For boat or airplane operations, this may differ from actual Course Over Ground (COG) due to winds, currents, etc.

Latitude - A position's distance north or south of the equator, measured by degrees from zero to 90. One minute of latitude equals one nautical mile.

Location – The actual physical place you occupy. The difference between a position fix and location is that a location is where you really are and a position fix is where a GPS unit says you are.

Longitude - The distance east or west of the prime meridian (measured in degrees). The prime meridian runs from the North Pole to the South Pole, through Greenwich, England.

Magnetic Declination – The difference between true north and magnetic north at a specific location.

Navigation - The act of determining the course or heading of movement. This movement could be for a plane, ship, automobile, person on foot, or any other similar means.

NAVSTAR - The official U.S. Government name given to the GPS satellite system. NAVSTAR is an acronym for Navigation Satellite Timing and Ranging.

Position fix - The GPS receiver's computed position coordinates.

Precision – Measure of the “repeatability” of the data. Taking repeated readings from a point will improve the precision of the sample mean.

Route - A group of waypoints entered into the GPS receiver in the sequence you desire to navigate them.

Track - Your current direction of travel relative to a ground position (same as Course Over Ground).

Waypoint/Landmark - Waypoints are locations or landmarks worth recordingand storing in your GPS. These are locations you may later want to return to oravoid. They may be check points on a route or significant ground features suchas a campsite, the truck, a cultural resource, or a favorite fishing spot).Waypoints may be defined and stored in the unit manually by taking coordinatesfor the waypoint from a map or other reference. This can be done before ever leaving home. Or more usually, waypoints may be entered directly by taking areading with the unit at the location itself, giving it a name, and then saving the point.

Wide Area Augmentation System (WAAS) - A system of satellites and ground stations operated by the Federal Aviation Authority that provide GPS signal corrections for better position accuracy for airplanes. WAAS consists of approximately 25 ground reference stations positioned across the United States that monitor GPS satellite data. Two master stations, located on either coast, collect data from the reference stations and create a GPS correction message. A WAAS-capable receiver can be adapted to ground use and give you a position accuracy of better than three meters, 95 percent of the time.

(*Courtesy*: Garmin International)

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Agronomic Practices for Sustaining Crop Production in Saline Soils

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Introduction

Natural weathering of soil minerals, seepage from up slopes, ingress of or inundation of area with sea water and anthropogenic causes like introduction of irrigation under inadequate drainage, shallow water table and with brackish water are the main factors of salt accumulation in soils. Though all soils contain some salts which serve as essential nutrients but when their concentration exceeds critical limits; growth, development, yield and quality of most of crops is adversely affected. Likewise, water makes our fields bloom and brings food to our plates. Indeed, it is absolutely essential to human health and life, and the history and cultures of our society. Global annual water resources are 47196 km3 (IWMI Research Report no. 19, 1998) while the demand is increasing especially from more paying competing urban (drinking) and industrial sectors as in most countries, agricultural water use gets low priority. To meet the growing demands of agricultural, urban and industrial sectors in our country; poor quality groundwater is increasingly exploited because 32-84 % of the groundwater aquifers in the states of Rajasthan, Haryana and Uttar Pradesh are unfit for irrigation, and their use in irrigation is likely to result in build-up of salinity, sodicity or toxicity in the soils (Minhas and Tyagi, 1999). Considering above facts of fresh water scarcity for agricultural use, it is inevitable to focus on evolving strategies for minimizing losses in crop production and salt build up in 6.73 m ha salt affected soils and areas practicing poor quality water irrigation particularly in arid and semi-arid regions. It is now known and recognized that the water conventionally considered unfit can be profitably used for crop production by adopting some appropriate techniques. Addition of amendments to neutralize RSC of sodic water and the exchangeable sodium in sodic soils developed due to irrigation with such water. Similarly leaching of soluble salts from the root zone in case of saline water irrigated soil is essential pre-requisites for sustainable crop production. In situations, where the development of soil salinity is due to shallow groundwater table, lowering of water table to a safe depth will be the first step in the reclamation of such soils. Therefore, special agronomic and cultural practices are required to minimize the harmful effect of salts and to maintain/restore good physical condition of the soil for better crop growth. The findings of research conducted at Central Soil Salinity Research Institute, Karnal and other places, have proved that optimum yields of selected salt tolerant crops can be obtained from the poor quality irrigated soils where nothing used to grow or very poor yields were obtained. In the present notes, important cropping systems and improved cultural practices for sustainable crop production in sodic and saline soils and water irrigated soils are proposed and highlighted.

Extent and Distribution of Salt-Affected Soils and Poor Quality Water

State-wise extent of salt affected soils shows that maximum area occurs in Gujarat followed by Uttar Pradesh, Maharashtra, West Bengal, Rajasthan, Tamil Nadu, Andhra Pradesh, Haryana, Bihar, Punjab, Karnataka, Orissa, Madhya Pradesh, Andaman & Nicobar Islands and Kerala (Table 1). Total area accounts for 6.73 m ha equivalent to 2.1% of the TGA of the country. Out of 584 districts 194 have salt-affected soils. About 2.96 m ha area is saline and rest 3.77 m ha is sodic (Yaduvanshi *et al.* 2008).

Table 1. Extent (m ha) and distribution of salt affected soils in India

State	Saline	Sodic	Total
Andhra Pradesh	0.078	0.20	0.27
Andaman & Nicobar	0.077	0.0	0.07
Bihar	0.047	0.11	0.15
Gujarat	1.68	0.54	2.22
Haryana	0.049	0.18	0.23
Karnataka	0.002	0.15	0.15
Kerala	0.02	0.0	0.02
Madhya Pradesh	0.0	0.14	0.14
Maharashtra	0.18	0.42	0.61
Orissa	0.15	0.0	0.15
Punjab	0.0	0.15	0.15
Rajasthan	0.19	0.18	0.37
Tamil Nadu	0.013	0.35	0.36
Uttar Pradesh	0.021	1.35	1.37
West Bengal	0.44	0.0	0.44
Total	2.96	3.77	6.73

Groundwater quality in some of the states in India is given in table 2. About 50% of groundwater is either marginal or poor. Sodic water constitutes 37% of the brackish groundwater in some states of north and north-western India (Table 3). Prolonged injudicious use of such water without amendment will cause soil sodification sooner or later.

Table 2. Water quality distribution (%) in some states of India

States	Good	Marginal	Poor
Punjab	59	22	19
Rajasthan	16	16	68
Haryana	37	8	55
Uttar Pradesh	37	20	43
Madhya Pradesh	75	10	15
Gujarat	70	20	10
Karnataka	65	10	25
Average	51	15	34

Table 3. Percent distribution of brackish waters in India

States	Categories		
	Saline	Sodic	Saline-sodic
Punjab	22	54	24
Haryana	24	30	46
Rajasthan	16	35	49
Gujarat	20	28	52
Average	20	37	43

Reclamation and Management

Salt Leaching

Reduction in crop yield depends on such factors as crop growth, the salt content of the soil, climatic conditions, etc. In extreme cases where the concentration of salts in the root zone is very high, crop growth may be entirely prevented. To improve crop growth in such soils the excess salts must be removed from the root zone. Leaching is the most effective procedure for removing salts from the root zone. Leaching is accomplished by ponding fresh water on the soil surface and allowing it to infiltrate and it is effective only when the salty drainage water is discharged through drains out of the area under reclamation. Process may reduce salinity levels in the absence of artificial drains when there is sufficient natural drainage, i.e. the ponded water drains without raising the water table. Leaching should preferably be done when the soil moisture content is low and the groundwater table is deep. Leaching during the summer months is, as a rule, less effective because large quantities of water are lost by evaporation. The actual choice will however depend on the availability of water and other considerations. In some parts of India for example, leaching is best accomplished during the summer months because this is the only time when water table is deepest, soil is dry and large quantities of fresh water can be diverted for reclamation purposes. The term reclamation of saline soils refers to the methods used to remove soluble salts from the root zone. Methods commonly adopted or proposed to accomplish this include the following:

Scraping

Removing the salts that have accumulated on the soil surface by mechanical means has had only a limited success although many farmers have resorted to this procedure. Although this method might temporarily improve crop growth, the ultimate disposal of salts still poses a major problem.

Flushing

Washing away the surface accumulated salts by flushing water over the surface is sometimes used to desalinize soils having surface salt crusts. Because the amount of salts that can be flushed from a soil is rather small, this method does not have much practical significance.

Drainage

Irrigation is the most effective means of stabilizing agricultural production in areas where the rainfall is either inadequate for meeting the crop requirements or the distribution is erratic. Before the introduction of large quantities of water through irrigation to an area, water balance between rainfall on the one hand and stream flow, groundwater table, evaporation and transpiration on the other exists. This balance is seriously disturbed when additional quantities of water are artificially supplied to grow agricultural crops, introducing additional factors of groundwater recharge by seepage from unlined canals, distributors and field channels, and from the irrigation water let on the fields more than the quantities actually utilized by the crops, causing rise in groundwater table. Once the groundwater table is close to the soil surface, its evaporation from the surface causes appreciable movement of groundwater and salts in the root zone.

A significant relationship between depth of groundwater and evaporation from the soil surface exists with a critical depth of water table above which there a sharp increase in the evaporation rate and therefore soil salinization takes place as shown in Fig.1. In general, the critical depth of water table ranges between 1.5 to 3.0 metres depending on soil characteristics, root zone of crops, salt content of groundwater etc. Provision of adequate drainage is the only way to keep root zone free of salts. Subsurface drainage problems may also arise due to the presence, at some soil depth, of a clay barrier, a hardpan, bed rock, or even a subsoil textural change. In many areas drainage problems also arise because of the accumulation and stagnation of rainfall or excess irrigation water on the soil surface. Surface drainage problems usually arise due to slopes that are too flat or to slow water penetration because of structural instability of the soils or to uneven land. Temporary water stagnation in standing crops results in problems of aeration, disease, weed control and nutrient supply. Proper land shaping and provision of surface drains are needed to solve the problems of surface water stagnation.

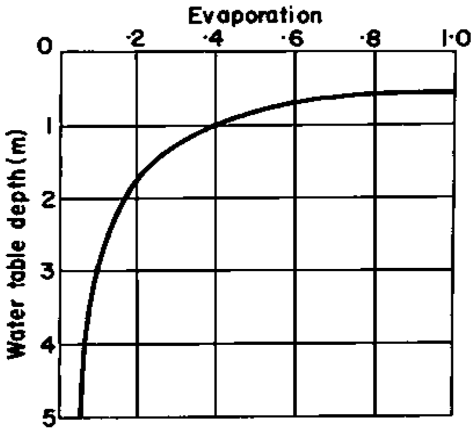

Fig. 1. Schematic relationship between the depth of groundwater and relative evaporation rate from soil

On Farm Management Options

Establishing a good crop stand in saline soils or with saline water irrigation is a challenging task. Unlike normal soils, the agronomic practices for crop production in saline water irrigated soils are different. An ideal package of cultural practices besides soil fertility and irrigation water management can ensure a good crop stand vis-à-vis good yield. No single management option in isolation can be fully effective in controlling the salinity of irrigated soils, but several practices interact with each other in an integrated manner but for better understanding each option should be understood separately.

Irrigation Management

Irrigation should meet both water requirements of crops and the leaching to maintain a favourable salt balance in the root zone for optimum yield. Multi-quality irrigation water, methods of irrigation, frequency and quantity of water applied could be possible interventions. Successful operation of field application must supply water to the plants at the right time in appropriate quantity and quality with minimum waste and at the place where the plants need it for optimum growth. On-farm water management technology includes proper land leveling and shaping, efficient design and layout of irrigation methods, scientific scheduling of irrigation under both adequate and deficient water supply conditions, irrigation management under high water table depths and crop planning for optimum water use.

Pre-Sowing Irrigation

In saline soils or saline water irrigation, salt often accumulate in the top few centimeters of the soil during non-crop periods. Where high water table exists, fallowing may result in excessive salt accumulation in the root zone particularly in arid and semi-arid regions. Under these conditions both germination and yields are adversely affected. A heavy pre-sowing irrigation to leach the accumulated salts from the root zone is very useful and essential to improve germination and early growth. Wherever available, pre-sowing irrigation should be given with good quality canal water. Deep tillage and inversion help to reduce salinity hazard.

Irrigation Intervals

During intervening periods between two irrigation cycles, crop evapo-transpiration reduces soil water, matric potential and solute potential at a rate which is governed by rate of ET and soil moisture characteristics causing variable effects on crop yields. These effects are more pronounced and set very aggressively in saline environments, so, irrigation in saline soils should be more frequent to reduce the cumulative water deficits. As the soil progressively dries out due to evapo-transpirational losses the concentration of salts in the soil solution and, therefore, its osmotic pressure increases making the soil water increasingly difficult to be absorbed by the plants. Thus infrequent irrigation aggravates salinity effects on growth. More frequent irrigations, by keeping the soil at higher soil moisture content prevent the concentration of salts in the soil solution and tend to minimize the adverse effects of salts in the soil. For these reasons crops grown in saline soils must be irrigated more frequently compared to crops grown under non-saline conditions so that the plants are not subjected to excessively high soil moisture stresses due to combined influence of excess salts and low soil water contents. Fig. 2 depicts changes in the total soil moisture stress to which the growing plants are subjected in a non-saline soil compared to a saline soil. Several studies have shown that growth of plants was reduced nearly proportionally to the areas under the curves. Thus, when the areas under two such dissimilar stress curves as A and B were equal, the growth of plants was found to be reduced to nearly the same level. If the saline soils were irrigated infrequently plants would be subjected to very high soil moisture stresses with consequent yield losses. But some contrary reports are also there which indicate that small interval irrigations will induce water uptake from shallow depths, increase unproductive evaporative losses from surface and increase the salt loads with saline irrigations.

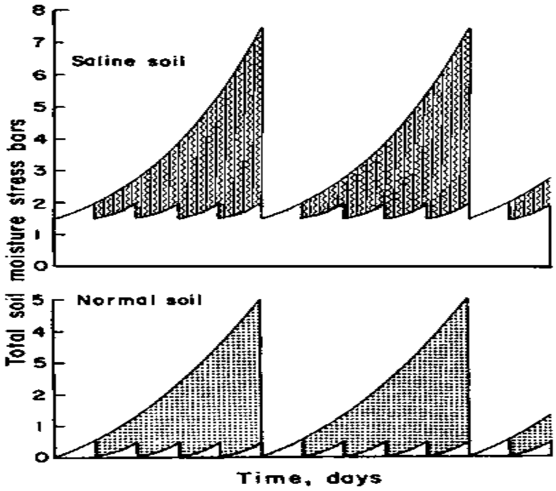

Fig. 2. Total moisture stress changes in saline and non-saline soil in the interval between two irrigations

Irrigation Method

It is established that frequent irrigations are helpful in saline soils in maintaining adequate availability of soil water. Sprinkler irrigation is an ideal method for irrigating frequently and with small quantities of water at a time. Leaching of soluble salts is also accomplished more efficiently when the water application rates are lower than the infiltration capacity of the soil and such a condition cannot be achieved by flood irrigation methods. Sprinkler irrigation also has the advantage that local toposequential differences in the level of the field will not cause non-uniform water application and salt leaching.

In the trickle or drip irrigation method water is supplied continuously at a point source and in the immediate vicinity of plant roots. The method is suitable for perennial or seasonal row crops; it has been found particularly useful when irrigating with water of high salinity. The method has the advantage that it keeps the soil moisture continuously high in the root zone, therefore maintaining a low salt level. The roots of the growing plants tend to cluster in the high soil moisture zone near the drippers and therefore avoid the salts that accumulate at the wetting front. Results of field trials (Goldberg *et al.*, 1976) to compare sprinkler and drip irrigation methods using water of two qualities (0.4 and 3 dS m^{-1}) are presented in table 4. The yield difference between the two methods of water application was greater when saline water was used.

Table 4. Effect of irrigation method and water quality on the yield of tomatoes, t/ha

Irrigation method	Electrical conductivity of water dS/m	
	0.4	3.0
Drip	66.7	65.0
Sprinkler	52.0	39.2

Further, the yield obtained by the drip method with saline water was almost equal to that produced when the high quality water was applied by this method. A more favourable distribution of salts in the soil profiles with drip irrigation in comparison with the sprinkler and furrow methods was also observed at the end of the growing season on a sweet corn plot, although in the drip irrigation method appreciable salt accumulation is likely to occur between the rows depending on the inter and intra row space between the drip points. Although sprinkler and trickle irrigation methods are highly efficient, both from the view of water use and salinity control, their high initial costs often preclude their use in regions where transport infrastructure and markets are not highly developed.

A soil factor of considerable importance in relation to growth of plants is the location of salts in relation to root zone or seed placement. Irrigation practices can be modified to obtain a more favourable salt distribution in relation to seed location or growing roots (Fig. 3). It is well known that salts tend to accumulate in the ridges when using furrow type irrigation. Salts leach out of the soil under the furrows and build up on the ridges with application of irrigation. Where soil and farming practices permit, furrow planting may help in obtaining better stands and crop yields under saline conditions. Certain modifications of the furrow irrigation method including planting in single/double rows or on sloping beds are helpful in getting better stands under saline conditions. Typical patterns of salt accumulation under different types of beds are shown in Fig.4.

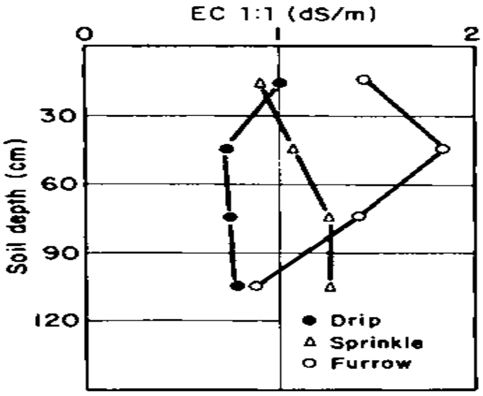

Fig. 3. Salinity profiles in sweet corn under drip, sprinkler and furrow irrigation

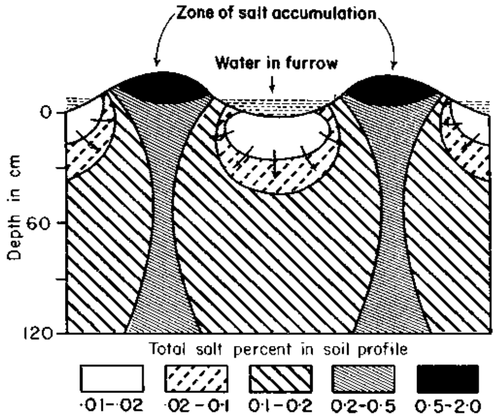

Fig. 4. Direction of salt flow and salt accumulation in furrow irrigation

With double beds, most of the salts accumulate in the centre of the bed leaving the edges relatively free of salts. Sloping beds may be slightly better on highly saline soils because seed can be planted on the slope below the zone of salt accumulation.

Mulching

During periods of high evapo-transpiration between the two irrigations and during fallow periods there is a tendency for the leached salts to return to the soil surface. Soil salinization is particularly high when the water table is shallow and the salinity of groundwater is high. Practices that reduce evaporation from the soil surface and/or encourage downward flux of soil water can help to control root zone salinity. Studies on soil salinity changes under bare fallow and straw mulch on fallow have shown that mulch reduced salinity on bare fallow soil. Under straw mulch a significant reduction in soil salinity results in favourable edaphic environments and thus increased crop yields. Periodic sprinkling of mulched soils result in greater salt removal and higher leaching efficiency than flooding or sprinkling of bare soil.

Crop Production on Saline Soils

Various options suggested for crop production in salt stress environment aim at preventing the salt build up to the levels that limit productivity of soils and control salt balances in the soil-water system and minimizing the damaging effects of salts on crops at plant level or field scale. Soil, crop, climate and social factors are the deciding criteria for adoption of specific agronomic practices adopted and listed in following sections.

Table 5. Soil salinity classes and effects on crop plants

Class	ECe (dS m^{-1})	Effect on Crop Plants
Non saline	0 - 2	Salinity effects negligible
Slightly saline	2 - 4	Yields of sensitive crops may be restricted
Moderately saline	4 - 8	Yields of many crops are restricted
Strongly saline	8 - 16	Only tolerant crops yield satisfactorily
Very strongly saline	> 16	Only few very tolerant crops yield satisfactorily

Choice of Crops and Cropping Sequences

Since crops vary in salinity tolerance from very sensitive or semi-tolerant to tolerant (Table 5); so the selection of crops and cropping sequences for saline water irrigation and saline soils is of paramount importance. These inter and intra-generic variations in salt tolerance of plants can be exploited for selecting crops or varieties that can produce satisfactory yields under given salt stress & the values of threshold salinity and slope of piece-wise response equation RY=100 – S (EC0 – ECt) can be approximated from Table 6.

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Strongly saline	8 - 16	Only tolerant crops yield satisfactorily
Very strongly saline	> 16	Only few very tolerant crops yield satisfactorily

Table 6. Salt tolerance of some important agricultural crops (Mass, 1986)

Sensitive	Moderately sensitive	Moderately tolerant	Tolerant
ECt < 1.2; EC0< 8	1.2- 3; 8 - 16	3 – 6; 16 - 24	6 -10; 24- 32
Chickpea	Broad bean	Wheat	Barley
Beans	Maize	Mustard	Cotton
Sesame	Groundnut	Cowpea	Sugar beat
Onion	Sugarcane	Oats	Safflower
Carrot	Alfalfa	Sorghum	
Green gram	Berseem	Soybean	
	Radish	Spinach	
	Paddy	Pearl millet	
	Cauliflower	Muskmelon	
	Chilly		

But defining absolute tolerance of crops is very difficult as it is modified by factors like growth stage, varieties, environmental, cultural practices and chemical composition of water etc. EC0 corresponds to minimum osmotic potential or maximum salinity at which the crops can absorb water and ECt is the threshold salinity at which production will start declining. Selection of the crops and their sequences will hence depend upon the tolerance levels of crops, degree of irrigation water salinity and consequent build up of soil salinity (Table 6 and 7). Similarly, the choice of first crop in saline soils will depend upon the soil salinity after the basic reclamation measures are implemented. Complete reclamation at once may not be attainable and in practice improvement of the soil is gradual. Hence, crops that are salt tolerant and can cope up with salinity stress are preferred in the early phase of reclamation.

Table 7. Salinity limits of irrigation waters for agricultural crops

Crops	Soil Texture	Pervious crop	ECiw (dS.m) for Yield (%)	
			90	75
Wheat	Silty clay loam	Sorghum	3.4	7.0
	Sandy loam	Bajra	6.6	10.4
	Loamy sand	Fallow	8.3	11.7
Barley	Sandy loam	Fallow	7.2	11.3
Rice	Silty clay loam	Rice	2.2	3.9
Maize	Slay loam	Wheat	2.2	4.7
Pearl-millet	Sandy loam	Wheat	5.4	9.0
Italian-millet	Sand	Sunflower	2.4	4.6
Sorghum	Sandy loam	Mustard	7.0	11.2
Sorghum Fodder	Sandy loam	Berseem	5.2	10.2
Mustard	Sandy loam	Sorghum	6.6	8.8
Soyabean	Silty clay loam	Mustard	2.0	3.1
Pigeon Pea	Sandy loam	Onion	1.3	2.3
Clusterbean	Sandy loam	Variable	3.2	4.5
Cowpea	Loamy sand	Variable	8.2	13.1
Berseem	Sandy loam	Sorghum	2.5	3.2
Onion	Sandy loam	Pigeonpea	1.8	2.3
Potato	Sandy loam	Okra	2.1	4.3
Tomato	Sand	Variable	2.4	4.1
Okra	Sandy loam	Potato	2.7	5.6
Chillies	Sand	Variable	1.8	2.9
Brinjal	Sand	Variable	2.3	4.1
Fenugreek	Sandy loam	Potato	3.1	4.8
Bitter gourd	Sand	Variable	2.0	3.4
Bottle gourd	Sand	Variable	3.2	4.5

Appropriate cultivation practices and growing of suitable crops help in leaching of salts and the crop cover also prevents re-salinization due to evaporation of saline water from bare surface. In saline water irrigated soils of arid and semi-arid areas of India, cotton, sorghum, pearl millet, cluster bean and moth bean could be grown during kharif, and during rabi wheat, barley, mustard, safflower and sugarcane could be grown depending upon the availability of water. The crop production as a function of soil salinity under field conditions has been studied at CSSRI and it was found that threshold tolerable soil salinity levels for wheat, barley and mustard are 4, 7 and 6 dS m^{-1}, respectively. After solving the salinity problem in the affected area, wheat, barley and mustard yields can be increased by 28, 30 and 13 percent, respectively. Further it was reported that pearl millet and cotton could be grown in saline soil up to ECe of 6.5 and 7.5 dS m^{-1}, respectively without significant reduction in yield. Cultivation of crops having low evapo-transpiration and/or high tolerance is one way of compensating for water deficiency. The recommended cropping sequences for saline soils are pearl millet-barley, pearl millet-wheat, pearl millet-mustard, sorghum-wheat or barley, sorghum-mustard, cluster bean-wheat or barley and cotton-wheat or barley. From the long-term experiments on cropping sequences in saline soils, it was observed that pearl-millet - wheat; pearl-millet- barley, pearl-millet- mustard, sorghum (fodder) - wheat and sorghum (fodder) - mustard cropping sequences were more remunerative in saline soils. Cotton based cropping sequences were not much beneficial since the yield of following rabi crops are drastically reduced. In water scarcity areas mustard could replace wheat since its water requirement is low as compared to wheat.

Crop Cultivars

In addition to inter-generic variations, crop cultivars also vary in their tolerance to salinity. Such cultivars (Table 8) have been identified on their rating for high yield potential, salt tolerance and stability under saline environments.

Table 8. Promising Cultivars for saline and alkaline environments

Crop	Saline environment
Wheat	Raj 2325, Raj 2560, Raj 3077, WH 157
P. millet	MH269, 331, 427, HHB-60
Mustard	CS416,CS330,-1, Pusa Bold
Cotton	DHY 286, CPD 404, G 17060, GA, JK276-10-5, GDH 9
Safflower	HUS 305, A-1, Bhima
Sorghum	SPV-475, 881, 678, 669, CSH 11
Barley	Ratna, RL345, RD103, 137, K169

Seed Rate and Spacing

Due to inhospitable soil environment, germination is adversely affected. Mortality of young seedlings and poor tillering of the crops are common in saline soils. Growth of crop plants is reduced. A higher seed rate of about 25% and closer spacing are advisable for good crop stand in cotton, pearl-millet, sorghum, wheat, barley, mustard etc. In case of transplanted crops, the number of seedlings per hill should be increased.

Treatment of Seeds/Seedling

The chemical treatment of seeds and seedlings has been reported to induce salt tolerance. In a field experiment on saline soils (ECe 12 dS m^{-1}), irrigated with saline water (ECiw 10.5 dS m^{-1}), the highest yield of wheat was obtained by pre-soaking seeds in 3 percent sodium sulphate solution.

Practice for Sowing/Planting

Sowing/planting practices can often be modified to obtain a more favourable salt distribution in relation to seed location or growing roots. Since salt tends to accumulate on the ridges under furrow method of irrigation, furrow planting may help to obtain better crop stand and yield under saline conditions. The sowing of sugar beet on one side of the ridge half way between top and bottom, opposite to the sun direction gave significantly higher yield than flat and ridge sowing. The salt concentration in the root zone under this method of sowing was comparatively less owing to more accumulation of salts on southern face of the ridge due to direct and intensive solar radiation on this face. Similarly in case of sugarcane, trench method of planting gave significantly higher yield than flat sowing attributable to low concentration of salts, as salts move to the top of the adjoining ridges. Moreover, the seeds should be sown in lines at an optimum depth with bullock or tractor driven seed drills. Seed-cum-fertilizer drill should be preferred to ensure uniform placement of seeds and fertilizers at the optimum depth. Sowing with seed drills will give a uniform stand and lead to the early emergence of seedlings. If seed drill is not available, sowing should be done by kera or pora method.

Fertilizer Management, Nutrient Availability and Uptake

Excessive uptake of certain ions may be seen in salt affected soils which often results in reduced uptake of some essential plant nutrients causing nutrient imbalances and deficiencies. Thus, although the available status of nutrients in a soil might not be in a deficient range per se, its application might compensate for the decreased uptake by plants resulting from the antagonistic effect of excess uptake of certain ions. Effects of sanility on plant nutrition are mediated through modification of retention, transformations and fixation of nutrients, interaction with uptake by roots due to reduced root growth and ionic competition, and disturbed metabolism within plants mainly through water stress.

Nitrogen

Due to lack of vegetation and organic matter, nitrogen deficiency is widespread in saline soils. Some of other reasons for low N status of saline soils are, high leaching losses, decreased rate of nitrification due to reduced efficiency of nitrifying bacteria, direct antagonistic effects of Cl-1 on NO_3 uptake and efficiency of these bacteria causing accumulation of NH_4-N and loss of a large fraction of the applied nitrogen in gaseous NH3 forms under high soil salinity (Chhabra, 1996). High concentration of salts (KCl or K_2SO_4) inhibits nitrification and resultant NH_4-N accumulation. The plants, which absorb N only as NH3-N, would show nitrogen deficiency even if nitrogen is present in the soil. Due to greater reduction of NO_3 to NO2 under anaerobic conditions of water-logged saline soils restrict availability and uptake of N. Poor symbiotic N fixation beause of adverse effects of salts on Rhizobia and reduced metabolism of N to amino acids and protein in plants themselves due to more negative osmotic potential of soil solution are the other factors of low availability, uptake and use efficiency. Altered metabolism of N in plants indicates that plant N content is a poor indicator of N deficiency; rather it is the protein-N which gives real picture. Thus most of crops grown in saline conditions respond to N application. Field experiments conducted at CSSRI, Karnal in saline soil indicated significant response of wheat, barley, mustard, pearl millet and cotton up to 160, 120, 100, 120 and 80 kg N ha^{-1}, respectively. Nitrogenous fertilizer should be applied in split doses to reduce nitrogen losses through volatilization and denitrification. Not only the amount but the method, time of application and source of N affects the use efficiency in saline soils. Foliar application of 3% solution of urea along with soil application is very beneficial and economical (Yadav and Rao 1998). Foliar application may also save an irrigation which is an added advantage in areas where groundwater is saline. Under moderate salinity urea is better source than CAN and $(NH_4)_2$ SO_4, but at higher salinity NO_3-containg fertilizers are better choice than NH_4-containing fertilizers.

Groundwater in certain areas contain appreciable amounts of NO_3 and irrigation with such water can meet crop N requirements but some times they become toxic to plants or may cause excessive vegetative growth, delayed maturity and shriveling of grains. For such conditions, last one or two irrigations should be avoided with such water in grain crops, rather it is advisable to grow fodder crops.

Phosphorus

Availability of phosphorus to plants increases up to a moderate level of salinity but thereafter it decreases. The reasons for modification in P availability are discussed in following section of this chapter. Because of increased Ca solubility from native $CaCO_3$ of saline soils, soluble forms of P in $Ca(H_2PO_4)_2.2H_2O$ get precipitated in presence of NaCl, KCl and NH_4NO_3. Higher retention of soluble P with increase in ionic strength of the soil solution implies need of higher application for meeting the crop requirements. Anion competition of phosphates with chlorides as both are absorbed by same mechanism, so excess concentration of Cl- as found in saline soils may severely affect P uptake. Soil salinity reduces plant root growth, decreasing the surface area actively participating in uptake of P and thus application of phosphorus gives response. Soil test value alone do not explain the P responses of plants in saline soils because these soils even when containing high amounts of extractable P show positive responses to applied P as availability of this nutrient is more a function of plant root surface area and the antagonistic effects of chloride ions. Thus it can be inferred that addition of P fertilizer is a must in saline soils.

Potassium

Saline soils are generally medium to high in available potassium but plant grown under high salinity may show K deficiency due to antagonistic effect of sodium and calcium on potassium absorption and or disturbed sodium/potassium ratio. Na toxicity may be less common in saline than alkali soils but its excess may cause reduction of K within plant. Not only the absolute content of K but its balance with respect to Na, Ca and Mg is affected in favour of Ca, Na and Cl- by soil salinity, resulting in reduced plant growth and yields. Loss of K may also take place with leaching process. Under such conditions application of potassium fertilizer might increase yield. A judicious application of bulky organic manures and chemical fertilizers would be inevitable to ensure stable crop yield. On moderately saline soils application of potassic fertilizers may increase crop yields either by directly supplying K or by improving its balance with respect to Na, Ca and Mg; however, under high salinity conditions it is difficult to effectively exclude Na from the plants by use of K.

Micronutrients

Though there very few reports of micronutrient (Fe, Mn, Cu and Zn) deficiencies are available but often there is a decrease in micronutrient content of plants with an increase in salinity. Reports indicate that under SO_4-type of salinity precipitation of Fe as $Fe_2(SO_4)_3$ may result in low availability of Fe to plants. Some decrease in availability of Cu, Fe, Mn, Si, Mo and Zn to plants with an increase in salinity could be due to high Ca content of saline soils, but this reduction in availability is not severe enough to cause deficiencies of respective nutrients.

Managing Cl⁻ and F Toxicity and Post Reclamation Plant Nutrition

High concentration of Cl^- disturbs many physiological processes of plants including amylolytic activity resulting in accumulation of starch and sugars. It also reduces chlorophyll, carbohydrates and many organic anions contents through disturbance in normal photosynthetic activities of plants and their reduced growth. Proper doses of N and P can decrease the toxic concentrations of soil absorbed Cl- in plants (Fig. 5).

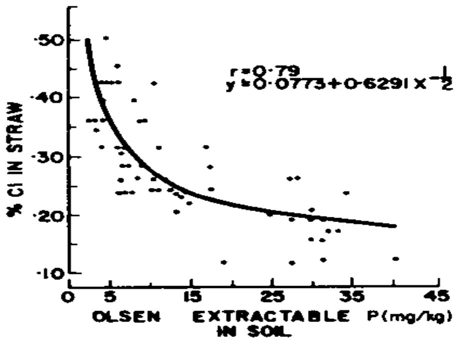

Fig.5. Effect of available soil phosphorus on the chloride content of wheat straw

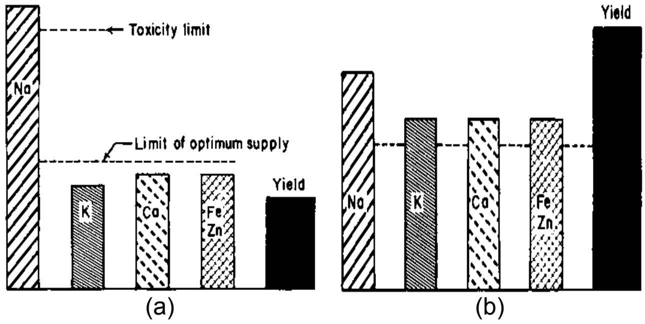

Fig. 6. Plant nutrient supply due to toxicity with (a) and without (b) fertilization for correction of an unbalanced/insufficient nutrient in saline soils

Though P and Cl- are absorbed through same mechanism, plants have better affinity to P and so toxicity of Cl- is decreased with its reduced uptake under proper levels of P application. The required quantity of phosphorus and potash along with first dose of nitrogen (one third for pearl millet, wheat and barley and half for cotton and mustard) when applied at sowing help in alleviating the toxicity of Cl- and meet crops nutrients requirements. The remaining quantity of nitrogen should be applied in two equal splits at first and second irrigation i.e. 25 and 45 days after sowing in pearl millet, wheat and barley and in one dose in cotton (60 days after sowing) and mustard (30 days after sowing).

Under limited water supply conditions, nitrogen applied in two equal doses at sowing and first irrigation in wheat and barley can serve the purpose. This scheme of time of nutrients supply avoids undue delay in maturity and thus number of irrigations with saline water. Application of phosphorus helps in increasing the yields of crops in saline soils by directly providing phosphorus or by decreasing the absorption of toxic elements like fluorine and chloride. It was observed that yields of wheat and mustard increased significantly with the application of 13 kg P ha^{-1} as compared to no application of phosphorus irrigated with saline water under field conditions. On moderately saline soils, application of potassic fertilizers may increase the crop yield either by directly supplying K or by excluding the uptake of Na, Ca and Mg. However, under high salinity conditions it is difficult to effectively exclude Na from the plant by use of potassic fertilizers. The soils should be monitored regularly after reclamation process is over, because with continuous cultivation may deplete one or more nutrients and soil may become deficient. So for sustaining crop production, optimum and balanced supply of nutrients based on soil tests and crop requirements should be ensured. In view of specific needs of saline soils, general application of NPK mixtures, zincated superphosphate and DAP may not be necessary in initial years of reclamation, however, after reclamation basal application of complex fertilizers should be encouraged for balanced nutrition of crops.

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Nutrient Management for Sustaining Crop Production in Salt Affected Soils

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Introduction

To ensure food security for ever increasing population of India which is increasing at an alarming rate of around 1.9 % per annum and is projected to reach the figure of 1.40 billion by 2025 AD; it needs to produce huge quantities of food grain, fodder and fuel. There is a little scope for bringing additional area under food crops because out of 182.2 m ha gross cropped area about 75 % has already been brought under cultivation of food crops. Rather, area under food crops is shrinking due to diversion of good fertile lands for non-agricultural purposes like urbanization, roads and industry. However, we have about 6.73 million ha salt affected soils which are lying barren or produce very low and uneconomical yields of various crops due to excessive accumulation of salts. This area is expected to increase with spread of water-logging and salinity due to increase in canal irrigation without provision of drainage and intensive exploitation of poor quality groundwater for agriculture in non-canal commands. Based on soil pH, exchangeable sodium percentage (ESP), concentration and nature of soluble salts and the reclamation procedure to be adopted, these salt-affected soils have been classified in two major categories viz. alkali (sodic) soils and saline soils. Nutrient constraints vis-a vis management strategies for improving and sustaining crop production and maintaining soil fertility are critically discussed in the present chapter.

Nutrient Management in Alkali Soils

About 3.77 million hectares area is severely affected by sodicity in the Indo-Gangetic plains. Sodic or alkali conditions alter availability of nutrients in soils and generally cause either nutrient deficiency or toxicity in these soils. Fertility of these soils with low nutrient reserves and their altered availability is confounded by the low supply of water and oxygen to roots in profiles with dispersive clays. The main problem is of high pH/ESP, high amount of calcium carbonate, very low amount of organic matter and poor physical conditions limiting nutrient availability and plant growth. Crops grown on these soils invariably suffer nutritional disorders (N, Ca and Zn deficiency and Na toxicity) resulting in low yields. Crop production and fertilizer use efficiency in these soils can be increased by following the reclamation technology involving integrated use of amendments preferably gypsum based on gypsum requirement of soil, balanced and integrated use of chemical fertilizers and organic/green manures which help in maximizing and sustaining yields, improving soil health and input use efficiency. Rice based cropping systems like rice-wheat; rice-berseem and rice-mustard are recommended on these soils.

Organic Carbon and Nitrogen

Alkali soils are highly deficient in organic matter which serves as storehouse of essential plant nutrients, especially available N throughout the soil profile. High exchangeable sodium (ESP >15), high pH (>8.5) and low biological activity, commonly associated with above properties of these soils, are deterrent to the accumulation of organic matter and its mineralization. Therefore, its efficient management and maintenance assumes greater significance (Swarup *et al.,* 2000) in salt affected soils. Results have shown that long-term balanced fertilizer use under rice-wheat system helps in maintaining the organic carbon status of these soils. Results further suggest that alkali soils have great potential for carbon sequestration (Lal and Swarup, 2004). Most crops grown on these soils invariably suffer from inadequate N supply. Moreover, nitrogen transformations are also adversely affected by high pH and sodicity, thereby affecting the efficiency of applied N through enhanced losses.

Numerous experiments have shown that recovery of fertilizer nitrogen normally ranges from 30 to 40 % for rice in alkali soils. Proper management of fertilizer N is thus necessary for better N use efficiency. Recovery of N can be still lower because of the adverse physico-chemical conditions in alkali soils. Under such situations, nitrogen use-efficiency can be increased by integrated use of organic and inorganic sources of N.

Phosphorus

Uncultivated barren alkali soils contain high amounts of available (Olsen's extractable) P. This is primarily due to the presence of sodium phosphates, which are water soluble. Water-soluble P increases with soil pH in all the major bench-mark series of alkali soils in the Indo-Gangetic plains, and strongly alkaline calcareous sodic soils have the bulk of soil P as Ca-P (54%) and residual inorganic fractions (28%). Olsen's extractable P of surface soil decrease due to its movement to lower subsoil layers, uptake by the crop and increased immobilization when alkali soils are reclaimed using amendments and growing rice under submerged conditions.

The critical values of response of crops to applied P vary greatly with the nature of the soil (clay content), stage of its reclamation, initial soil-test value, crop to be grown and the type of amendment used for reclamation. Results of a long-term fertility experiment conducted on a gypsum-amended alkali soil (texture loam, pH 9.2; ESP 32) with rice-wheat and pearl millet-wheat cropping sequence and NPK fertilizer use showed that phosphorus applied at a rate of 22 kg P ha^{-1} to either or both rice and wheat crop in rotation significantly increased the grain yield of rice when Olsen's extractable P (0-15 cm soil) had decreased from the initial level of 33.6 kg ha^{-1} to 12.7 kg P ha^{-1}, which is very close to the widely used critical soil-test value of 11.2 kg P ha^{-1} . Though wheat responded to applied P when available P level decreased to a low of 8.7 kg ha^{-1}, and pearl millet did not respond to applied P even at this level of critical soil-test value. Rice and wheat responded to P application in pyrite-amended alkali clay-loam soil (pH 9.3, ECe 3.42 dS m^{-1}, CEC 20.1 meq 100 g^{-1} and ESP 46.7) testing low in available P (4.63 ppm). These studies indicate that recommendations for P fertilization in alkali soils should be based on soil test. Single superphosphate (SSP) is a better source of P than other phosphatic fertilizers because of high Na of alkali soils and as it contains appreciable amount of calcium sulphate. Recent studies on integrated nutrient management showed that continuous use of fertilizer P, green manuring and FYM to crops significantly enhanced the yields of rice and wheat and improved available P status of the gypsum amended alkali soils.

Potassium

Alkali soils of Indo-Gangetic plains generally contain very high amounts of available K. Studies so far indicate that the crops do not respond to applied K even after 20 years of rice -wheat and pearl millet-wheat cropping systems in alkali soils. Lack of crop response is attributed to the presence of K-bearing minerals and their dissolution and large contribution of non-exchangeable K (> 90%) towards total K uptake by the crops. Potassium application increased K uptake of plants and reduced the release of K from non-exchangeable reserves from 95 to 70 %. The decrease was about 51 % with the use of K combined with organic manures. The quantity : intensity (Q/I) relationship remained virtually unaltered after continuous cropping. Due to low leaching, a large portion of applied K remained in the top 30 cm soil.

Micronutrients

Alkali soils are sufficient in total zinc but generally deficient in its available fraction. Only 3.3 % of the total Zn is attributed to the exchangeable, complexed, organically bound and occluded forms, which are considered to be available during crop growth. Thus zinc deficiency is very common in rice and its deficiency symptoms appear in the early growth stages (21-25 days), which delay maturity and reduce yields. Therefore significant response of crops to its application is observed on alkali soils. Application of 9 kg Zn ha^{-1} (40 kg zinc sulphate) eliminated Zn deficiency in rice grown on alkali soils treated with gypsum, pyrites, farm-yard manure (FYM) and rice husk and raised the available Zn status of the soil to a level which is adequate to meet the t requirement of 2-3subsequen crops. With the application of FYM and Sesbania green manure it was possible to prevent the occurrence of Zn deficiency in rice grown on alkali soils. Organic amendments like press mud, poultry manure and farmyard manure could effectively supply zinc to rice from native and applied sources in a saline sodic soil.

The alkali soils are rich in total Fe and Mn but are generally poor in water-soluble plus exchangeable and reducible forms of Fe and Mn. There exists negative relationship between pH and Fe-Mn availability. Soluble Fe and Mn salts when applied to alkali soils are rendered unavailable because of rapid oxidation and precipitation, and their recovery by soil-test methods is very low. Thus higher addition of Fe and Mn salts is needed to correct the deficiencies or to have beneficial effect on crop growth. Transformation of Fe and Mn in alkali soils is very strongly influenced by organic matter under submerged conditions; pH per se being relatively less important. This is primarily because of intensely reduced conditions (drop in redox potential) and enhanced PCO_2 created by organic matter under submerged conditions in rice culture Addition of FYM, rice husk and green manures had a marked effect in increasing the extractable Fe and Mn by 10 to 15 times, with corresponding decrease in reducible forms. Available Fe and Mn and rice yield increased significantly when alkali soils were flooded for 15 and 30 days before transplanting rice; the effects being more pronounced at higher levels of ESP. However, benefit of iron application to rice could be realized in sodic soils only when it was applied along with Zn.

Adoption of rice-wheat system for more than two decades on gypsum-amended alkali soils resulted in decline of the DTPA- extractable Mn to a level of 2.7 mg kg^{-1}, where wheat responded to manganese sulphate application at a rate of 50 to 100 kg ha^{-1}. Substantial leaching losses of Mn occur following gypsum application in alkali soils. Foliar application of Mn gives better results than soil application. Nutrients such as B and Mo are not likely to be limiting factors for plant nutrition in alkali soils, though at higher concentrations they could prove toxic. However, once the alkali soils are amended with gypsum/pyrites and leached, concentrations of these elements in solution drops to within safe limits and remain no longer toxic to plants.

Organic and Green Manures *vis-a-vis* Integrated Nutrient Management

Nutrient imbalance created by continuous use of plant nutrients particularly N alone or combined with suboptimal rates or omission of other nutrients (especially P and Zn), is the primary cause of non- sustainable yields in alkali soils. Sesbania green manuring or the use of farmyard manure improves the organic carbon and N status of soil and crops yields especially when combined with gypsum. But the use of inorganic N fertilizer showed hardly any residual effect. Long-term field studies conducted on a gypsum-amended alkali soil showed that incorporation of Sesbania aculeata at 50 days produced 3.85 Mg ha^{-1} $year^{-1}$ of dry biomass, which in turn contributed 110 kg N and 11 kg P ha^{-1} $year^{-1}$ and increased significantly the grain yield of rice and wheat with average increase being 1.48 and 0.67 Mg ha^{-1}, respectively. Even if half of this N is available to the crops, a green-manure crop could substitute for 50 to 60 kg fertilizer N ha^{-1}. Application of 40 kg N ha^{-1} along with green-manuring gave rice yield equivalent to 120 kg N ha^{-1} without green- manuring thereby saving 80 kg N ha^{-1}. Green-manuring with Sesbania significantly increased the organic carbon and available nutrients (N, P, K, Ca, Mg, S, Fe, Mn and Zn) and promoted uptake of these nutrients by rice and wheat crops. The advantages of Sesbania green manuring in highly deteriorated alkali soils reclamation included increase in crops yields and N contribution when it was decomposed for one week under submerged conditions before transplanting of rice.

Recent studies on integrated nutrient management showed that rice and wheat yields significantly increased with integrated use of green manure or FYM and 100 % recommended inorganic fertilizers (N_{120} $P_{26}K_{42}$ kg ha^{-1}) as compared to 100 % recommended inorganic fertilizers alone. Yield of rice could be maintained even by applying lower doses i.e. 50 % of recommended dose of inorganic fertilizer application (N_{60} P_{13} K_{21} kg ha^{-1}) when used in conjunction with FYM (10 t ha^{-1}) or green manuring. Growing of in situ green manure or application of 10 t FYM ha^{-1} saved not only 60 kg N and 13 kg P ha^{-1} as inorganic fertilizer in rice but also improved fertility of soil.

Nutrient Management in Saline Soils

In India about 2.96 million hectares are lying barren due to problems of waterlogging and soil salinity. Out of these 1.146 million ha lie in various canal commands. Saline soils are those which have excessive amounts of soluble salts, (ECe>4 dSm^{-1}, pHs < 8.5 and ESP <15). These soils predominantly have a high concentration of chloride and sulphate of sodium, calcium and magnesium. Many times these soils have shallow water table representing brackish groundwater, which may be the major cause of salinity due to capillary rise under arid and semiarid climatic conditions. Provision of adequate subsurface drainage to lower the depth of water table and to facilitate leaching of salts has long been recognized as fundamental to the reclamation and management of saline soils. During leaching of these soils release of soil nutrients especially N, P, K, Ca, Mg and Mn and their loss to the ground water have been reported. Moreover, the choice of crops to be grown in saline soils under reclamation is also of paramount importance, since different crops differ widely in their tolerance to salinity.

Nitrogen

Nitrogen is the most limiting nutrient for crop production in saline soils as they are poor in N status and organic matter. Volatilization is a major N loss mechanism that reduces the efficiency of applied N. Volatilization losses increased with increase in salinity. Volatilization losses of N from rice fields increase by about 100% when soil salinity (ECe) increase from 4 to 8 dSm^{-1}. Application of N through ammonium sulphate showed highest amount of loss being 37.4 per cent at soil salinity of 8 dSm^{-1}, while fertilizer placed in soil (UPP-urea in paper packet and UB –urea briquette) reduced losses to about 5-6 %. Results also showed that sulphur coated urea followed by urea briquette were more efficient than prilled urea for rice. Poor nitrification rates of NH_4^+ - N at high soil salinity was chiefly responsible for higher volatilization of N from saline soil. Apart from antagonistic effects of high amounts of Cl^- and SO_4^{2-} on the absorption of NO_3 in waterlogged saline soils, poor aeration and anaerobic conditions may restrict the availability to and absorption of N by plants leading to low efficiency of applied ammonical fertilizers. Further, high concentration of salts inhibits nitrification and results in ammonical nitrogen accumulation (Swarup, 1994). Due to these reasons, it is better to use NO_3-N fertilizer as compared to NH_4-N in saline soils. Plants face high water stress in saline environments which further restricts the proper metabolisation of the absorbed nitrogen. These factors along with higher leaching losses of NO_3^- during reclamation of the saline soils results in low availability of N to the plants and therefore nitrogen requirement of crops is higher in saline soils than in normal soils.

Phosphorus

Available P status of saline soils is highly variable. Phosphorous availability does not show any regular trend in relation to soil salinity probably because of the varied concentration of neutral soluble salts of Ca, Mg and Na in the experimental soil. These may displace exchangeable Ca and change the ionic composition of the soil solution thus influencing the extraction of soil phosphorus. Availability of P increases up to a moderate level of salinity but thereafter it decreases. Application of P significantly enhanced the yield of mustard, wheat and pearl-millet, the effects being more pronounced at high soil salinity. Increase in salinity decreased available P concentration and uptake by the crops. Absence of P in the drain water effluent and available P status of the soil profile after crop harvest indicated very slow movement of P; the large portions being retained by the top soil (30 cm) thereby drastically reduce the chances of ground water pollution through phosphorus fertilization. Availability of fertilizer P in the soil may be modified by soil salinity due to higher precipitation of added soluble P.

Potassium

Available K status of saline soils is high initially but after continuous leaching and cropping it declines to a level where crops respond to its application. Application of K fertilizer in saline soil increases crop yields in several ways: (i) by directly supplying K, (ii) by improving tolerance of plants to Na uptake (iii) by improving water use efficiency, (iv) by improving N use efficiency. Plants grown under high salinity may show K deficiency due to antagonistic effect of Na and Ca on K absorption and /or disturbed Na/K or Ca/K ratio. Under such conditions, application of K fertilizer is likely to increase yields. Studies showed that application of K enhanced yield of pearl millet and wheat, and also reduced the contribution of non-exchangeable K towards K uptake by plants. The contribution of non-exchangeable K towards total K uptake was 97 per cent in plots receiving no fertilizer K whereas K application at 21 and 42 kg ha^{-1} reduced it to 83 and 71 per cent respectively. Pearl millet was more exhaustive of K than wheat. This implies that continuous cropping with higher level of K along with N and P would result in rapid depletion of K reserves thereby rendering the soil poor in K fertility.

This suggests that unless K fertility is maintained, yield will remain at low levels rather will show declining trend. Presence of K in the drain effluent (3.2 to 8.2 mg K L^{-1}) and higher level of available K into the lower soil depths indicated continuous release of native and applied K from saline soils, thereby contributing towards higher K content of groundwater in the vicinity of saline areas. K concentration and salinity of drainage effluent were lower during rainy season (July-September) than in winter (November–March) and summer season (April–June). Leaching losses of native and applied K were also confirmed in laboratory column experiment when a highly saline soil (ECe 43 dS m^{-1}) was leached with good quality water (EC 0.3dS m^{-1}) maintaining a constant water head in the column.

Micronutrients

In a micro plot field study effect of micronutrients namely, Fe, Mn and Zn and their combinations was studied on yields of wheat and availability of micronutrients in a reclaimed saline soil with sub-surface drainage system (ECe 5.5 dSm^{-1}, organic carbon 0.36 per cent, DTPA extractable Zn 0.56 mg kg^{-1}, Fe 4.3 mg kg^{-1}, and Mn 2.65 mg kg^{-1}. Results showed significant increase in grain yield following Zn and Mn fertilization. Highest yield was obtained when both Zn and Mn were applied. However, application of Fe had no effect on yields of crops grown. After crop harvest recovery of added Fe, Mn and Zn was 25.1, 23.7 and 17.1 per cent, respectively.

Nutrient Interactions and Balanced Fertilization

Nutrients interactions play an important role for sustaining crop production in saline soils. Studies on nutrient interactions showed that N and K interacted significantly on wheat yield, N concentration, uptake and recovery. High dose of N alone had a depressing effect on yield. Application of K had significant effect on yield at all levels of applied N. Increasing rates of N and K enhanced significantly N and K concentration and uptake. In fact, the much higher N and K uptake with the higher K rate indicated that there might be a complementary uptake effect between N and K. It was concluded that K^+ enhanced NH_4^+ assimilation in the plant and that K^+ did not compete with NH_4^+ in the absorption process of the plants. The recovery of N and N-use efficiency increased with K application at all levels of applied N and more so at the highest K rate. These results thus suggest the importance of adequate K for efficient N use. Interactions between nitrogen and phosphorus and between phosphorus and potassium were significant. However, increasing rates of P and K significantly enhanced N concentration in grain and straw and uptake by pearl millet and wheat, the effect being more pronounced when both P and K were applied together. The highest uptake of N by pearl millet (122 kg ha^{-1}) and wheat 159 kg ha^{-1}) was attained at the highest P and K rate. In fact, the much higher N uptake with the highest P and K rate indicated that there might be a complementary uptake effect between N and P and N and K. This is possibly because of a more balanced use of soil nutrients in the presence of adequate phosphorus and potassium for efficient N use by crops in saline soils. Drain effluents did not have NH_4^+ and NO_3^-N, thereby indicating little danger of ground water pollution as a result of leaching of nitrates.

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Sodic Soils Reclamation and Nutrient Management for Sustainable Crop Production

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The population of India is escalating at an alarming rate of around 2.2% per annum and is expected to stabilize at 1.40 billion in the year 2040 AD. To have food security for such a large population India needs to produce large quantities of food grain, fodder and fuel. Out of gross cropped area of about 182.2 m ha, about 75% is already under food crops. There is a little scope for bringing additional area under crops to meet the ever-increasing demand. Rather, due to diversion of good fertile lands for non-agricultural purposes like urbanization, roads and industry, the area under food crops is shrinking. While there is need to concentrate and improve agriculture in good areas and increase production per unit area, there is a potential to boost production by bringing marginal soils like salt affected lands and soils with availability of only poor quality of irrigation water.

In India, about 6.73 million ha, are lying barren or produce very low and uneconomical yields of various crops due to excessive accumulation of salts. This area is expected to increase with spread of waterlogging and salinity due to increase in canal irrigation, and intensive exploitation of poor quality ground waters for agriculture in non-canal commands. Based on soil pH, exchangeable sodium percentage (ESP), concentration and nature of soluble salts and the reclamation procedure to be adopted, these salt-affected soils have been classified in two major categories viz. alkali soils and saline soils. The fertility status of 2.4 million hectare of alkali/sodic soils of Indo-Gangetic plains is generally poor due to high pH, excess soluble and exchangeable Na, higher amounts of $CaCO_3$, negligible to low organic matter content and adverse soil physical conditions.

Reclamation of Sodic Soils

For sodic soils, the main problem is of high pH, high ESP, high amounts of calcium carbonate and poor physical conditions limiting nutrient availability and plant growth. Quite often due to low yields, efficiency of added chemical fertilizers is very low and unprofitable. Crop production and fertilizer use efficiency in these soils can be increased by following the reclamation technology involving use of amendments like gypsum and others to lower pH and ESP followed by leaching to remove the reaction products. Some amounts of salts are always present in soil. When the concentration of these salts is low, they are not harmful for the growth of plants. But with the increase in salt content of the soil to high levels, plant growth is adversely affected which, in turn, decreases the productivity of the agricultural crops. Keeping in view the fact that plant growth can be restricted or entirely prevented by increased levels of alkalinity in the soil, these soils have to be reclaimed so that they become productive. Reclamation of alkali/sodic soils basically requires neutralization of alkalinity and replacement of most of the sodium ions from the soil-exchange complex by the more favourable calcium ions:

$$2Na - soil(X) + Ca^{2+} (Solution) = Ca - soil (X) + 2Na^{+} (Solution)$$

This can be accomplished by the application of chemical amendments that directly or indirectly furnish or mobilize divalent cations, usually Ca^{2+} for the replacement of sodium from the exchange of the soil. The type of chemical compounds and their quantities required for reclamation of alkali/sodic soils depends upon physico - chemical properties of the soil, desired rate of replacement of sodium ions, and economic considerations.

The effectiveness of each of these amendments mainly depends upon the presence or absence of alkaline – earth carbonates (particularly $CaCO_3$) in the soil. When soil contains $CaCO_3$, any soluble sources of calcium and acids or acid formers may be used. When the soils are non-calcareous, application of acids or acid formers is not recommended and only soluble sources of calcium should be used. Application of sparingly soluble Ca –salts for the reclamation of sodic soils is not recommended because its solubility decreased with increase in pH of the soil. Farmyard manure, rice husk, straw, pressmud (an sugar cane industries by product) and green manures are some the commonly used organic amendments. The process of reclamation by organic materials is often slow.

Amendment Requirements

The quantity of an amendment required for reclamation of an alkali soil depends on the exchangeable Na to be replaced and depth of the soil to be reclaimed. This quantity is often referred to as gypsum requirement (GR) of soil. Acids or acid formers react immediately with lime stone, naturally present in alkali soils, to produce soluble calcium. Materials such as sulphur or iron pyrite must first be oxidized to produce sulphuric acid which in turn produces calcium sulphate, and consequently are less effective than gypsum or sulphuric acid. Gypsum should be broadcast and incorporated in the surface soil by disking or by using a cultivator. Mixing of gypsum in deeper soil decreases its effectiveness, as a fraction of the applied gypsum can react with soluble carbonates to precipitate Ca as $CaCO_3$.

Biological Amelioration

Organic materials and the action of plant roots improve biological activity in the soil. The decomposition of materials increases the concentration of CO_2 and organic acids in the soil which help in mobilizing calcium by dissolving calcium compounds. This can be accomplished by green manuring, incorporation of crop residues, application of FYM, press-mud and other organic materials.

Integrated Nutrient Management

The objectives of maximising yields and fertilizer use efficiency, maintaining soil productivity, proper environment and ecological balance can be met by balanced use of inorganic fertilizers and organic sources of nutrients such as organic manures like FYM and compost, green manures and bio - fertilizers. The crop yields are higher when both chemical and organic source are used as compared to either chemical or organic sources added individually. This is attributed to the proper nutrient supply as well as creation of better soil physical and biological conditions. Fertilizers supply available forms of nutrients readily to the plants on application as opposed to organic manures which make available only a fraction of their total nutrients in the first few weeks after application.

Efficient Use of Fertilizers

For alkali soils, the main problem is high pH, high ESP, high amounts of calcium carbonate and poor physical conditions, limiting nutrient availability and plant growth. Crop grown Crop production and fertilizer use efficiency in these soils can be increased by use of amendments like gypsum. On the other hand, the appropriate prescription of fertilizers, they must be given in right quantity, at the right time and place, from the right source, and in the right combination are beneficial for fertilizer use efficiency. Different aspects of efficient fertilizer management are discusses in this section.

Nitrogen

Alkali soils are very low in organic matter and available N throughout the soil profile. Because of this, most crops suffer from inadequate N supply. Nitrogen transformations are adversely affected by high pH and sodicity. Numerous nitrogen use experiments have shown that the recovery of fertilizer nitrogen normally ranges from 20 to 40% for rice in alkali soils. Proper management of fertilizer N is thus necessary for better N use efficiency. Because of the adverse physico-chemical conditions, the recovery can be expected to be still lower in the salt affected soils. Another experiment showed that application of inorganic fertilizers, the N use efficiency in rice was similar as compared to integrated use of organic and inorganic fertilizers but it is increased in wheat with residual effect of organic manures (Yaduvanshi 2001, b)

Table 2. Ammonia losses from integrated nutrient management system in rice field under reclaimed sodic soil.

Treatment combination	Urea application			Total N lost	% Urea N lost	pH
	1st	2nd	3rd			
Control	1.23	-	-	1.23	-	8.56
N_{120}	8.49	8.21	6.76	23.46	19.55	8.49
N_{120} P_{22}	8.28	7.35	6.70	22.33	18.61	8.48
N_{120} P_{22} K_{42}	8.14	7.24	6.65	21.75	18.13	8.45
N_{120} P_{22} K_{42}	5.82	5.20	5.06	16.08	13.40	8.10
N_{120} P_{22} K_{42}	6.73	5.74	5.28	17.75	14.79	8.15
N_{180} P_{39} K_{63}	12.12	10.60	9.48	32.20	17.89	8.49
Mean	8.26	7.39	6.66			
CD(P=0.05)	0.51	0.91	1.19			
Stage of Urea application		0.32				

In alkali soils ammonia volatilization losses are a major constraint in increasing N efficiency. High pH/alkalinity and high amount of calcium carbonate increase volatilization losses of applied N in alkali soil. Researchers observed that 32 to 52 % of the applied N was lost through volatilization in alkali soils. The experimental results indicate that ammonium fertilizers when broadcasted directly without incorporation, NH_3 volatilization losses ranged from 10 to 60 % of the fertilizer - N applied. Losses of ammonia were higher at the field moisture range and in unreclaimed alkali soils. Another field studies showed that ammonia volatilization losses decreased significantly with FYM or green manuring combined with urea - N application compared with urea - N application alone. The losses of NH_3 volatilization from green manuring combined with urea - N were lower (13.4%) as compared to alone urea - N application (19.5%), the use of green manuring could save 6 per cent fertilizer - N (Table 2), possibly because in the former, nitrifying population could adequately oxidize the ammonical - N from green manuring (Yaduvanshi 2001, a). Rao and Batra (1983) also reported lower losses from green manuring (5.6%) as compared to urea - N (30 %) under laboratory incubation studies. Yaduvanshi (2001a) also reported that ammonia volatilization losses are more up to 24 hours of urea application and sharply declined during the next 48 hours. Significant decreases in ammonia losses were measured when addition of second and third split urea - N application in compared to first urea - N basal application. The benefits were attributed to reduce

N losses through volatilization thereby increasing the absorption of NH_3 - N by plant at the time of second and third split application.

Method and Time of N Application

To get the maximum advantage from the applied fertilizer – N, it must be given in right quantity, at the right time and place, from the right source, and in the right combination. Nitrogen application should synchronies with the growth stage at which plants have the maximum requirement for this nutrient. Rice and wheat use nitrogen most efficiently when it is applied at the tillering stage. Rice plant use N around the panicle initiation/jointing stage also. Therefore, split application of N for wheat [(1/2 at sowing, remaining 1/2 N in two splits at tillering (21 days) and 42 days after sowing] and for rice (half at transplanting + 1/4 at tillering + 1/4 at panicle initiation) resulted maximum efficiency. Another field experiments have shown that maximum yields of rice and wheat were obtained when N was applied in 3 equal splits, as basal and at 3 and 6 weeks after transplanting/sowing. Proper management of fertilizer N is thus necessary for better N use efficiency. Because of the adverse physical-chemical conditions, the recovery can be expected to be still lower in the salt affected soils. Under such situation nitrogen use efficiency can be increased by integrated use of organic and inorganic sources of N (Yaduvanshi, 2001b).

Based on the above, it is recommended that to increase crop production and fertilizer-N efficiency, i) apply 25% more N than the recommended doses for non-sodic soils, normally add 120-150 kg N ha^{-1}; ii) Split N application in to three doses, 50% as basal, 25% as top dressing after 21 days and another 25 % after 25 days of transplanting/sowing; iii) practice green manuring with Sesbania, which will add N equivalent to 60-80 kg N through urea, and minimize N losses; and iv) Apply fertilizer at the time of puddling and mix in the soil rather than broadcast on the surface to minimize N losses.

Phosphorus

Next to nitrogen, P is the most critical nutrient required for efficient crop production in normal soils. But barren alkali soils have high amounts of available (Olsen's extractable) P and have been categorized as medium to high in available P status. Due to high pH and the presence of soluble carbonates and bicarbonates, sodium phosphates are formed in these soils which are water soluble. Sodic soils are reported to contain high amount of soluble phosphorus. Research conducted at CSSRI has revealed no response to added phosphorus on sodic soils in early years after reclamation. However, other studies indicate that sodic soils are not always high in available phosphorus and significant increase in yields of some crops is obtained with application of P fertilizer. Using amendments in these soils and growing rice under submerged conditions, Olsen's extractable P of surface soil decreased due to its movement to lower sub-soil layers, uptake by the crop and increased immobilization (Chhabra *et al.*, 1981).

Table 3. Effect of 12 years of rice-wheat and 8 years of pearl millet - wheat cropping sequence and fertilizer use on available P status and crop yields in a sodic soil

Treatments		Grain yield (Mg ha^{-1})								Av P kg ha^{-1}	
Rice /millet	Wheat	Rice			Wheat		Millet* Mean	Wheat Mean		After 1985-86 wheat	After 1993-94 wheat
		1974	1985	Mean	1974-75	1985- 86	Mean 93	1986-94	1986-94		
Control		3.81	3.17	3.17	0.84	0.78	1.04	0.75	1.10	1.79	9.6
N	N	6.64	4.73	5.33	4.11	4.00	4.53	1.71	3.48	8.7	4.0
NP	NP	6.56	6.92	6.84	3.71	4.73	4.89	1.95	4.78	7.1	60.0
NP	N	6.63	6.97	6.79	4.14	4.62	4.87	1.93	4.49	45.2	14.6
N	NP	7.17	6.47	6.71	3.90	4.89	4.93	1.94	4.66	45.9	15.6
NPK	NPK	7.08	6.97	6.96	4.05	4.58	4.83	2.11	4.90	67.4	56.6
NPK	N	6.45	6.68	6.80	4.02	4.32	4.62	2.07	4.58	4.7	15.0
N	NPK	6.85	6.45	6.59	4.14	4.28	4.70	2.01	4.71	46.5	14.8
LSD (p=0.05)		0.96	0.55	0.52	0.82	0.36	0.41	0.38	0.54	8.9	5.9

* Average of six crops. Pearl millet during 1988 and 1990 was completely damaged due to heavy floods.

Long term field studies were conducted on a gypsum amended alkali soil (pH 9.2,ESP 32) with rice wheat and pearl millet cropping sequence and NPK fertilizer use for 25 years (1974-75 to 1999-2000). The sources of N, P and K were urea, single super phosphate and muriate of potash respectively. Phosphorus applied at a rate of 22 kg P ha^{-1} to either or both rice and wheat crop in rotation significantly enhanced the grain yield of rice (Table 3) (Swarup and Singh 1989). When Olsen's extractable P in 0-15 cm. soil depth had come the initial level of 33.6 kg ha^{-1} to 12.7 kg ha^{-1} which is very close to widely used critical soil test value of 11.2 kg P ha^{-1}. Wheat responded to apply P when available P came down close to 8.7 kg P/ha in 0-15 cm soil depth and nearly close to critical level (11.6 kg P ha^{-1}) in the lower depths (15-30 cm). Application of N alone significantly enhanced the grain yield of pearl millet but phosphorus applied either or both crops had no effect on yield though available P declined to less than the critical soil test value in 0-15 and 15-30 cm soil depths. Further studies that crop responses to applied P were limited in the initial years of cropping and that too only to rice crop in a rice-wheat cropping sequence. Application of 22 kg p ha^{-1} significantly affected the rice and wheat yield. Studies on integrated nutrient management showed that continuous use of fertilizer P, green manuring and FYM to crops significant enhance the yield of rice and wheat and improve available P status of the alkali soils.

Potassium

Application of K fertilizer to either or both the crops had no effect on yields of rice and wheat (Swarup and Singh, 1989). Lack of crop responses to applied K in these soils is attributed to high available K status due to presence of K bearing minerals and ii) large contribution of non-exchangeable K (97%) towards total K uptake by plants and reduced the release of K from non-exchangeable reserves. Studies conducted so far suggest that application of K fertilizer to rice-wheat system can be avoided with out having any adverse effect on crop productivity and K fertility status. The Contribution of the non-exchangeable K towards total potassium removal was about 94.9 % in the absence of applied K decreased 69.9 % with use of K. The decreased was about 50.6 % with use of K combined use with organic manures.

Zinc

Besides the use of amendment sand nitrogen, application of Zn is important for optimum crop yields in alkali soils. Though most of the alkali soils contain high amounts of total Zn (40 to 100 mg Zn kg^{-1} soil) yet the available Zn (DTPA extractable) is quite often less than 0.6 ppm. This is due to high pH, low amount of organic matter, high amounts of soluble P, high calcium carbonate, limiting the solubility of Zn in the calcareous alkali soils. Rice crop raised in the soils invariably suffers due to deficiency of Zn. The deficiency symptoms appear after 15 to 21 days of transplanting in the form of brown rusty spots on the third mature leaf. The affected plants show stunted growth, poor tillering, delayed maturity and low grain yield. An application 10 to 20 kg of zinc sulphate is sufficient to get optimum yields of crops.

Combine Use of Organic Manures and Inorganic Fertilizers

In intensive cropping system and heavy use of chemical fertilizers have created economic, environmental and ecological problems and are adversely affecting the sustainable agriculture. Organic manures play an important role in the sustainability of a cropping system. Continuous adoption of rice - wheat system may lead to the emergence of other micronutrients deficiencies especially that of Mn. With the application of FYM and green manuring crops it has been possible to prevent the occurrence of Zn and other micronutrients in rice grown on alkali soil. However, applying organic and green manures as a primary source of plant nutrients may not support the sustainability concept. Therefore, integrated use of organic manures and chemical fertilizers is extremely important for the long-term sustainability of rice -wheat and other cropping system.

Long -Term Fertilizer Experiments in India (Swarup 2000) revealed that rice yields in rice-wheat system declined in most experiments, whereas wheat yields remained more or less stable. But whether or not this stability in wheat yields would continue in future remains to be seen. However, the results of two core projects under Irrigated Rice Research Program of IRRI showed declining trends in rice-wheat yields. Duxbury *et al.,* (2000) also showed that 8 out of 11 long-term rice-wheat experiments that had run for more than 8 years resulted in a downward trend in rice yields over time. This contrasted with only 3 of 11 showing a downward trend in wheat. Nutrient imbalance created by continuous use of plant nutrients particularly N alone or combined with sub-optimal rates of other nutrients (especially P and Zn) has been the primary cause of non-sustainable yields in a rice-wheat cropping system on alkali soils.

Green manuring has a long and chequered history in India. In the intensive farming system, farmer may not be able to practice green manuring in a traditional manner by devoting an entire season to a green manure crop. The green manures crops can be grown easily during summer months i.e. after the wheat harvest and before transplanting paddy. In fifty days dhaincha green manure produced about 4.2 t/ha dry matter and accumulate 90 kg N, 11 kg P and 90 kg K and gave a saving of 60 kg N and 11 kg P /ha (Yaduvanshi 2001b). Another field studies conducted by Swarup (1991, b) on a gypsum amended alkali soils showed that incorporation of 50-day-old *Sesbania canabina* produced 3.85 Mg/ha/year of biomass (dry weight) which in turn contributed 110 kg N and 11 kg P/ha/year and enhanced significantly the grain yield of rice and wheat. Ghai *et al.* (1988) reported a decomposition period of 5-day for *Sesbania* species in a reclaimed sodic soil as compared to a period of 10-15 days normally practiced for non-alkali soils. However, the advantages of green manuring in alkali soils were more when it was decomposed for one week under submerged conditions prior to transplanting of rice (Swarup, 1988).

Recent studies on integrated nutrient management showed that rice and wheat yields significantly increased with integrated use of green manuring or FYM and 100 % recommended fertilizer (120 N, 22 kg P and 42 kg K ha^{-1}) as compared to 100% recommended inorganic fertilizers alone (Table 4). The yield of rice and wheat could be maintained even at lower (50% recommended dose) of inorganic fertilizer application (N60 P13 K21) when integrated with FYM or *Sesbania* green manuring. The response of rice to the application of 100% recommended treatment (120 kg N, 26 kg P and 42 kg K ha^{-1}) and its combined use with green manuring or 10 t ha^{-1} FYM and 150% recommended treatment (180 kg N, 39 kg P and 63 kg K ha^{-1}) was 2.98, 4.27, 4.10 and 3.54 t ha^{-1}, respectively. Further, the addition of green manuring or 10 t FYM/ha in combination with 60 kg N, 13 kg P and 21 kg K ha^{-1} (50% recommended dose) the rice mean yield (5.79 t ha^{-1}) was at par with yield (5.51 t ha^{-1}) obtained from the 100% NPK recommended treatment (120 kg N, 26 kg K and 42 kg K ha^{-1}). Application of green manuring and 10 t FYM ha^{-1} saved 60 kg N and 13 kg P ha^{-1} as inorganic fertilizer in rice (Yaduvanshi, 2001b). These results suggest that integrated use of chemical fertilizers, organic manures including green manure and recycling of crop residues, assumes greater significance of improve efficiency of chemical fertilizers in alkali soils, especially during post reclamation period.

Table 4. Effect of different treatments on yield and NPK soil status of rice-wheat cropping system

Treatments	Yield (t ha^{-1})		Soil Available Macro-nutrients (kg ha^{-1})		
	Wheat 04-05	Rice 2005	N	P	K
Control			91	7.8	160
N_{120} P_0 K_0	3.64	3.78	144	6.2	158
N_{120} $P_{26}K_0$	4.25	4.65	168	14.8	155
N_{120} $P_{26}K_{42}$	4.46	4.92	169	15.8	275
N_{60} P_{13} K_{21}	3.87	4.08	132	11.4	232
N_{60} P_{13} K_{21} + GM	4.66	6.07	175	18.2	285
N_{120} $P_{26}K_{42}$ + GM	5.02	5.62	201	20.8	301
N_{60} P_{13} K_{21} + FYM	4.22	5.26	176	19.1	291
N_{120} $P_{26}K_{42}$ + FYM	5.17	5.54	198	21.5	298
N_{180} P_{39} K_{63}	5.12	5.64	197	24.7	315
CD (P=0.05)	0.49	0.54	9.7	0.98	11.7

Recommendations

Efficient, balanced and integrated nutrient management is an integral part of reclamation of sodic lands. Therefore, to sustain productivity during and after reclamation following strategies must be adopted:

1. To get maximum benefits of reclamation technology it is essential that soils are ameliorated to desired ESP levels so that crop does not suffer on account of sodicity (Na toxicity and / or Ca deficiency). It has been demonstrated that highly deteriorated sodic soils can be reclaimed by using gypsum @ 25% GR+FYM @ 20 Mg ha^{-1} and long-term productivity of rice and wheat and soil fertility could be sustained.

2. The high soil pH values associated with sodic conditions adversely affect availability of essential plant nutrients especially N and Zn. Since these soils are highly deficient in organic matter and nitrogen, it is recommended that during the first few years after reclamation crops be fertilized with 25 % more nitrogen compared to recommended dose for normal soil. Split application of nitrogen through urea (1/3rd as basal, 1/3rd each at 21 and 45 days crop growth) should be followed. In rice basal dose of urea should be applied before puddling under pre-submerged conditions to reduce ammonia volatilization losses and enhance nitrogen use efficiency.

3. It is essential to apply 40 kg zinc sulphate per hectare to rice for first few years and then it should be applied on soil test basis.

4. Farmyard manure, organic residues and green manuring help in increasing the productivity because of the nutrients they contain and also hasten the reclamation process. Therefore, it is extremely important to integrate the use of organic resources and chemical amendments.

5. Though barren and uncultivated sodic soils initially test high in available P because of soluble sodium phosphate, both rice and wheat require P fertilization @ 22 kg P ha^{-1} when Olsen's P comes down to critical soil test value of 12 kg ha^{-1} to sustain productivity and maintain soil P fertility.

6. Continuous monitoring of soil nutrient status and quality of underground water is a must for sound fertilizer recommendations other than N, P, and Zn and repeat application of gypsum if necessary.

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Irrigation Induced Land Degradation Dynamics in Command Areas of India: A Case Study

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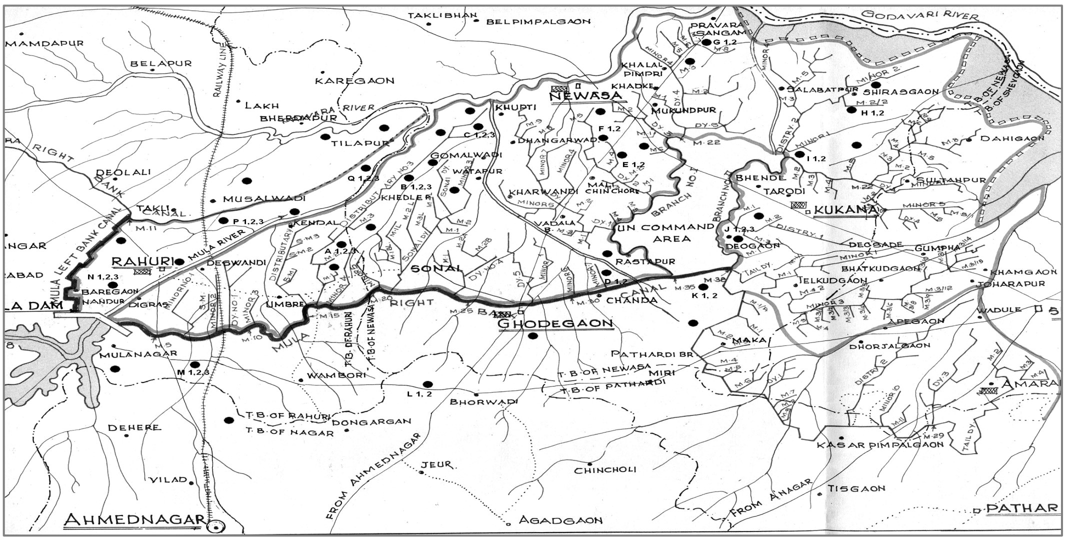
Irrigation induced salinization and alkalization has emerged as twin problems in the command areas under different agro-ecological situations in general and under arid and semi-arid ecosystems in particular. In order to understand the menace of irrigation induced land degradation in arid and semi-arid zones, a case study was carried-out in Mula Command Area of Maharashtra with the following objectives:

- To study the changes in hydro-physical behaviour of dominant soil series with change in irrigation intensity and irrigation induced salinization and alkalization.
- To study the effect of irrigation induced salinization and alkalization on dispersion and swelling behaviour of these soils.
- To study the dynamics of ESR-SAR relationships of these soils.
- To determine threshold electrolyte concentrations to maintain stable hydraulic properties.

Mula Command Area is located in Ahmednagar district of Maharashtra with two major canal systems viz; Mula Right Bank Canal (MRBC) and Mula Left Bank Canal (MLBC). MRBC covers about 1,03,749 ha of land across the length of 58 km and MLBC covers about 14,453 ha of land across the length of 18 km. Canals were made operational and irrigation started between 1971 and 1976. In head and middle reaches of the command area high water demanding sugarcane and cotton based cropping systems are prominent whereas in tail reaches, sorghum based cropping systems are followed by the farmers. About 60, 25 and 15 percent soils can be texturally categorized under fine, medium to fine and coarse to medium, respectively. However, 50, 28 and 22 per cent cultivated lands can be classified as deep, medium and shallow, respectively.

Soil profiles were selected on the basis of degree of severity of the problem. In the whole command area 40 soil profiles were selected. In MRBC distributory Number 3, Chanda minor and Deogaon Branch Number II were selected in head, middle and tail reaches. However, in MLBC profiles were selected in head, middle and tail reaches. Soil profiles from outside the command were also selected on the basis of soils series. In MRBC, 9, 8 and 7 profiles were selected in head, middle and tail reaches, respectively. In MLBC, three profiles each in head, middle and tail ends of the canal were selected. Three profiles each representing fine (Clay), medium to fine (Clay Loam) and coarse to medium (Sandy Clay Loam) were selected from the area outside the command. Depth-wise bulk soil samples were collected at the interval of 20 cm. Entire command area is represented by three dominating soil series viz: Otur (fine montmorillonitic isohyperthermic family of Typic Haplustert), Sawargaon (Fine loamy montmorillonitic isohyperthermic family of Vertic Haplustept) and Sibneri (Fine loamy mixed isohyperthermic family of tropic Lithic Ustorthent). Infiltration studies were carried out nearby the sampling profile sites. Metallic cores for studying saturated hydraulic conductivity were also collected depth-wise at the interval of 20 cm.

Important properties of dominant and representative soils of different reaches of the command area showed that most of the soils were clay in texture. All the fine and medium textured soils were calcareous in nature containing appreciable amounts of $CaCO_3$ with high pH. Most of the soils of head reaches in both MLBC and MRBC were alkaline, those of middle reaches were saline and those of tail reaches were normal in reaction. Hazards of irrigation induced land degradation were more prominent in MLBC than MRBC. Clay soils with alkaline reaction were highly prone to dispersion. Dispersion index of about 20 per cent was observed in the clay soils of head reaches. This may be because of higher sodium contents on exchangeable sites. Swelling behavior of soils was measured in terms of Coefficient of Linear Extensibility (COLE), which was high for alkaline soils. This may be because of increased distance of separation between clay platelets of montmorillonite. Fine textured soils outside the command area were normal in reaction, calcareous in nature with normal swelling and dispersion behaviour. If these soils are brought under stressed irrigation in tail end, the soils remain normal with accumulation of some salts in RBC. If the same soils are brought under frequent irrigation, as at middle end, soils become saline in reaction with EC > 8.0 dSm^{-1}. However, under intense and heavy irrigation situations, as at head end, soils tern alkaline with pH>8.5. This observation is well supported by the data obtained on Ca^{2+}+Mg^{2+}, Na^{+} and $CaCO_3$ content. Calcium carbonate played a major role in degradation of these soils. As the intensity of irrigation increased, exchange sites occupied by calcium and magnesium were replaced by sodium resulted in precipitation of calcium as $CaCO_3$. This observation also indicates that development of salinization and alkalization starts simultaneously but the hazard of salinization appears much earlier than alkalization.



Indicates soil sampling locations

Fig, 1. Soil sampling locations in Mula Command Area

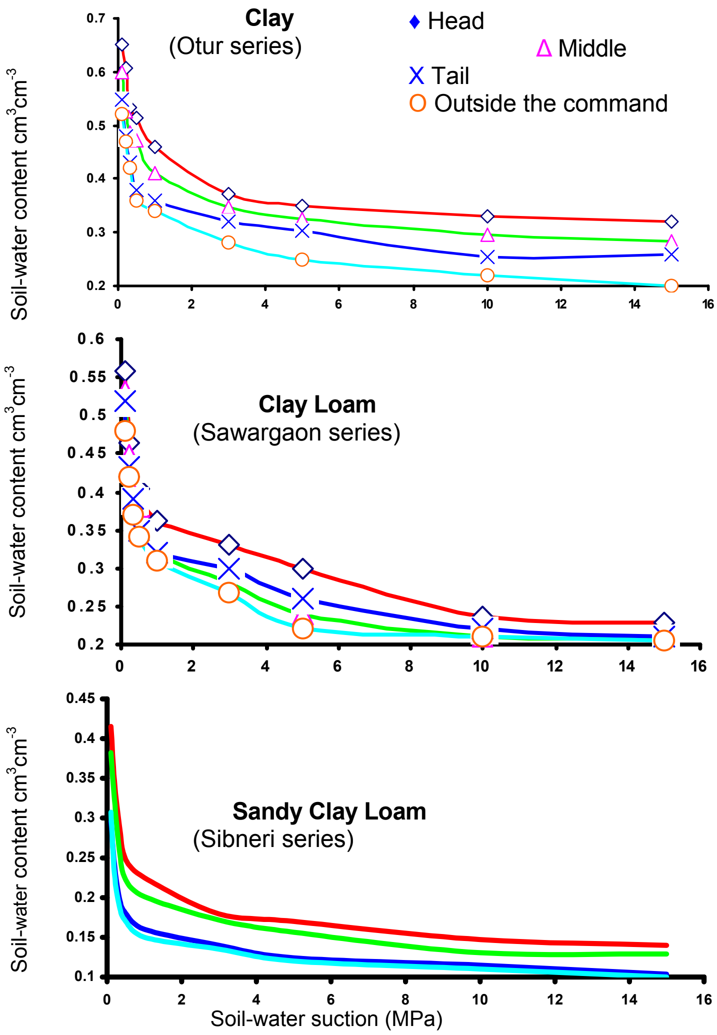


Fig. 2: Moisture characteristics curves of dominant soils of different reaches of Mula Command

Infiltration rate was determined near the profiles using double ring infiltrometers. Clay, clay loam and sandy clay loam soils outside the command area had steady state infiltration rate of 4.5, 9.2 and 54.0 mm per hour, respectively. Infiltration rate reduced drastically with the intensity of irrigation. Such reduction was large in clay as compared with clay loam and sandy clay loam soils. Saturated hydraulic conductivity values also showed the similar trend. In fine textured alkaline soils of head reach, it was difficult to determine saturated hydraulic conductivity even with falling head method.

Moisture characteristics curves for each soil and depth were developed using pressure plate apparatus at 0.1, 0.2, 0.33, 0.5, 1.0, 3.0, 5.0 ,7.0, 10, 15 MPa suction points. Comparison of soils at head, middle, tail reaches and outside the command area under same soil series is presented in Fig. 2. Water retention at a given suction point was observed in the order clay>clay loam>sandy clay loam owing to their clay contents. Irrespective of texture and series, water retention behavior increased with increase in intensity of irrigation over soils present outside the command area. The tendency of retaining more water with increase in intensity of irrigation was more prominent in fine textured soils over medium and coarse textured soils. This is mainly because of (i) increase in alkalization facilitated higher dispersion of clay and silt particles and (ii) relatively higher swell-shrink potential of these soils. Dispersion and swelling increased the total surface area exposed by the clay minerals resulted in higher water retention.

Unsaturated hydraulic conductivity (K-θ) functions of soil in head, middle, tail reaches and outside the command area in three soil series were studied. Soil in Otur series, being fine textured, exhibited poorer conductivity values than soils in Sawargaon and Sibneri series. A net decline in K-θ of all the soils was observed with increased intensity of irrigation over the respective soils outside the command area. This showed that the intensive irrigation practices lead to poor hydraulic conductivity and may result into water logging. Irrigation induced changes were more prominent in clay soils under low water content range and in sandy clay loam in high water content range. However, clay loam soils exhibited little changes only in low water content range. Due to enhanced dispersion of silt and clay, flowing water might have carried dispersed particles and plugged the conducting pores. Also swelling of clay might have pushed pore-walls closer that brought down the effective diameter of conducting pores. Hence the magnitude of change was large in fine textured soils than medium and course. High micro-porosity could be the major reason of large changes in low water content range in fine textured soils. Degree of deterioration was much less in clay loam than the clay soil. This may be because of differences in clay mineralogy of the two soils. The case study clearly brought-out the ill effects of injudicious use of irrigation water on fine textured soils of Maharashtra.

Management of Degraded Lands in Canal Commands

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India has made significant investments in creating irrigation potential of > 50 M ha. However, the irrigated areas which have contributed significantly in increasing food grain production are now facing serious problem of rising ground water table and soil salinization. Such problems are now serious in areas that have received canal irrigation. The impact of soil degradation in irrigated areas due to soil salinization and water logging has not been evaluated adequately. In the Nagarajunasagar project command area nearly 25,000 ha out of the 140,000 ha under irrigation have been affected by salinity and water logging in a period of 14 years.

Table 1: Extent of soil degradation (human induced) under different degradation types

Degradation type	Degree of degradation					% Area affected
	Slight	Moderate	Strong	Extreme	Total	
Water erosion	27.3	111.6	5.4	4.6	148.9	45.3
a. Loss of topsoil(Wt)	27.3	99.8	5.4	-	132.5	40.3
b.Terrain deformation(Wt)	-	11.8	-	4.6	16.4	5.0
Wind erosion	0.3	10.1	3.1	-	13.5	4.1
a. Loss of topsoil(Wt)	0.3	5.5	0.4	-	6.2	1.9
b. Loss of topsoil/terrain deformation (Et/Ed)	-	4.6	-	-	4.6	1.4
c. Terrain deformation/over blowing(Ed/Co)	-	-	2.7	-	2.7	0.8
Chemical deterioration	6.5	7.3	-	-	13.8	4.2
a. Loss of nutrients(Cn)	3.7	-	-	-	3.7	1.1
b. Salinization(Cs)	2.8	7.3	-	-	10.1	3.1
Physical deterioration	6.4	5.2	-	-	11.6	3.5
Waterlogging(w)	6.4	5.2	-	-	11.6	3.5
Total (affected area)	40.5	134.2	8.5	4.6	187.8	57.1
Land not fit for agriculture					18.2	5.5
Stable terrain Under natural condition(Sn)					32.2	9.8
Total geographical area of India					328.7	100.0

It is clear that non-judicious use of irrigation water irrespective of its quality leads to soil salinization and sodification. Continuous accumulation of salts in root zone results into soil salinization. These salts may come from irrigation water, mineral dissolution, precipitation, capillary rise or all of these. The process of sodification initiates with replacement of exchangeable calcium by sodium.

Irrigated soils exhibit differential physico-chemical behaviour at temporal scale. Physical properties of irrigated soils limit its productivity. Irrigated soils if not managed properly deteriorate in hydraulic properties e.g. infiltration rate, saturated hydraulic conductivity, unsaturated hydraulic conductivity, soil-water diffusivity, soil-water retention etc. The exchange phase-solution phase behaviour of these soils is highly sensitive to water management inputs.

Flocculation, deflocculation, dispersion, swelling, ESR-SAR relationships are the major processes responsible to bring changes in hydro-physical behaviour of soils due to irrigation induced salinization or sodification. When irrigation is practiced water remains in equilibrium with soil and slowly infiltrates downward. The composition of the soil solution is decided by mineralogy, water quality and exchange phase-solution phase behaviour of the soils. Besides several parameters of the soil solution at equilibrium, sodium adsorption ratio (SAR) and total electrolyte concentration are the major attributes which decides the hydro physical behaviour of irrigated soils. SAR is a relation between soluble sodium and soluble divalent cations, which can be used to predict the exchangeable sodium fraction of soil equilibrated with a given solution.

The increased irrigation by tube-wells, supplemented by canal irrigation, has resulted in depletion and lowering of underground water at the rate of almost 1 metre per year in the central Punjab causing concern of depleting groundwater resource for the posterity and increasing the groundwater table in the south-western sectors resulting in the problem of salinization and changes in land use. Effect of irrigation on soil degradation due to water logging and accumulation of salts in soils of Punjab was studied and it was observed that in the Sangrur and Kapurthala districts total salt-affected areas appreciably decreased from 98,000 ha to 66,000 ha. On the other hand, such areas in the Faridkot district during the same period markedly increased form 6,500 ha to 82,000 ha. Whereas the ground water table in Faridkot district rose at the rate of 0.5-1.0 meter per annum, the ground water table in the Sangrur and Kapurthala districts receded at the rate of about 0.2 meter per annum in the past. The rise in the groundwater table in Faridkot appeared to be due to seepage from newly constructed canals, inadequate drainage, influx of groundwater table due to lower topographic position and insufficient water expenses. Because of the brackish nature of ground water the rise in water table was accompanied by accumulation of salts at the surfaces during dry months leading to the formation of salt affected soils.

On the other hand the installation of a large number of tube-wells for pumping out underground water for irrigation in Sangrur and Kapurthala districts and the general gradient of ground water towards south-western sectors resulted in lowering of the ground water in these areas. The changes in groundwater table followed by salinization/sodification and/or amelioration of the salt-affected areas under study have obliged farmers to changes in land-use pattern in favour of wheat-paddy rotation at the cost of maize, cotton or citrus cultivation. Area in Faridkot once known for cotton production in the state is now being increasingly used for paddy production where irrigation water is available and thus aggravating the problem of water logging and salinity due to the addition of large quantities of salts through tube-well waters of marginal quality for irrigation. On the other hand areas in Sangrur and Kapurthala which were previously abandoned for cultivation because of sodicity problem have now being reclaimed and brought under paddy-wheat rotation after reclamation of the soils with gypsum.

Maintaining Quality of Soil Resource

Maintaining soil quality by ameliorating degraded land and increasing organic matter content is imperative for sustaining agricultural productivity. Soil organic matter is probably the most important indicator of soil quality (Rasmussen and Collins, 1991); and that an increase in per cent organic matter content is suggestive of positive change in soil quality through reduction of soil erosion by increasing water table aggregates. Farmers using alternative cropping practices such as green manures often report improvements in soil tilth. Some of the new land-use systems have disregarded the time tested highly effective system of crop rotation as well as the practice of green manuring. Experimental evidences of growing green manure crop before paddy transplantation do suggest a better yield even without the addition of fertilizers apart from its positive effects on soil tilth and pore space. Although microbial life of the soil is often considered as a key element of soil health or quality, more research data are needed to evaluate the economic potential of new options and their impact on the soil resource.

The impact of soil degradation processes is not limited to national boundaries. There are evidences to show that the land degradation processes such as loss of organic matter and increase in carbon dioxide contents are contributing to global changes adversely affecting the humanity at large. This will warrant efforts to combat soil degradation not only at national level but also at international level. Similar concern has recently been raised while estimating the stock of SOC in black cotton soils of India, SOC stock in different physiographic regions of India, soil organic matter status of various soils in India, the total carbon stock of the Indo-Gangetic Plains of India and while estimating the formation of secondary carbonates in Indian soils.

Management Options for Reclaiming Irrigation Induced Degraded Lands

Keeping in view the fact that plant growth can be restricted or entirely prevented by increased levels of salinity and alkalinity in the soil, these soils have to be reclaimed so that they become productive. The processes of accumulation of salts and build-up of ESP have to be reversed. To achieve these objectives provision of adequate drainage, replacement of Na^+ ions from the exchange complexes and leaching out of soluble salts below root zone have to be ensured. Without adequate drainage and leaching of salts proper reclamation cannot be achieved on a long term basis. In addition to decreasing salts and ESP levels in the root zone and maintaining them below the permissible limits (which depend upon salt and Na^+ ion tolerance of the crops), soil and water management practices must ensure prevention from reverting the salinity and ESP to the original conditions.

Systematic planning for reclamation work requires characterization of the problem (e.g. extent and kind of salinity or alkalinity/sodicity) as the first step. Thereafter, for each specific problem specific systems of management have to be followed. The physical, hydro-technical, chemical and biological methods are normally used for the management of irrigation induced degraded lands.

Physical methods include deep ploughing, sub-soiling, sanding, profile inversion, scrapping etc. Hydro-technical techniques include leaching of salts, provision of drainage, use of leaching curves etc. Under chemical methods, application of gypsum is the prominent one. Other chemical techniques include application of calcium chloride, calcite, phospho-gypsum and iron pyrites etc. Biological methods include green manuring, addition of FYM and other organic manures, incorporation of crop residues, pressmud etc.

Crop Production under Salt Affected Black Soils

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Introduction

In the course of the present century, the world population has increased from less than two thousand million to over five and a half thousand million. Until one hundred years ago, the expanding population's increasing needs for food, fuel, fibre and construction materials were met from the land by cultivating progressively larger areas. The much greater increase in population during this century has been supported mainly by intensifying the use of much of the land that is already cultivated. In the next 25 years a further 2000 million people will be added to the global population. Most of these people will live in the tropics. As a result , the demands which will be placed on the soil and water resources of the tropics will far exceed those of the past.

According to the *FAO Land and Plant Nutrition Management Service*, over 6% of the world's land is affected by either salinity or sodicity (Table 1). The term salt-affected refers to soils that are saline or sodic, and these cover over 400 million hectares, which is over 6% of the world land area (Table 1) . Much of the world's land is not cultivated, but a significant proportion of cultivated land is salt-affected. Of the current 230 million ha of irrigated land, 45 million ha are salt-affected (19.5 percent) and of the 1,500 million ha under dryland agriculture, 32 million are salt-affected to varying degrees (2.1 percent).

Table.1. Regional distribution of salt-affected soils, in million hectares

Regions	Total area	Saline soils		Sodic soils	
	Mha	Mha	%	Mha	%
Africa	1,899	39	2.0	34	1.8
Asia, the Pacific and Australia	3,107	195	6.3	249	8.0
Europe	2,011	7	0.3	73	3.6
Latin America	2,039	61	3.0	51	2.5
Near East	1,802	92	5.1	14	0.8
North America	1,924	5	0.2	15	0.8
Total	12,781	397	3.1%	434	3.4%

Source. FAO Land and Plant Nutrition Management Service

Types and Causes of Salinity

Natural or Primary Salinity

Primary salinity results from the accumulation of salts over long periods of time, through natural processes, in the soil or groundwater. It is caused by two natural processes. The first is the weathering of parent materials containing soluble salts. Weathering processes break down rocks and release soluble salts of various types, mainly chlorides of sodium, calcium and magnesium, and to a lesser extent, sulphates and carbonates. Sodium chloride is the most soluble salt.

The second is the deposition of oceanic salt carried in wind and rain. 'Cyclic salts' are ocean salts carried inland by wind and deposited by rainfall, and are mainly sodium chloride (Table 2). Rainwater contains from 6 to 50 mg/kg of salt, the concentration of salts decreasing with distance from the coast. If the concentration is 10 mg/kg, this would add 10 kg/ha of salt for each 100 mm of rainfall per year. Accumulation of this salt in the soil would be considerable over millennia. The amount of salt stored in the soil varies with the soil type, being low for sandy soils and high for soils contain a high percentage of clay minerals. It also varies inversely with average annual rainfall. For example, in Western Australia, the salt content of a 40 m profile ranges from 170 to 950 tonne/ha for rainfall averaging from 1000 mm to 600 mm per year.

Secondary or human-induced salinity

Secondary salinisation results from human activities that change the hydrologic balance of the soil between water applied (irrigation or rainfall) and water used by crops (transpiration). The most common causes are (i) land clearing and the replacement of perennial vegetation with annual crops, and (ii) irrigation schemes using salt-rich irrigation water or having insufficient drainage. Prior to human activities, in arid or semi-arid climates, the water used by natural vegetation was in balance with the rainfall, with the deep roots of native vegetation ensuring that the water tables were well below the surface. Clearing and irrigation changed this balance, so that rainfall on the one hand, and irrigation water on the other, provided more water than the crops could use. The excess water raises water table and mobilises salts previously stored in the subsoil and brings them up to the root zone. Plants use the water and leave the salt behind until the soil water becomes too salty for further water uptake by roots. The water table continues to rise, and when it comes close to the surface, water evaporates leaving salts behind on the surface and thus forming a 'salt scald'. The mobilised salt can also move laterally to water courses and increase their salinity.

Irrigation water adds appreciable amounts of salt, even with good quality irrigation water containing only 200-500 mg/kg of soluble salt. Irrigation water with a salt content of 500 mg/kg (i.e. 500 mg/L) contains 0.5 tonnes of salt per 1,000 m3. Since crops require 6,000-10,000 m3 of water per hectare each year, one hectare of land will receive 3-5 tonnes of salt. Because the amount of salt removed by crops is negligible, salt will accumulate in the root zone, and must be leached by supplying more water than is required by the crops. If drainage is not adequate, the excess water causes the water table to rise, mobilising salts which accumulate in the root zone. When the crop is unable to use all the applied water, waterlogging occurs.

The problem being dynamic in nature, the extent keeps on changing. as a result of soil degradation, there have been negative effects such as decrease in farm production due to abandoned farm lands, decline in resource productivity, and cut back in resources use. Similarly at the regional level there have been displacement of labour from agriculture, widening of income disparities and adverse effect on the sustainability of agriculture based sectors. For better management of land and water resources would not only tackle dynamic nature of soil salinity but also increase the productivity of the soils.

The Problem

For agricultural purposes, the soils that contain excessive concentrations of soluble salts or exchangeable sodium or both are referred to as problem soils. These salts seriously hamper crop growth and yields. An estimated 950 million ha of salt-affected lands occur in arid and semi-arid regions, nearly 33% of the potentially arable land area of the world. Productivity of irrigated lands is severely threatened by build up of salt in the root zone. Soil degradation through salinisation has seriously affected the productivity of over 1.2 mha of land in Gujarat state. The wide spread salinity in the state has caused social hardship to the people inhabiting such areas. In the arid and semi arid regions where low rainfall coupled with uncertainty of its occurrence has been the limiting factor in the crop production. The salt affected soils are an important ecological entity in India and it is estimated that nearly 6.73 mha is affected with this menace.

The reclamation and management of salt-affected soils has become important and urgent due to ever increasing pressure on land resources to meet food requirements of increasing population and also to mitigate the perils of irrigated agriculture in many irrigation project command areas. In addition, since salt-affected soils commonly occur in productive irrigated lands, their reclamation and strategies to prevent further proliferation is of paramount importance. Salt-affected soils cover an area of about 6.73 million ha in India; almost half of it lies in canal command areas. Five states, namely; Haryana, Punjab, Rajasthan, Gujarat and Andhra Pradesh accounts for 48 per cent of total salt affected soils of the country.

Saline Vertisols

Among 11 soil orders (Andisols, Alfisols, Aridisols, Entisols, Histosols, Inceptisols, Mollisols, Oxisols, Spodosols, Ultisols, Vertisols), Vertisols form an important soil group. These soils can be defined as clay soils with high shrink-swell potential that has wide, deep cracks when dry. Most of these soils have distinct wet and dry periods throughout the year. Soils with high content of swelling clays, deep, wide cracks develop during dry periods .Soils with 30 % or more clay to a depth of 50 cm and shrinking/swelling properties.

Vertisols and associated soils are generally very deep (150-200 cm), fine textured with clay content ranging from 45-68 per cent and montmorillonite as the dominant clay mineral. The soils exhibit high shrink-swell potential and develop wide cracks of 4-6 cm extending up to 100 cm depth. The water holding capacity is high but permeability is imperfect to poor. These soils are calcareous in nature (2 to 12 % $CaCO_3$). The salinity status in the cultivable land varies widely from EC 0.5 dS/m in monsoon to 50 dS/m in summer. The saline Vertisols in Gujarat occurs in Bara tract which experiences a tropical climate. The annual rainfall ranges from 275-1484 mm with an average of 737 mm. The onset of monsoon is erratic which normally affects crop seeding operations, germinations and seedling establishment.

The Vertisols have low permeability; soils having comparable salinity affect the crop growth in a greater magnitude as compared to the light textured soils. As these soils can sustain the deep rooted crops and are having fine capillary pores, salt concentrations even at a considerable depth affect the crop growth and contribute to surface salinity through capillary rise. The salinity of surface soils varies from 0.46 – 21 dS/m. The salinity of the sub-soil of Bara tract ranges from 0.4 – 159 dS/m. This transient salinity fluctuates with depth and also changes with season and rainfall. Even in the absence of contribution of ground water, the excess use of water may also help the sub-soil salinity to come to the surface layer.

The light textured soils with salinity of more than 4 dS/m are classified as saline soil. In the heavy textured soils i.e. Vertrisols and associated soils, because of their low permeability the salinity of >2 dS/m is detrimental for crop production. In the area it was found that 39.6 % of surface soils are free from salinity (< 2dS/m), 49.3 % soils are saline (2-4 dS/m) and only 11.1 % soils are having salinity greater than 4.0 dS/m. Whereas 10 % of the sub-soils are having salinity less than 2 dS/m , 15 % between2-4 dS/m and 75 % greater than 4 dS/m. this pattern of salinity build up may be because of previous continuous contact with saline or brackish water due to the proximity to the sea. The sub-soil salts are very difficult to leach down further because of the presence of high saline groundwater table.. Though shallow rooted rainfed crops are not affected by the sub-soil salinity, deep rooted crops like cotton and arhar are affected because of poor contribution of soil moisture from lower profile.

Causes of Origin of Salts

The possible sources of excess salt in soils are given below.

1) High salt deposits inherited by the soil from the original parent material during soil forming process,

2) Salts contained in the irrigation water applied or in the water lost in conveyance through irrigation distributions system,

3) Salt may come through upward movement (capillary action) of shallow brackish ground water,

4) High sub-soil water table thus poor drainage conditions,

5) Back water flow or intrusion of sea water in coastal area,

6) Seepage from canals and farm-irrigation systems due to injudicious use of water, and

7) High cropping intensity and replacement of low water requiring crops by crops of high water demand thus, gradual rise adds in raising water table.

Agriculture has evolved through various stages of shifting cultivation into semi-permanent systems, and to systems of continuous cultivation. All of these systems are being practiced in different parts of the world at the present time. All of them can be sustainable, and all can fail, depending on the biophysical and socio-economic conditions in which they are practiced. Indications of success or failure are given by changes in per caput food crop production in different regions. Declining in the productivity of soils leads to the expansion of cultivation onto marginal soils. Within a stable political and social environment, farmers will always strive to evolve a system that is sufficiently productive to support their immediate social group, for the present and foreseeable future. Where markets exist, they will also strive to increase production to provide economic benefits for themselves and their families. Difficulties arise, however, as a result of changing social, economic and political circumstances. Of greatest significance among these has been the increasing demands on the land as populations have grown, leading to conflicts over both land and water supplies. Productivity will only rise in favorable social and economic circumstances, and it is the role of governments to establish such circumstances.

Establishing Sound Principles of Good Soil Management

Good soil management has always required that the soil be used in such a way that its productivity is maintained—or preferably, enhanced. This requires that the chemical and physical condition of the soil does not become less suitable for plant growth than when cultivation commences. Cultivation normally means that the soil will, in fact, deteriorate both due to nutrient removal by harvesting crops, and to physical damage to the soil structure. What is essential is that the deterioration is reversible, by chemical additions to the soil, mechanical manipulation, or natural processes of fertility restoration under pasture or trees. This implies that the soil must be resilient, i.e. after being subjected to the stresses involved in crop production; it must have the ability to return to its former condition, or an improved condition (Greenland and Szabolcs, 1994).

The land must produce on a secure basis, the natural resources must be protected, and the management system must be economically viable and socially acceptable. However it must also be recognized that land cannot be managed sustainably unless the soil, which is a component of the land, is properly managed. This requires maintaining and improving soil productivity, avoiding and rectifying soil degradation, and avoiding environmental damage.

Maintaining and Improving Soil Productivity

If a soil is to sustain the production of crops it must provide the nutrient requirements of the crop; provide a physical medium, in which the plant roots can grow adequately so that water and nutrients can be absorbed,which stores sufficient water for the crop and which allows water to enter and move in the soil to maintain the water supply as it is transpired by the crop and evaporates from the soil and provide a medium in which soil organisms are able to:decompose organic materials, releasing nutrients to the plants; assist the transport of nutrients to plant roots;compete successfully with pathogens which might otherwise infect roots and damage the plants; and form the soil organic compounds which will have a favourable effect on other soil properties.

Crop Production Technologies in Saline Black Soils

The vertisols are characterised by heavy textured and domination of shrink -swell type clay minerals, which create unfavourable soil physical conditions for crop growth. It is proposed to further strengthen research in relation to preventive, ameliorative measures and evaluation of different tree species of fodder, fuel and fruits for such conditions, and management of soils.

Cotton is the dominant crop grown in the kharif followed by sorghum and pearl- millet. Pigeon pea is also grown in some area. Mostly rain fed kharif crops are grown in this area In the rabi season the land is either kept fallow or some fodder sorghum is grown on the residual moisture.

1. Land Configuration and Tillage Practices

Alternate ridges and furrows are the most commonly used layouts in the Vertisols and associated soils of India. The ridges are of 35 cm high and 75-100 cm wide depending upon the space requirement of the crops. In saline soils the plot size can be kept small and well levelled to facilitate proper leaching and uniform irrigation. The ability to cover large areas rapidly is essential in Vertisols and associated soils i.e. more so in saline and sodic soils because of very narrow workable moisture range. If the tillage is attempted when the soil is too wet, it is difficult to run the machines and it also destroys the soil structure badly. If tillage is attempted when the soil is too dry, it requires more draft. The big clods formed hamper the seed germination. For deriving maximum advantage, the sol would have to be primarily tilled early in the dry season. It would help in both reducing the evaporation by cutting up capillaries and conserve moisture and thus reduce the salinity build up in the soil.

2. Suitable Crops

Usually the Vertisols are best suited for the graminaceous crops such as rice, sugarcane, grasses etc. because of their extensive root system which can withstand the damage caused by cracking. However, because of the presence of high sub-surface soil salinity and prevailing ground water table with high salinity, crops with high water requirement are not recommended. The grain millets as well as fodder millets can be successfully grown without irrigation in a normal monsoon year or with one or two irrigations in deficit rainfall years. Cotton and pigeon pea are best and extensively grown on Vertisols because of their deep root system, both under irrigated and rain fed conditions. These crops can mine both moisture and nutrients from deeper layers of the soil. In an average normal rainfall year 80 percent potential yield of cotton and pigeon pea can be obtained from these soils without irrigation. In the rabi season, crops like durum wheat, oilseed crops like mustard, safflower and dill can be grown with limited irrigation and /or irrigation of canal water in conjunction with saline ground water. These crops can be successfully grown in the saline black soils with salinity range of 4-5 dS/m (Gururaja Rao *et al.*, 2001a). Experiment on farmers field revealed that durum wheat yields upto 2.5-3.0 t/ha with 3 supplemental irrigations in these soils. Vegetable crops such as chilli, brinjal and tomato can be cultivated with fair success. These crops need well drained soils because of their intolerance to water logging conditions and can be grown in the month of Sept/Oct after withdrawal of effective monsoon. Among fruit crops sapota, aonla, bel, ber, and pomegranate hold promise in these soils.

For highly saline soils cultivation of salt tolerant and economically important crops like Salvadora persica can be grown in the salinity range of 10-40 dS/m. Salt tolerant forage grasses like Dichanthium annulatum, Aeluropus lagopoides and Eragrostis species can be successfully grown up to salinity of 14.8 dS/m (Gururaja Rao *et al.*, 2001b).

3. Bio Saline Agriculture

In areas with poor resource endowment situations, the farmers are not in a position to adopt chemical ameliorative measures. Under such situations, one of the options is to go in for salt tolerant plant types. It is proposed to strengthen the crop breeding programme, exploitation of natural resources (vegetation) and screening of halophytes of economic use.

4. Sowing

Sowing is the most difficult operation in agriculture. The narrow working moisture range and crust formation, which are unique to Vertisols and associated soils, cause hindrance to uniform germination of seeds. In the saline conditions, the germination of seed is further reduced. In the kharif season if proper germination of seeds is not achieved after first two showers, the success of achieving the same is diminished in these soils because of temporary water logging associated with rains. The first monsoon showers reduce the salt on the top few cm of the soils and close the cracks which cause the temporary waterlogging of 3-7 days by successive rains. Moreover the uncertainty of rains also contributes to the delay and poor germination. Cotton is sensitive at germination stage (Bajwa *et al.*, 1992) but can be grown if proper germination is ensured by the pre-sowing germination with good quality water. In most parts of the Vertisols and associated soils area, pre-sowing irrigation is done because the land is not free for cultivation at ideal soil moisture condition and hence the farmer has to irrigate the land for getting proper tilth for sowing and uniform germination. In saline and sodic soil pre-sowing irrigation not only reduce the initial saline condition but also negates the effects of crusting. In case of post sowing irrigation, the germination and seedling establishment are to be followed by hoeing which provides the effect of soil mulch and reduce the excess soil moisture loss. In the Vertisols of Central India, pallewa (pre-sowing irrigation) or irrigation immediate after dry sowing of wheat is essential for proper germination and seedling establishment of wheat.

5. Water Management

Soil and groundwater situations in the area emphasizes the need for deficit water management with supplemental irrigation in the kharif season and minimum irrigation form canal water during rabi season. Scheduling of irrigation is very difficult in the Vertisols and associated soils particularly when the soil is affected by varying degree of salinization. Cracking and surface sealing affect the water use efficiency. I the area where there is a substantial sub-surface salinity and high saline ground water problem there cannot be any irrigation for the purpose of leaching the salt. Therefore, the prevention of further rise of salinity level is of strategic importance. Moreover leaching requirement concept does not apply to Vertisols due to lack of uniformity in water movement in the soils to effect leaching. In these soils the scheduling should be planned and framed in such a way that the net depth of soil penetrated by water does not exceed 60-70 cm which is well within the root zone.

5.1 Options of Conjunctive Use

As such the ground water needs sufficient dilution before its use for agriculture purpose. Construction of tube wells in these areas should be made in such a way that the water could be blended in the channels in an appropriate proportion to get the desired quality at the outlet. As the use of saline water in long term may lead to deterioration of the soil structure, constant monitoring of water quality and salinity status of soil is needed. The choice of the crops should be made on the basis of salt tolerance and low water requirement. Experiments conducted on the use of saline water and conjunctive use of waters on saline black soils indicate that low water requiring crops such as mustard, safflower and dill may be ideal options for these areas. Two good quality waters of 5 cm each along with one saline water (4.0 dS/m) is sufficient to raise these crops successfully. In general cultivation of low water requiring salt tolerant crops, better moisture conservation practices needs to be adopted.

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Management of Land Degradation in Arid and Semi Arid Areas

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Introduction

World population has increased from less than two thousand million to over six thousand million In the course of past century. Until one hundred years ago, the increasing needs of expanding population for food, fuel, fiber and construction materials were met from cultivating progressively larger area of land. Steep increase in population during last century has been supported mainly by intensifying the use of most of the already cultivated land. In the course of the next twenty-five years another two thousand million people will be added to the global population. Most of these people will live in the arid and semiarid areas. As a result, future demands on soil and water resources in these areas will far exceed those of the past. The aim of this chapter is to summarize past and present soil management practices for ecological and environmental sustainability with intensified use of soil and water resources in arid and semi-arid areas. It is intended to assist all those concerned with agricultural development and the environment to recognize the problems of soil degradation, compatibilities and incompatibilities of increased agricultural production with protection of the environment. Chapter also describes about management practices evolved under lower demographic pressure in the past and have sustainable soil management systems, adapting both to the environment and to existing social and economic circumstances.

An understanding of the factors determining sustainability of these systems and their breakdown under increasing demographic pressure can make it possible to establish sound principles of sustainable soil management. Such management aims not only to maintain or improve soil productivity, but also to avoid or rectify if necessary all forms of soil degradation so that damage to the environment is prevented. The ways in which these principles may be applied to the development and implementation of more productive and sustainable management systems are also discussed.

The Problem

Population of the world has reached the level of one thousand million in more than one million years. This figure was reached in the middle of the last century. It is now increasing by approximately one thousand million every ten years. Perhaps surprisingly, in view of Thomas Malthus' prediction in 1798 that the world would shortly outgrow its ability to feed itself, the world continues to support its rapidly increasing population (Fig.1). Two factors underlie the ability of the earth to support the enormous increase in number of people now living: the resilience of soils in response to increasing demands made on them; and the increasing

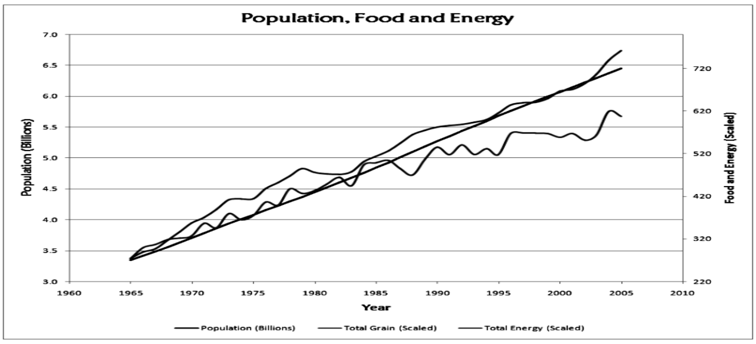


Fig. 1. Projected growth of population vis-à-vis food and energy requirement of world

knowledge of farmers and scientists about how to manage productivity and sustainability of soils. Probably the most important advance in knowledge which has helped to sustain the huge growth in population was the discovery of how to manufacture inorganic fertilizers. Other advances in crop improvement and pest management, including the use of pesticides, have of course made a significant contribution. Much of the debate about the sustainability of systems requiring high inputs of synthetic chemicals has focused on the possible damage to the health of those living on the produce of those systems. The health of the population supported by food grown under intensive management systems is, in fact, better than ever before achieved. A soil management system that depends on large inputs of inorganic fertilizers may be sustainable when considered in isolation, but the sustainability of mineral and energy resources from which the fertilizers are made must also be taken into account. In addition, the environmental effects of the movement of chemicals (from fertilizers and pesticides) out of the soil and into the groundwater, and of by-products released into the atmosphere, should also be considered. Particular attention should be paid to the effects of these chemicals on the plant and animal populations, and the biodiversity of those populations. The traditional system depended on the erosion of silt from higher land, thus resulting in degradation of the upland areas.

Perhaps the biggest challenge facing farmers, economists and soil scientists today is to develop sustainable farming systems together with the political and socio-economic conditions in which they can be practiced, so that a much larger population may be supported by the soils of these less fertile areas. Many attempts to introduce continuous arable cropping systems into the arid and semi-arids have failed. Often, the maintenance of the nutritional status of the soil has not been adequate. Other causes of failure include soil degradation in one or more of the following ways physical degradation due to erosion, compaction and crusting; chemical degradation associated with nutrient mining and acidification; biological degradation associated with loss of organic matter; and deterioration of drainage conditions causing water logging or salinization.

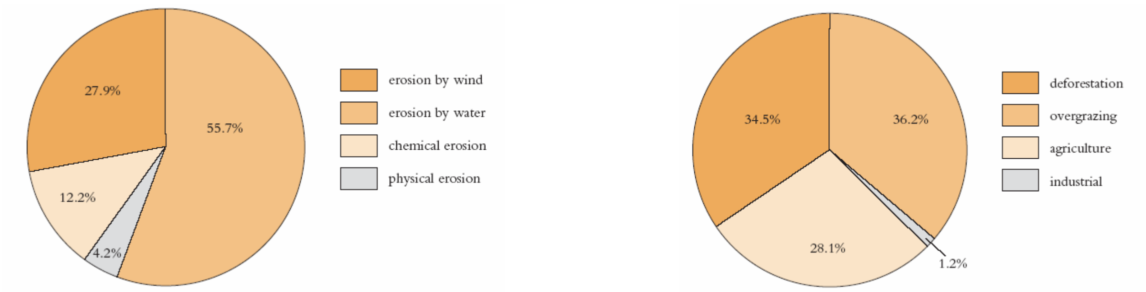
Degraded Land at Glance

Globally, 1,964 million ha of land has been facing human-induced degradation (UNEP 1997). Of this, 1,643 million ha are subject to soil erosion by water and wind, 239 million ha to chemical deterioration, 68 million ha to compaction and 11 million ha to water logging. In addition, an estimated 955 million ha of arable land on earth are affected by soil salinity and/or sodicity (Szabolcs 1992). In India alone, an estimated 175 million ha land accounting for 53 % of geographical area of our country is subject to various kinds of degradation. Of this, an estimated 150 million ha are subjected wind and water erosion. Extent of salt affected soils in India is 6.72 m ha (Saline 3.0 mha, Alkali 3.7 mha; NRSA & Associates 1996).

While arable cropping has often been found to be non sustainable, production of tree crops in these areas has presented relatively few problems with respect to sustainability. Although much remains to be done, the basic principles of good soil management are now well established. They should now be widely known and understood, evaluated and adapted to suit the specific soils and environmental, social and economic conditions of different regions. The necessary policies must then be implemented so that good soil management may be practiced in such a way that it provides a satisfactory livelihood for the farmer and his or her family.

Principles of Good Soil Management

Good management always emphasizes the use of soil in such a way that its productivity is maintained or preferably, enhanced. This requires that the chemical and physical conditions of the soil do not become less suitable for plant growth than when cultivation commenced. Cultivation normally means that the soil will, in fact, deteriorate due both to nutrient removal with harvesting of crops, and to physical damage to the soil structure. What is essential is that the deterioration should be reversible, by chemical additions to the soil, mechanical manipulation, or natural processes of fertility restoration under pasture or trees. This implies that the soil must be resilient, *i.e.* after being subjected to the stresses involved in crop production.



(a) (b)

Fig. 2. Types of land degradation (a) and their causative factors (b)

It must have the ability to return to its former condition, or an improved condition (Greenland and Szabolcs, 1994). Good soil management must not only serve the immediate needs of the farmer but should also be acceptable to the wider community. This requires maintaining and improving soil productivity, avoiding and rectifying soil degradation, and avoiding environmental damage.

Maintaining and Improving Soil Productivity

If a soil is to sustain the production of crops it must provide the nutrient requirements of the crop, a conducive physical medium in which plant roots can grow adequately and absorb water and nutrients. Soil should be able to store sufficient water for meeting crop requirement and allow it to enter and move in the soil to maintain the supply as it is transpired by the crop and evaporates from the soil. It should provide a medium for soil organisms so that they can decompose organic materials releasing nutrients and assisting plants in transport of nutrients to plant roots. Soil medium must support microbes to compete successfully with pathogens which might otherwise infect roots and damage the plants and form the soil organic compounds which will have a favorable effect on other soil properties.

Soil Nutrients Management

A few soils contain sufficient nutrients to allow them to be mined for many years without significant loss of yield, but the majority of soils can only be exploited for a few years before their ability to supply nutrients falls to a low level. If yields are to be maintained, and the soils used to produce crops on a continuing basis, a method by which nitrogen, phosphorus, potassium and other nutrients can be replaced has to be found. Nitrogen is a special case because it can be fixed from the air. A great deal of efforts have been made to quantify and maximize the contributions that can be made to the nitrogen nutrition of crops by natural nitrogen fixation processes, and to find soil management systems in which biological nitrogen fixation is maximized. Likewise maintaining phosphorus, potassium and other nutrients normally requires the use of inorganic fertilizers.

Managing Soil Physical Conditions

Soils under natural vegetation normally support an active population of soil micro-flora and fauna. When the vegetation is cleared to grow a crop, the soil is exposed to the impact of rain, people, animals and machines, treading and inducing compaction of the soil. Exposure and subsequent drying of the soil can also lead to surface crusting. This reduces the rate at which water can enter the soil and cause water to run off the surface leading to soil erosion. Therefore, managing soil physical properties must aim to preserve the structure of the soil where this is already favourable or to create a favourable structure by suitable tillage or other practices where such a structure does not exist (FAO, 1993). Tillage is also important for weed control, and this is often the most significant reason for ploughing. If the soil is naturally well structured as is often the case under forest canopy for long period is easy to seed. A major advantage of zero- and minimum-tillage techniques is that they can be used to leave a cover of crop residues on the soil to protect it from the impact of direct rainfall. This prevents the dispersion of soil material from aggregates, and maintains the infiltration capacity of the soil, so minimizing run-off and the consequent soil erosion problems.

In drier areas, the cover also protects soil from wind erosion. Keeping a cover on soil is now widely recognized as the most important factor in soil conservation. Wind erosion is best controlled by trees planted as windbreaks, although crop residues can be equally effective if they persist on soil. Water erosion can be controlled by bunding of fields or provision of barriers on watershed scale. The barrier can be a simple earth bund, constructed so that it will lead water into a grassed channel in order to avoid gully formation.

Managing Soil Organic Matter and Soil Biological Conditions

Soil organic matter is extremely important for productivity, and particularly so for the poorer soils of arid and semi-arid areas. Its direct contributions to nitrogen and sulphur nutrition of crops, and its role in stabilizing soil aggregates and supporting the soil biota responsible for creating pores through which air and water move cannot be ignored. In addition, soil organic matter plays a major role in the retention of cationic nutrients by dominant soils of these areas which have clays composed of kaolinite, and low activity iron and aluminium oxides clays with only a weak ability to hold nutrient cations. Furthermore, under acid conditions, some of the organic compounds present in soil form complexes with aluminium which would otherwise be toxic to plants. In addition to physical and chemical effects, organic matter provides substrate for supporing biological life in the soil. Under natural vegetation the amount of organic matter in the soil tends to be established at a relatively high level but under cultivation, addition is usually much less than from the natural vegetation, and consequently the OM level tends to fall. If good crops are grown and all residues returned to the soil, the level established after cropping may be different than under grassland.

Table 1. Changes in soil properties (0-30 cm) under different tree-crop combinations in 5 years

Land use system	Organic carbon (%)	Available N (kg ha^{-1})
Crop based system	+0.07	+10
Eucalyptus based	+0.12	+21
Acacia based	+0.20	+31
Populus based	+0.17	+25

A general principle of sustainable soil management systems is that return as much organic material as possible to arable upland soils but it should be free from toxic contaminants, and the costs and problems of collecting and spreading should be socially and economically acceptable.

Avoiding Erosion

Erosion is a natural process and is difficult to eliminate completely. However, on cultivated land there is a real risk of accelerated erosion if the natural vegetative cover of the soil is compatible with the cultivation of large areas by machinery. Trees used as windbreaks to control soil erosion by the wind are usually essential in drier areas of light textured soils, as are contour bunds and channels designed to drain away runoff water in areas subject to erosion by water. Other techniques such as tied ridge cultivation and alternate strip cropping can also be effective for erosion control.

Avoiding and Rectifying Soil Degradation

The major forms of soil degradation are displacement of soil (water and wind erosion), and deterioration of soil without displacement, which usually involves both chemical and physical properties. Chemical degradation include, loss of nutrients and organic matter, acidification associated with removal of nutrients or misuse of fertilizers, increased leaching by soil exposure due to removal of vegetative cover, increased temperatures and oxidation of the soil organic matter due to exposure and cultivation, salinization and sodication often associated with inappropriate irrigation practices and inadequate drainage and pollution from improper management of industrial and mining wastes. Physical degradation involves crusting, compaction and water-logging. Other forms of degradation include the problems of salinization and sodication or alkalinization. Sodication causes dispersion of the clay and inhibits water movement into and through the soil. Whether or not the effects of soil degradation can be easily corrected depends on the extent to which the problem has developed. This, in turn, may be controlled by good soil management. Some soils are more resistant to certain forms of degradation than others, and the ease for their management (Fig. 3).

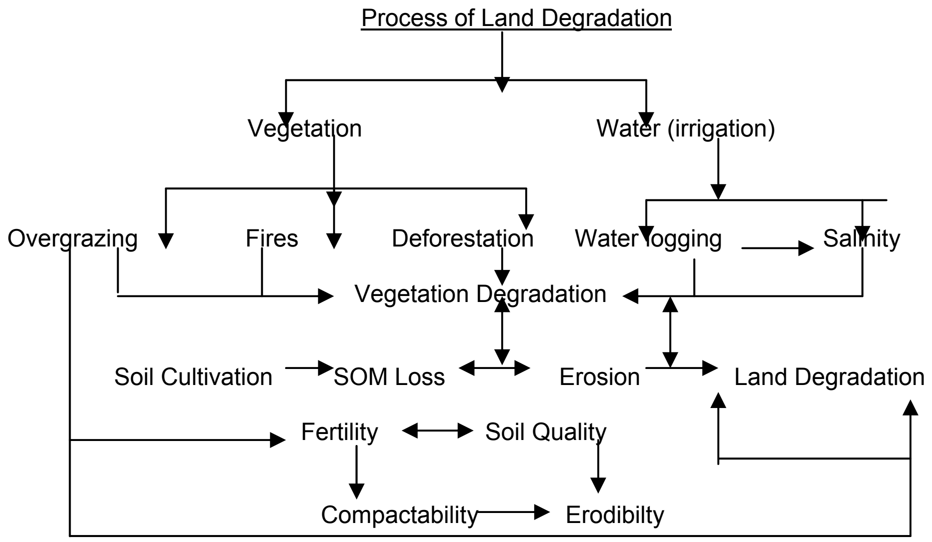


Fig. 3. Schematic diagram of land degradation processes

Rectifying Chemical Degradation

Chemical degradation due to nutrient removal in crops cannot be avoided for the majority of soils. It can, however, be readily corrected by use of fertilizers or manures, or both. Another form of soil degradation is associated with the cultivation of soils which are poorly drained, or where the water table is close to surface. Salts and sometimes potentially toxic ions such as boron may be carried into fields with irrigation water. Unless there is adequate drainage, and sufficient water is supplied to wash out excess salt and undesired ions, salt will accumulate and reach phytotoxic levels. This problem is commonly found in areas where dams have been constructed, and areas below the dam which receive irrigation water. The water stored behind dam is also likely to raise water tables in areas below the dam. In saline groundwater areas this may not only induce salinity but will make drainage of the area receiving irrigation more difficult. In addition to salinity, sodication can be a serious problem. This is not necessarily associated with poor drainage, but arises when irrigation water with high content of sodium is used, or when sea-water flooding occurs. Sodium displaces other ions in the exchange complex, and at about 15 percent of sodium saturation the clay will disperse. This makes the soil extremely difficult to manage for crop production as it becomes extremely sticky when wet, cloddy when dry, and the smaller clay particles will tend to move down the soil profile, a process sometimes known as internal erosion. This leads to extremely compact subsoil, in which water movement and root development are largely inhibited. Many saline soils are also alkaline due to the presence of sodium carbonate, but these do not show the features of sodic soils because soluble salts prevent dispersion of clay. Management of sodic soils involves addition of gypsum, which provides a concentration of calcium sulphate in the soil solution sufficient to flocculate the clay, thus giving rise to a more easily manipulated structure. The calcium will also gradually displace sodium from the exchange complex, so eliminating the cause of the condition.

Avoiding and Rectifying Physical Degradation

Deterioration of soil structure is the commonest form of physical degradation. It involves loss of stability of aggregates in surface soils leading to crusting and compaction, and consequently poorer infiltration rates, greater run-off, erosion and translocation of clay particles to subsurface layers. Loss of porosity in the subsurface soil layers leads to loss of water transmission and storage capacity. Physical degradation of soil is most commonly found where heavy machinery is used to clear and cultivate the soil. Problems occur mostly in soils of intermediate texture and low organic matter content, particularly sandy and silty loams. Difficulties can be avoided by using no-till and mulch farming techniques, and careful attention to restrict cultivation at times when soil is too wet as wet cultivation readily damages the structure. Maintaining a relatively high organic matter content can increase soil aggregate stability, although even high organic matter soils are also subject to damage by wet cultivation.

Practice of Good Soil Management

The principles of good soil management are universally applicable. The practices which embody those principles vary quite widely according to specific soil, climate and other environmental conditions. Productive capacity of soils is being degraded as a result of decreasing organic matter, deteriorating structural condition, or declining nutrient levels in majority of the humid tropics perennial crops systems, though oil palm, rubber, cocoa, bananas and plantations have been grown for many years throughout the humid tropics. The crops provide a cover for the soil and usually return sufficient residues to maintain a satisfactory organic matter level. In arable cropping systems, dominant soils of the humid tropics are often simple to manage as far as their physical properties are concerned. They have relatively stable aggregation and are free draining. However, efficient drainage and high rainfall means that they are often severely leached of nutrients, and are strongly acid. Hence, management of their chemical properties by careful use of fertilizers and lime, combining tree crops with arable cropping systems is widely practiced. These systems can be sustainable, depending on the efficiency of the tree crop in recycling nutrients, soil organic matter and control of acidity.

Table 2. Components of sustainable soil management systems

Humid tropics	Sub- Humid tropics	Semi-arid tropics	Wetlands
Trees: Avoid erosion, recycle nutrients, mulch, maintain OM, suppress weeds Fertlizers: increase yield, replace nutrients Lime: control acidity, replace Ca (and Mg) Relay and intercropping: minimize soil exposure, control erosion Terracing and contour bunding: control erosion, remove excess water	Trees: Avoid erosion, recycle nutrients, mulch, maintain OM, suppress weeds Fertlizers: increase yield, replace nutrients Lime: control acidity, replace Ca (and Mg) Green manure: provide nitrogen, maintain organic matter, minimize soil exposure Contour bunding: control erosion	Animals: transfer nutrients, provide manure Fertlizers: increase yield, replace nutrients Grassed contour strips, hedgerows or bunds: control erosion, provide animal feed Raised beds: control water on heavy clays Tree windbreaks: control erosion by wind Irrigation and drainage: supplement rainfall, avoid soil salinity and water-logging	Terracing or bunding: retain water Puddling: minimize drainage, control weeds Irrigation: supplement rainfall, natural floods Fertlizers: increase yield, replace nutrients Surface drainage: remove excess water

In wetter parts of sub-humid tropics, plantation agriculture with perennials has some times been sustainable, while the chemical condition of the soil is usually better in the more humid areas where dominant soils are usually physically weak, and therefore readily eroded. Alley farming, in which rows of trees are planted along the contour, and crops grown between them, has been widely promoted as a sustainable system for the sub-humid tropics. In what must be regarded as a model system, rows of the fast growing legume *Leucaena leucocephala* are planted, and maize or cowpeas grown between the rows. Lopping from the trees are used as a mulch to protect the soil and provide nitrogen. Although it is inevitable that the trees will compete with the crop for water and nutrients, they too have the potential to provide an economic return. Indeed, if this system is to be accepted more widely then an economic return from the trees in addition to their value in controlling erosion and building soil fertility must be an important consideration. Indigenous agro-forestry practices at present appear to offer a better basis for sustainable farming systems for the semi-arid tropics than alley farming, except on some larger farms where the alleys are of a size which allows mechanized cultivation between the tree rows. Continuous arable farming under no-till mulch conservation systems, and using fertilizers to maintain nutrient levels, is certainly superior to the plough-till system in terms of productivity maintenance. Although current evidence indicates that yields decline under no-till systems, they do so more slowly than under plough-till systems. It also appears that, at intervals of several years, a break in cropping can rebuild soil productivity. It is not clear why this break should be necessary, but control of pests may be the main reason. For the system as a whole to be sustainable, it requires that the ‘fallow’ crop offers some economic advantage, and a legume based pasture may be the best provided that livestock can be economically raised.

In the semi-arid tropics uncertain rainfall and long dry seasons make sustainable crop production difficult in the semi-arid tropics. Pastoralism, rather than crop production, offers the greatest prospect of sustainability. This ensures that the vegetation persists, and continues to provide the essential ground cover. In most parts of the arid and semiarid the demand for food has meant that stocking rates have often exceeded sustainable limits, and arable cropping has continued to invade traditional grazing areas. The extent to which fertility is restored is often limited. This has lead to falling productivity, sometimes partly arrested by the introduction of fertilizers to supplement the animal manure used on the crops. In some instances, shorter duration crop varieties, e.g. sorghum, have helped to overcome water shortages by reducing the length of time that the crop is using water. The demand for nutrients, however, is not reduced. Legumes nearly always require an adequate level of soil phosphorus, and so fertilizer phosphorus has normally to be used together with a suitable legume. In order to maintain the productive capacity of land in the arid and semi-arid a cropping system is required where the rate at which soil fertility can be restored (under a rest crop) is much improved compared with the changes under native grassland. Unfortunately, after many years of experimentation, there are only a few areas where combinations of grasses and legumes have been identified as suitable for soil improvement and grazing use.

Crop Tolerance to Waterlogging and Soil Salinity

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Introduction

The plants differ widely for the tolerance of different kind of stresses from sensitive ones, whose normal growth is inhibited by low stress to the most resistant, which grow profusely in different kind of stress conditions. Crop plants even exhibit differences in their resistance to water stagnation, salinity and salinity of the irrigation water. Four criteria are generally followed to evaluate comparative tolerance of crops to different kind of stresses: *Germination of crops, Plant survival, Absolute plant growth or yield and Relative growth or yield.* A large numbers of investigations on differential response of crops or varieties have been reported at germination stage and attempts made to extrapolate the tolerance limit for final performance. More than often-such attempts are likely to be frustrating because tolerance characteristics differ from one stage of growth to another.

Plant survival has been used as a criterion by ecologists but without yield, plant survival alone has little value to the farmer. On the other hand, it can be useful criterion for plant breeders. Absolute plant growth or yield is of greatest interest to the farmers. However, this criterion does not permit comparison between crops because yields for different crops are not expressed in comparable terms. The relative growth or yield is defined as the yield on saline and waterlogged soils as a fraction of the yield on a non-saline/waterlogged soil under similar environment and nutritional conditions. This criterion is reliable provided the level of other essential factors such as nutritional factor or water does not affect yield reductions. The main difficulty with this method, however, is to decide at what level of yield reduction, different plants should be compared. A researcher comparing the salt tolerance at 10 percent yield reduction may essentially end up differently than the other who is comparing the salt tolerance at 50 percent yield reduction. Nevertheless, this criterion is favoured world over and is widely used for relative comparison. In addition to these four criteria, attempts have also been made to evolve a criterion based on metabolic parameters. The sodium and potassium contents in plant tissues and particularly their ratios have been found to be suitable parameters to adjudge the relative tolerance of crops. This lecture summarize the effects of stress due to excess water as a result of surface stagnation, stress due to excess water as a result of high water table and stress due to excess salts in the root zone on plant growth.

Surface Water Stagnation Stress

Surface stagnation of rain/irrigation water in the croplands is assuming a serious dimension due to unplanned implementation of development projects, rising water table in irrigation commands, unrealistic drainage system design and their inadequate maintenance. The problem is even more severe in alkali lands under reclamation, where water continues to stand on land surface for longer duration than normal lands. High sodium concentrations and high pH impart adverse soil physical properties leading to poor air-water relationships. Application of gypsum ($CaSO_4.2H_2O$ and continuous cropping for 2-3 years improve surface layers, but subsoil layers continue to conduct poor water penetration, low water storage and movement (Sharma, 1986). Most of crops not adapted to wet-land conditions are severely affected when water stagnates even for a short period. The extent of damage or yield reduction depends upon the crop and its growth stage, duration of water stagnation/flooding, type of soil and prevailing agro-climatic conditions. In alkali soils where the problem of water stagnation is more acute after irrigation or rains, one can cite only a few experimental evidences that have been gathered to quantify the yield loss (Sharma & Swarup, 1988, 1989b).

Several field experiments have been conducted at CSSRI, Karnal to evaluate the effect of water stagnation on growth of different crops. The soils of this site were initially highly sodic but after the addition of gypsum and continuous rice-wheat cropping, the pH2 and ESP of the soils decreased in the range of 8.6-8.8 and 22-25, respectively in 0-30 cm soil depth. These crops were cultivated following recommended package and practices. Water stagnation treatments were applied at different crop growth stages for different period. In the drained treatment, excess water was drained in a drainage channel 12 hour after irrigation, in the second, third, fourth and fifth treatments, irrigation water was allowed to stand for 1, 2, 4 and 6 days, respectively. During the water stagnation period and thereafter, oxygen diffusion rates (ODR) were measured daily with an oxygen diffusion rate meter at a depth of 15 cm. Root and plant samples were analyzed for different nutrients. Surface water stagnation for 1, 2, 4 and 6 days reduced plant growth parameters, yield and yield components of different crops. The data in general reveal that water stagnation for more than one day is harmful to various crops (Table 1). It has also been shown that the adverse effects of water stagnation are relatively more when water stagnation occurs at the early growth stages than at the latter. Water stagnation decreased ODR and reduced ion uptake, especially of N, P, K, Zn, Cu and increased the absorption of Na, Fe and Mn. The general pattern of ODR depletion following water stagnation showed that in these soils, values were not only lower than the drained plots but low ODR values persisted for longer duration resulting in lower yield (Fig. 1). It is believed that poor aeration due to water stagnation and imbalance in the nutrient uptake might have caused yield reduction of the crops, although several other factors such as reduced root growth, ionic imbalance and/or nutrient stress might have contributed to the overall decline in the yield. Nitrogen deficiency triggered by flooding is considered to be an important cause of low yields (Swarup and Sharma, 1993). Studies have also shown that increasing the rate of top-dressed urea-N (50-75%) after water stagnation helps in alleviating the adverse effects of temporary water stagnation. Supplementing N also promoted uptake of N, P, K, Zn. Since, such a strategy cannot be adopted on large scale, it cannot be recommended as a long-term solution of the problem. The results of these studies clearly indicated that to ensure optimum yield of crops in partially reclaimed sodic soils excess irrigation water must be drained within one day of irrigation or rains. An integrated drainage system would be the most cost-effective and eco-friendly solution of the problem.

Table 1. Response of various crops to short-term water stagnation

Duration of water stagnation (days)	Grain yield (Mg/ha) Wheat	Barley	Mustard	P. millet	Sunflower	Pigeon pea
0	4.41	3.65	1.43	2.22	1.86	1.41
1	3.70	3.52	1.31	2.08	1.62	1.35
2	3.63	3.39	1.20	1.89	1.50	1.22
4	3.13	3.18	1.12	1.74	1.38	1.16
6	2.35	2.75	1.02	1.63	1.29	1.11
CD (p = 0.05)	0.28	0.28	0.22	0.12	0.06	0.13
Growth stages:						
Vegetative	--	3.22	1.11	1.90	1.51	1.17
Flowering	--	3.37	1.32	1.98	1.55	1.34
CD (p = 0.05)	--	NS	0.14	0.10	0.04	0.10

* Vegetative: Barley–25 days after sowing (DAS), Mustard–30 DAS, Sunflower–50 DAS, Pigeon pea–35 DAS, Pearl-millet–25 DAS.
** Flowering: Barley–65 DAS, Mustard–60 DAS, Sunflower -80 DAS, Pigeon pea–75 DAS, Pearl-millet–50 DAS.
(Source: Sharma & Swarup, 1988; Sharma & Swarup, 1989b; Singh *et al*., 2002, 2003; Thakur *et al*.,. 2003; Sharma *et al*.,., 2005)

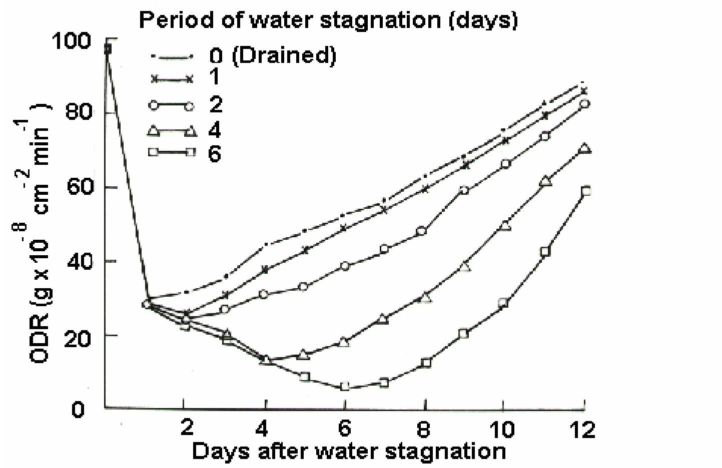

Fig. 1. Oxygen diffusion rates in different water stagnation treatments

A review of the available data on the yield of various crops as a function of water stagnation was made. The application of the Maas and Hoffman model yielded the threshold and slope values as reported in Table 2. It may be seen that in most cases the threshold is less than 1 day and decline in yield from 4.5% to 23% for each additional day of water stagnation.

High Water Table Stress

Since the soil is the living medium for plant roots, its environment in term of salt and water regimes, aeration, temperature and tilth determine crop growth. Although, the depth of water table has no direct effect on crop growth, but indirectly it effects crop growth by influencing the soil edaphic environment and often crop yields are affected with high water table. For many crops and soils, it is desirable to have water table at least below 80 cm. However, shallow water table may not always be a curse, particularly when it is free from salinity hazard, as is the case in most humid regions. Water table contributes substantially towards the crop evapo-transpiration. On the other hand, shallow water table causes the hazard of soil salinization, especially where the ground water is brackish and potential evaporative demand is high. The gradual and irreversible salinization of soils may have been the process responsible for destruction of once thriving agricultural civilizations. Presence of water table at soil surface or near/within root zone, replaces air from soil pores leading to O_2 deficiency. Oxygen deficiency affects root growth and nutrients uptake by growing plants. The optimum depth of water table for various crops in non-saline areas is given in table 3.

Table 2. Water stagnation tolerance of various crops at different locations in India

Site	Crop	Water stagnation tolerance indices		
		Threshold (days)	Slope (%)	DWS_{50} (days)
Delhi	Pigeon pea	1.6	23.2	3.8
Hisar	Cow pea	0.8	6.6	8.4
	Pigeon pea	0.5	9.2	6.0
Karnal	Wheat	0.0	7.0	7.2
	Barley	1.0	4.4	12.2
	Mustard	0.5	6.8	7.9
	Pearl millet	0.0	5.3	9.4
Ludhiana	Wheat	1.9	9.2	7.3

Table 3. Optimum depth of water table for various crops in non-saline areas

Crop	Depth of water table (cm)	Crop	Depth of water table (cm)
Rice	$\leq$ 30	Soybean	125
Wheat	60	Gram	90
Barley	90	Maize	120
Sugarcane	60	Cotton	125
Cowpea	75	Pearl millet	125

Water table affects O_2 supply to the growing plants and nutrient uptake. For an example, oxygen content of a heavy soil at depth of 23 cm was sharply reduced as the water table was raised from 90 to 30 cm depth and the cotton yield and nutrient uptake were decreased accordingly (Table 4).

Table 4. Water table depths and soil air O_2 content, yield and nutrients uptake of cotton

Water table depth (cm)	O_2 at 23 cm (%)	Cotton yield (g)	Nutrient uptake by 5 plants (mg)		
			N	P	K
30	1.6	57	724	85	1091
60	8.3	108	1414	120	2069
90	13.2	157	2292	156	3174

Source: Meek *et al.,* (1980)

Excess Salts in Root Zone Stress

Soil Salinity and Plant Growth

Excess salinity affects crop growth in three ways *i.e.* first and most important is increase in salts concentration causing low availability of water to plants even though the soil may appear quite moist. This is because the osmotic pressure of the soil solution increases with the increase in salt concentration and the plants are unable to extract water as readily as they can from a relatively non-saline soil. In addition to the osmotic effect of salts in the soil solution, at high concentration, absorption of an individual ion may prove toxic to the plants. Besides, preferential absorption of one ion may also retard the absorption of other essential plant nutrients necessary for normal growth of plants. It is believed that the adverse effects are usually due to cumulative effects of these factors although one or other may be dominating under specific conditions. In many cases salinity problem occurs along with the problem of alkalinity. It is particularly true in the case of saline-alkali soils. Maybe therefore, crop selection in such cases ought to be made on the basis of tolerance to soil salinity than alkalinity. The yield reductions due to excessive salts could be ascribed to the following three factors, which may influence plants singly or in combination.

- General osmotic effect regulating osmotic pressure of the medium
- Imbalance in the ions' uptake
- Toxic effects of accumulation of certain causative ions on specific plants

Since crops differ in their tolerance to salinity, selection of crops and cropping sequences for saline soils assumes significance in overall management of saline soils and more so particularly for selection of first crop. Since complete reclamation is not attained in the initial years, tolerant or semi-tolerant crops that can withstand antecedent salinity levels are preferred (Table 5).

Table 5. Crop groups based on response to salt stress

Sensitive Group		Resistant Group	
Highly sensitive	Medium sensitive	Medium tolerant	Highly tolerant
Lentil	Radish	Spinach	Barley
Mash	Cow pea	Sugarcane	Rice (transplanted)
Chickpea	Broad bean	Indian mustard	Cotton
Beans	Vetch	Rice (direct sowing)	Sugar beet
Peas	Cabbage	Wheat	Turnip
Carrot	Cauliflower	Pearl millet	Tobacco
Onion	Cucumber	Oats	Safflower
Lemon	Gourds	Alfalfa	Taramira
Orange	Tomato	Blue panic grass	Karnal grass
Grape	Sweet potato	Para grass	Date palm
Peach	Sorghum	Rhodes grass	Ber
Plum	Minor millets	Sudan grass	Mesquite
Pear	Maize	Guava	Casuarina
Apple	Clover, berseem	Pomegranate	Tamarix
		Acacia	Salvadora

In arid and semi-arid regions of northwest India, the recommended cropping sequences for saline soils are pearl millet-barley, pearl millet-wheat, pearl millet-mustard, sorghum-wheat or barley, sorghum-mustard, cluster bean-wheat or barley and cotton-wheat or barley. Pearl millet-wheat, pearl millet-barley, pearl millet-mustard, sorghum (fodder)-wheat and sorghum (fodder)-mustard cropping sequences are more remunerative. Cotton based cropping sequences are not beneficial because winter crops following cotton suffer. In water scarcity areas, mustard could replace wheat in cropping sequence as its water requirement is low than wheat. Maas and Hoffman (1977) prepared a comprehensive table listing EC_t, slope and EC_o for many crops with the piecewise linear model. Such comprehensive data for Indian conditions is lacking. Gupta (1992) collated the existing information on this subject and determined EC_t , slope and EC_o for several crops and soil/climatic conditions (Table 6).

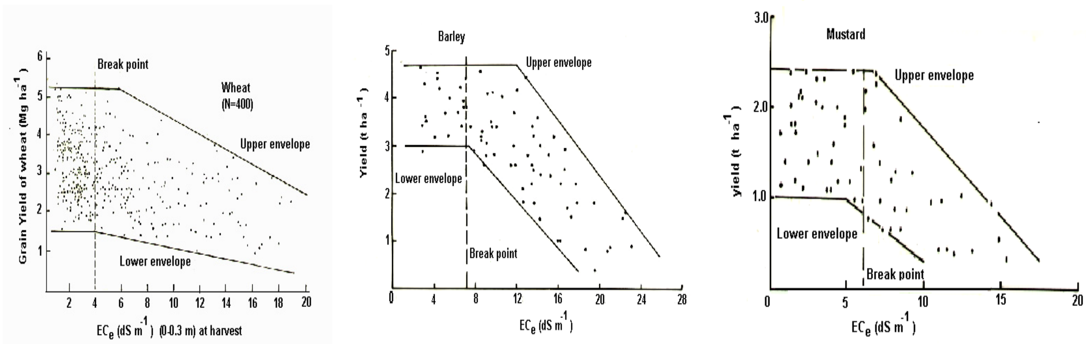

Fig. 2. Relationship between soil salinity and wheat, barley and mustard yield on farmer's field

Based on a review of experimental evidence Gupta and Yadav (1986) reported critical limits of salinity of the irrigation water at which yield declines by 10, 25 and 50 percent of optimum yield that is expected with use of fresh water. The relative crop tolerance of 3 major crops wheat, barley and mustard to salinity of 0-30 cm soil depth is depicted in Fig. 2. Such data could be made use of in working out tolerance of a crop to soil salinity provided leaching fractions could be properly estimated.

Table 6. Crop tolerance to soil salinity for working out leaching requirement

Sites	Soil type	Crop	Critical EC (dS m^{-1})	Slope (%)	EC_{50} (dS m^{-1})
Sampla	Sandy loam	Wheat	4.0	29.0	5.7
		Mustard	6.0	15.0	9.3
		Barley	7.0	19.0	9.6
Karnal	Sandy loam	Mung bean	1.8	20.7	3.3
		Mustard	3.8	6.9	11.0
		Sorghum	2.2	10.6	6.9
Agra	Sandy loam	Wheat	8.2	19.8	10.7
		Mustard	6.1	20.7	8.5
		Berseem	3.5	12.5	7.5
		Tomato	1.3	6.5	9.0
Dharwad	Black clay	Wheat	2.3	20.5	4.7
		Safflower	2.8	20.7	5.2
		Sorghum (w)	2.1	3.9	14.9
		Itallian millet	6.1	50.0	7.1
Indore	Black clay	Berseem	2.3	20.5	4.7
		Safflower	2.8	20.7	5.2
		Sorghum (w)	2.1	3.9	14.9
		Italian millet	6.1	50.0	7.1
		Sataria	1.1	2.2	23.9
Indore	Black clay	Berseem	2.0	11.2	6.5
		Safflower	2.8	5.0	12.8
		Maize	0.5	7.9	6.8

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Multitier Cropping System for Higher Productivity in Reclaimed Sodic Soils

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Yield plateau of rice-wheat system in reclaimed sodic soil is a cause of concern. Horticulture based multi-tier system in reclaimed sodic soils has the potential to enhance the profitability in the hands of farmers. Fruit based multi-tier cropping system can be defined as a planting system comprising combinations of plants with various morpho-phenological features to maximize the natural resource use efficiency and enhanced total factor productivity. Perennial tree based cropping system offer efficient alternative for improving the total factor productivity of stressed lands. Horticulture based multi-tier cropping system was identified as an ideal model for crop diversification in upland situation (Dey *et al.,* 2003).

Benefits of Multi-tier System

1. Fruit trees are efficient enough in providing higher economic return even under stressed growing conditions
2. The approach aims at improving productivity by effective utilization of air space which is not utilized in single tier system.
3. The summation of productivity of the component crops can increase the total productivity of the land where poor soil fertility coupled with low water holding capacity of the soil contributes towards low crop productivity.
4. Higher labour requirement per unit area of multi-tier system contribute towards creation of job opportunities at site.
5. High return per unit area under upland conditions is the ultimate result of fruit based multi-tier cropping system.

Fruit based Multi-tier Cropping System

The fruit based multi-tier cropping system is a self-sustainable system where solar energy can be harvested at different heights, soil resources can be efficiently used and cropping intensity is increased. The system consists of three main components viz. main crop, filler crop and inter crops which occupy three different tiers in space of the production system.

- **Main crops:** The main crops are the fruit species having a larger canopy size and prolonged juvenile as well as productive phase. They utilize the upper most layer of the multi-tier system from which the economic productivity is obtained. Generally the crops utilize the entire land after 20-25 years whereas only 25-30 % of land is effectively used up by the main crop up to 10 years. Under the multi-tier system, these plants are planted at wider spacing. Mango based multi-tier system was found suitable for upland situation (Nath *et al.,* 2003).

- **The filler crops**: The filler crops are the fruit species which are precocious in nature, prolific bearers having short stature. They utilize the middle layer of the multi-tier system from which economic productivity is obtained. These plants are planted with the purpose to generate additional income from the land during the initial 10 years of the orchard (during the juvenile and initial bearing stage of the main crops) by utilizing the unused land and space. The plants are generally hardy in nature and have shorter economic life than the main crops. The filler crops are planted within the main crop at a closer spacing. The filler plants can be removed after the main crops attain effective canopy size for yielding economically.

- **Inter crops:** The intercrops occupy the lower most layer of the multi-tier system and are grown in the remaining unused land of the multi-tier system. Generally the intercrops are the location specific annual crops, selected as per the climatic and socio-economic suitability. The inter crops also include the dependant crops like creepers which are grown with the support of main or filler crops. During initial years of the multi-tier system any crops can be taken whereas during the later years shade tolerant crops can be grown as inter crops.

Layout of Fruit based Multi-tier Cropping System

For laying out the fruit based multi-tier cropping system, suitable crop combinations should be decided based on the climatic and soil suitability, availability of irrigation facility and socio-economic requirements. For main crop, fruit plants with bigger size canopies like mango, litchi, *aonla*, etc. can be considered. For filler crop, the short stature plants with precocious and prolific bearing habit like guava, lemon, lime, custard apple, papaya etc. can be considered. Under rainfed conditions, crops like *aonla* or sapota or mango can be planted as main crop and custard apple or guava or lime etc can be planted as filler crops. Under irrigated conditions, litchi or mango can be planted as main crop and guava or lime or lemon or papaya can be planted as filler crop. For intercropping during the initial 10 years, different legumes like pigeon pea, horse gram, black gram, cowpea, French bean, millets, oilseeds like niger, ground nut, fodder like *Stylosanthes*, Dinanath grass etc. should be grown as kharif crops under rain fed conditions whereas high value crops like vegetables or flowers should be grown under irrigated conditions. After 10 years, shade tolerant crops like turmeric can be grown as intercrops.

Farmers' Feedback about Multi-tier Technology

Direct interview of farmers who have adopted the fruit based multi-tier cropping system revealed the following feedbacks about the technology.

- It is an effective technology for 100% utilization of land and generating higher income from the first year onwards.
- With the adoption of the technology, there has been a marked change in the input use pattern by the farmer, particularly a significant increase in the use of seeds of improved varieties, organic manure and farm labour. A two fold increase in the use of pesticide by the farmer warrants integration of integrated pest management practices in the fruit based multi-tier cropping system
- With the adoption of the technology there has been a shift in the waste utilization pattern from the farming system. The leaf litter which was used earlier for fuel purposes is now being used for composting purpose. A significant proportion of paddy straw produced is being used for mulching of fruit plants.
- The increased availability of fruits and vegetables in the multi-tier system has resulted in increase in the consumption of fruits and vegetables in the household
- The multi-tier system has been effective in generating more job opportunities for the women particularly in the operations like marketing of produce, weeding, fertilizer application.
- Arrangements for protecting the plants from grazing animals and provision of irrigation water during the initial years of orchard establishment are the major concerns which need due attention in the technology promotion schemes.

Profitability

The estimation of Benefit:Cost (B:C) ratio of different fruit based multi-tier cropping systems by NABARD showed that mango based system resulted B:C ratio of 2.40, litchi based system resulted B:C ratio of 2.86 and *aonla* based system resulted B:C ratio of 2.51.

Conclusion

Fruit based multi-tier cropping systems were found to be effective alternatives to the traditional rice based monocropping system for increasing the profitability under rainfed as well as irrigated upland conditions of the eastern plateau and hill region. In the locations having comparatively better soil conditions and facilities of supplemental irrigation (uplands near the water bodies) in the watersheds, litchi based multi-storied models with guava as filler crop can be grown with intercropping of French bean, cowpea or horse gram during the initial 8 years. In the comparatively flat upland watersheds, mango + guava + French bean/ paddy can be most suitable options during the initial 10 years whereas intercropping of turmeric can suitably be practices under the grown up orchards. This system may be profitably used in reclaimed sodic soil also.

Suggested Models for Different Agro-climatic Conditions

Rainfed conditions	Cropping system
Arid (<400mm rainfall)	*Ber* + *Karonda* + *Guar/moth*
	Khejri + *Lasoda* + *Phalsa*
Semi-arid (400-800 mm rainfall)	*Aonla* + Guava + Black gram
	Aonla + Custard apple + Legumes
Subtropical (800-1200mm rainfall)	*Aonla*/ *Bael* + guava + Black gram
	Mango + Guava + *Stylosanthes*
Tropical (>1200mm rainfall)	Mango + Citrus + Tapioca
Coastal	Coconut + Black pepper + Banana

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Multi-enterprise Agriculture to Improve Nutrient and Water Productivity in Reclaimed Lands

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Introduction

The farm of Central Soil salinity Research Institute, Karnal was affected largely with soil alkalinity (high pH) at the time of its establishment in 1969. Within few years of its establishment, a technology for reclamation of alkali soil was developed; and now most of the crops except a few very sensitive ones can be grown successfully. Among crops, rice-wheat rotation was found more cost-effective but this rotation has led to depletion of water level and loss of soil fertility. Due to intensive agriculture and climate change in recent years the productivity of crops is continuously going down. Simultaneously, land holding is diminishing continuously with consistent increase in population. Owing to reduced farm size and increased cost of cultivation farmers are facing financial hardships. From rice-wheat cropping system farmers get income only two times in a year when the crops are harvested during early summer or early winter but a farmer needs regular income to meet out his day-to-day needs. For this he has to borrow loan but when unable to repay back his economic and mental situation is disturbed. Because of above cited reasons there is pressing need to reorient the present farming systems and adopt those, which can improve water productivity as well as provide regular income and employment. Also, there is need to reverse natural resource degradation trend and build the farmers confidence in agriculture. Multi-enterprise agriculture (popularly called farming system approach) seems to be a viable solution to these problems. By doing so, the cost of cultivation can be reduced to a large extent and the residues/by-products/ wastes of different kinds available within the system of various components may be recycled to improve soil health and other shared benefits.

Multi-enterprise Agriculture

A multi-enterprise agriculture project has been initiated at the Central Soil salinity Research Institute, Karnal since *rab*i season 2005-06 as a model for 2.0 ha land with the following objectives:

- Comparative evaluation of crop enterprise diversification options in the reclaimed sodic land.
- To increase water, nutrient and energy use efficiency through diversified agriculture systems.
- To reduce cost of cultivation for higher returns through recycling of residues within the system.
- Assess chemical, physical and biological changes in soil under different land use options/systems.
- To identify profitable, sustainable and eco-friendly agriculture model for 2 ha land holding.

Main theme of this project is to find alternatives which use less water. The idea behind Multienterprise agriculture is that in conjunction with agriculture a farmer can adopt several related enterprises such as dairying, horticulture, floriculture, bee keeping, vegetables, fisheries, poultry, duckery, mushroom, gobar gas and vermi-compost *etc.* to improve his family income and generate employment. Each component is monitored meticulously for soil physical, chemical and microbial properties and other parameters. The water use efficiency and economic productivity are also being monitored. The main enterprises/ components/capsules along with their area those are being used in the model are as follows:

A. Grain Production (0.8 ha cropped area)

- 0.2 ha. Rice-Wheat cropping
- 0.2 ha. Maize -Wheat- Moong cropping
- 0.2 ha. Winter Maize -Soybean
- 0.2 ha. Pigeon pea (SD) - Mustard-Fodder Maize

B. Floriculture (0.2 ha)

Flowers like Marigold and Gladiolus *etc.* are being grown during *rabi* season and crops like baby corn, sweet corn *etc*. during *kharif* season.

C. Fodder Production for 4 Cross-bred Cows/Buffaloes and Their Heifers/Calves (0.4 ha)

Fodder requirement: 35-40 kg/day/animal (Sorghum/Maize) and 60 kg berseem/day/animal. With feeding this fodder 7 to 8 litre/day/animal can be produced. For every 2.5 to 3.0 liter milk one kg balanced Multi-enterprise Agriculture to Improve Nutrient and Water Productivity in Reclaimed Lands 255 concentrate will be required. Year round fodder production is maintained by adoption of forage crop rotations using berseem, maize, maize+ cowpea and multi-cut sorghum.

D. Horticulture and Vegetables (0.2 ha)

Seasonal vegetables are being grown in between the rows of guava and papaya trees.

E. Vegetables (0.2 ha)

The approach is to have green vegetables all the year round.

F. Fish Farming, Bee Keeping, Poultry, Duckery and Mushroom (0.2 ha)

On the basis of 2 years average data, *i.e.* 2006-07 and 2007-08, wheat gave a net income of Rs 37109 per ha and B:C ratio of 3.08. By contrast, berseem fodder) and bottle gourd/ Ghia (vegetable) provided a net income of 43542 and 56082, respectively with respective B:C ratios of 4.99 and 2.95. Performance of soybean and pigeon pea was not satisfactory and proved uneconomic. While seeing comparative economics of crop rotations it was found that maize-oat-berseem, sorghum-berseem and rice-wheat were the most remunerative crop rotations amongst all the cropping sequences undertaken in the selected plots. On an average of the 2 years net income, these rotations provided Rs 63656, Rs 59522 and Rs 53826 per ha, respectively. The B-C ratio for these crop rotations was 3.64, 2.34 and 2.15, respectively. Bee keeping and fish production are also profitable enterprises. On the dyke of fish ponds (alkaline soil with initial pH about 10) in the west direction alkali tolerant fruit trees like aonla, karonda have been planted and growing well. However, in the east and north direction where soil is almost normal banana and guava has been planted and banana and guava have already started fruiting and supplying regular income. The growth and fruiting showed distinct effect of soil alkalinity. Seasonal vegetables being grown between the fruit trees are providing regular income. The dung received from cattle is being used for making compost; vermi-compost and gobar gas besides some of it is used as fish feed. Together with crop production, bee keeping is also a good enterprise, wherein from 15 boxes 343 kg honey was been extracted and a net income of Rs.17,000 was recovered within 6-7 months in the first year. In this occupation there is no need of much space but gives honey production starting from October to June. From second year onwards there will not be the cost of infrastructure and only little management will be required. It is an established fact that honeybees produce more honey and profit if grown where flowers are cultivated. For some crops like mustard, sunflower and fruit trees honey bees help in pollination and thus increasing their yields. In the second year 10 more boxes were added but due to inclement weather during summer and winter, the honey bees could not produce enough honey thus gave a meager net income of Rs 3432. Overall, honey bee keeping proved a beneficial enterprise. Fish cultivation is a valuable and economical enterprise, particularly on those farms, which are located at the lower elevation. From O.12 hectare of fishpond with investment of Rs. 27,863 a net profit Rs. Of 12,528/- can be obtained within a year; and on the dykes of fishpond, fruit trees, like banana, guava have been already planted, which will give additional income in between the spaces of fruit tees. One side of the pond, where dug out soil was placed even now the soil pH is more than 10 (Highly alkaline), so on that side alkali tolerant fruit species like Karonda and Amla have been planted. All these will contribute to the income of the farmer. When the pond is emptied, the pond water that is very rich in plant nutrients can be used for irrigation. The dung from 4-5 animals is sufficient to produce gobar gas that can be used for cooking food of 7-8 family members and preparing vermi-compost. The slurry removed after making gobar gas is being used for composting. The compost and vermi-compost are being used for growing vegetables and fruit trees organically, which fetches more income to the farmer. Apart from this, solar heater can be installed to meet electricity problem of the family. Thus, it can be inferred that by adopting multi-enterprise system by synergetic blending of different components, regular and sustainable income can be generated and risk of failure of one crop is covered with other component. *In-situ* recycling of residues has tremendous potential to increase productivity, profitability, water productivity and livelihood security. By following this system, burning of straws/stubbles can be avoided which consecutively help in pollution free environment.

Interpreting Soil Profile for Salinity / Sodicity

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Introduction

A soil profile is a freshly exposed undisturbed pit of a soil with a dimension of approx. 5'X5'X6'. It is primarily used for studying observable and measurable characteristics of soil called soil morphology, under field condition. The soil morphology is expressed by the number, kind and arrangement of soil horizon. The diagnostic layers, called soil horizon, reflect essentially the soil formation processes. During soil profiles studies, a soil horizon is commonly identified using characteristics such as colour, texture, structure, consistence and the presence or absence of carbonates. Other properties such as presence of absence of concretions, mottles, salts, distribution of roots, pores and slickensides, gilgai, micro-relief, drainage and lithological parameters are studied for characterizing specific landscape. The measurements in the laboratory such as particle size analysis are required to supplement field observations. The fundamental soil formation processes include the addition or losses of organic and mineral matters, translocation of these mineral from one point in the soil profile and deposition at another and transformation of the mineral and organic matter in the soil and formation of definite layers or specific features by means of a variety of reactions.

The processe by which organic materials are decomposed and synthesized to a new organic substance *(humus*) is called humification. The humus largely controls fixation and release of nutrients to maintain soil optimum fertility status. The processes of mobilization and translocation of inorganic and organic soil constituents such as humus, Fe_2O_3, Al_2O_3, SiO_2, $CaCO_3$ and soluble salts is called *eluviation*. The reverse process which is immobilization and accumulation of mineral and organic soil components at a depth below the soil surface is called *illuviation*. Apart from these, important processes such as salinization, alkalization, calcification, gypsification, argillation, gleization are occurring in salt affected and waterlogged soils. Salinization is the process of accumulation of soluble salts. Alkalization (*solonization*) refers to the process of developing higher exchangeable sodium percentage (ESP) and shift of soil pH showing alkaline character. It is usually associated with higher concentration of sodium carbonate and bicarbonates in soil saturation extract in a sodic soil. In the arid and semi arid climatic condition, accumulation of calcium carbonate and gypsum usually occur a depth below the soil surface. Such processes, called *calcification* and *gypsification,* are often found in the salt affected soils profiles restricting leaching and movement of salts. The movement and accumulation of clay and finer soil particles from the upper to the lower soil horizon is called *argillation* a typical process commonly found in the salt affected soils.

Selection and Description of Soil Profile and Collection of Soil Samples

In India, salt affected soils are essentially characterized by the surface encrustation of soluble salts in semiarid and arid regions and surface salt efflorescence in the irrigated and coastal regions. Several methodology such as analysis of remote sensing data in the form of false color composites (FCC) and aerial photographs are used for detection and delineation of salt affected soils. The contrasting tone, texture and pattern of image elements pertaining to barren and partially cropped salty land are used for interpretation of salt affected soils. Typical spectral pattern of severely, moderately and slightly salty surfaces are generated from the computer aided analysis of digital remote sensing data and correlated with the field checks or ground truths data. During ground survey, preliminary soil information such as landform, physiography, topography, vegetation and land uses, elevation, slope and aspects, erosion and deposition and drainage patterns are considered for selecting a soil profile. The surface and sub-surface features and climatic conditions representative of the area are also considered prior to site selection. In general, a profile pit to a depth of 1.5 m is exposed for such study. The soil horizons are identified based on the soil depth, horizon boundary, texture, structure, consistency and color followed by the critical analysis of finer elements such as concretions, mottling, cutans, roots, pores indicating the pedogenic processes. The presence of clay cutans, iron (Fe) and manganese (Mn) mottling, and calcium carbonate concretions are typical indicators of the soil formation processes and genesis of salt affected soils. Soil samples are collected from each horizon scrapping uniformly from the lower to the upper boundary of the horizon separately up to the parent material. The collected soils are mixed thoroughly and transferred to a polythene bag with prior labeling for profile No. horizon designation, depth, location and date of sampling. Such bag is further transferred to a cloth bag with similar labels or tags

Codes and Description of Soil Horizons

The master horizons usually present in the salt affected soils are designated as O (organic), A, E, B, C, R. The detailed description of the horizons and its symbols is presented as follows:

Master Horizon

A: The mineral horizon consisting of humified organic matter intricately mixed with mineral fraction, and a transitional horizons to an underlying E, B, or C with properties resulting from cultivation, pasturing, or similar other disturbances.

B: The dominant fraction constitutes one or more of the following:

- Illuvial concentration of silicate clay, iron, aluminum oxides, humus, carbonates, gypsum, or silica alone or its combination,
- Evidence of removal of carbonates
- Coatings of sesquioxides adequate to give conspicuously darker/ redder color,
- Alteration that forms silicate clay or liberates oxides or both and that forms granular, blocky, or prismatic structure if volume changes accompany changes in moisture content, or
- Brittleness

C: A mineral horizon or layer, excluding bed rock, that is either like or unlike the mineral from which the solum is presumed to have formed, relatively little affected by pedogenic process.

R: Hard bedrock

Transitional and Combination Horizons

The master horizons may not be uniform in character by which they have been designated and may be having subordinate properties of other. These horizons are subdivided using the symbols as **AB, EB, BE, BC**, etc. The master horizon symbol that is given first designates the kind of horizon whose properties dominate the transitional horizon. An AB horizon, for example, has characteristics of both an overlying A horizon and an underlying B horizon, but it is more like the A than like the B.

Horizons in which distinct parts have recognizable properties of the two kinds of master horizons indicated in the capital letters. The two capital letters are separated by a virgule (/), as E/B, B/E, or B/C. Most of the individual parts of one of the components are surrounded by the other.

Subordinate Distinctions Within the Master Horizons and Layers:

Lower letters are used as suffixes to designate specific kinds of master horizons and layer. The symbols and their meanings are as follows:

c: *Concretions and nodules.* This symbol is used to indicate significant accumulation of concretions or nodules.

k: *Accumulation of carbonates.* This symbol is used to indicate the accumulation or higher concentration of alkaline earth carbonates, commonly calcium carbonate,

m: *Cementation or induration.* This symbol is used to indicate continuous cementation by 90% and is physically root restrictive. If the horizon is cemented by carbonates, "km" is used; by silica, "qm"; by iron, "sm"; by gypsum, "ym"; by both lime and silica, "kqm"; by salts more soluble than gypsum"zm";

n: *Accumulation of sodium.* This symbol is used to indicate an accumulation of exchangeable sodium,

q: *Accumulation of silica.* This symbol is used to indicate the accumulation of secondary silica,

t: *Accumulation of silicate clays.* This symbol is used to indicate an accumulation of silicate clay that has formed and subsequently translocated within the horizon or has been moved into the horizon by illuviation or both,

y: *Accumulation of gypsum.* This symbol is used to indicate the accumulation of gypsum,

z: *Accumulation of salts more soluble than gypsum.* This symbol is used to indicate the accumulation of salts more soluble than gypsum.

Diagnostic Subsurface Horizons

Taxonomy is the part of classification that is concerned with relationships and is the systematic distinguishing, ordering and naming of type groups within a subject field. *Taxon* reflects soil properties or a set of soil properties that are diagnostic for differentiation of pedons. The differentiae are the soil properties that can be observed in the field or measured in the laboratory or can be inferred either from other properties that are observable in the field or from the combined data of soil science and related disciplines. The diagnostic both surface and subsurface, a number of soil properties, soil moisture and temperature regimes have been used to define soil *taxa*. Among the diagnostic subsurface horizons, the argillic and nitric horizons are important in classifying salt affected soils.

Argillic Horizon

Argillic (L. *argilla*, white clay) is an illuvial horizon in which layer lattice silicate clays have accumulated to a significant extent by illuviation. The process of illuviation does not preclude concurrent formation of clay in the illuvial horizon. The illuvial horizon has distinctly finer texture than the overlaying *eluvial* horizon or the underlying parent material if the mantle is uniform throughout its depth. The ratio of clay content is in general close to 1.2 or larger. In general, an increase in clay content to an extent of 20% or more occurs within a vertical distance of 15 cm. The lower boundary of the argillic horizon is gradual and commonly irregular.

Natric Horizon

The nitric (L. *natrium*, sodium) horizon is a special kind of argillic horizon enriched with sodium ion. It is commonly occurring in barren sodic soils. It has a prismatic or columnar structure in some part and hard enough to break into blocks. The SAR is > 13 (or 15% or more saturation with exchangeable sodium) in some sub-horizons within 40 cm of the upper boundary. Or contain more exchangeable magnesium plus sodium than calcium plus exchange acidity (at pH 8.2) in some sub-surface horizon within 40 cm of the upper boundary if the SAR is >13 (or ESP > 15) in some horizon within 2 m of the surface.

Equipments

Equipments required for soil profile studies are as follows:

- Digging and excavating tools such as pick axe, shovel, spade, knife, khurpi
- Post hole and screw type augers with extension or attachments up to 2 m depth
- Global Positioning System (GPS) to record location and Abney level to record slope
- Hand lens or magnifying glass 10x20 x magnification for identification of structure, clay cutans etc.
- Measuring tape, dilute HCl (6 N), water bottle, soil pH kit (test tube, universal indicators, barium sulfate and pH chart), base maps, topo-sheets, satellite imageries etc.
- Munshell Color Chart, data recording books, profile examination forms, hard clip board, drawing / cartographic materials/ stationery, marker pen, polythene bags, cloth bags, rubber bands, tray with shoulder
- Brass cores, hammer, aluminum boxes for cores

Determination of Parameters (pHs, ECe and ESP) for Diagnosis of Salt Affected Soils

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I. **Preparation of saturated soil paste**

Apparatus:

Container of 500 ml capacity

Procedure:

Take about 150-200 gm soil in the container and add distilled water while stirring with a glass rod. At saturation, the soil paste glistens, as it reflects light and flow slightly when the container is tipped. Keep the saturation paste to about 4-6 hours to attain equilibrium.

II. **Determination of pHs of the saturated soil paste**

Apparatus:

pH meter equipped with glass electrode

Procedure:

Set the pH meter with known alkaline buffer to adjust pH at 9.2. Insert the electrode in the paste, press the button to initiate the pH reading and note the reading after it becomes stable.

III. **Preparation of saturation extract**

Apparatus:

Pressure extractors, compressor pump, filter paper and test tubes / culture tubes / plastic bottles of 50 ml capacity

Procedure:

Transfer the saturated soil paste to the Buckner funnel with a suitable filter paper placed in the funnel and a test tube / culture tube placed at the outlet of the funnel tied with thread and corked to make it air tight. Initiate for applying pressure through a pressure pump. The extract is collected in the test tube / culture tube. Such extract that contains soluble salts are used for determination of electrical conductivity and chemical analysis of soluble cations such as calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K) and anions such as carbonate, bicarbonate, chloride and sulfate.

IV. **Electrical conductivity of saturation extract (EC_e)**

Electrical conductivity (K) is defined as the reciprocal of the electrical resistivity (specific resistance). The resistivity (S) is the resistance (R) in ohms of a conductor whose length (l) is 1 cm and cross sectional area (a) is 1 cm^2. Hence, electrical conductivity is expressed in reciprocal of ohms per cm or mhos per cm. The term electrical conductivity and specific electrical conductance have the identical meaning.

$S = (R.a)/l$, $K=1/S = l/(R.a)=cm/(ohm\ cm^2) = ohm^{-1}cm^{-1}$

The factor l/a is known as cell constant. Following are the apparatus and chemicals required for the analysis:

- *Conductivity bridge*
- Reagents: Standard potassium chloride solution, 0.02 N KCl. Dissolve 1.4912 g of KCl in water and make the volume 1-liter. It has an electrical conductivity 2.768 mmhos cm^{-1} or dSm^{-1} at 25^oC.

Procedure:

(a) Determination of cell constant: Rinse and fill the conductivity cell with standard 0.02 N KCl solutions. The cell constant (K) of a conductance cell is determined by measurement of electrical conductance (C) of standard KCl solution and use the equation:

$K = L/C$ where

L = known specific electrical conductance in mmhos/cm of standard solution usually 0.02 N KCl.
C = measured conductance of the standard solution in mmhos or deci Simens

(b) Determination of conductivity of saturation extract: Rinse and fill the cell with the test solution to be measured and its conductance is recorded. The specific conductance (dS/m) is calculated by using the equation

$L = KC$.

The Temperature of the solution is taken into account in the calculation of the result. The electrical conductance of solution increases approximately 2% per degree C. Electrical conductivity calculated at temperature (t) is corrected by multiplying it with temperature factor (ft).

$L_{25} = Lt \times ft$

The values of ft are given in annexure I. For example to convert values measured at 20°C to the values at 25°C, multiply by a factor of 1.112. For intermediate temperatures, linear relations may be used between the two values.

The relations between conductivity, total salt and osmotic pressure is given below:

Total cations (or anions), meq/l = 10 x EC dS/m
2. Total salt concentration, mg/l = 640 x EC dS/m
Osmotic pressure, atmosphere at 25^{o}C = 0.36 x EC dS/m

V. Determination of Exchangeable Sodium Percentage

Principle

Exchangeable sodium is generally determined extracting soil with ammonium acetate method. The ammonium ion replaces sodium from the exchange complex and concentration of sodium is measured with a flame photometer.

$$\text{Clay-Na} + NH_4OAc = \text{Clay-}NH_4 + NaOAc$$

Reagents

1. **Neutral ammonium acetate (1N**): Dissolve 77.08 gm of ammonium acetate in 800 ml distilled water and adjust the pH 7 using ammonium hydroxide or acetic acid. Make up the volume 1000 ml.
2. **Ethanol: (60%)** Take dehydrated alcohol and dilute it with distilled water to make it 60%.
3. **Standard Sodium solution**: Dissolve 2.4 gm dry sodium chloride in 1 litre distilled water. This will give a stock solution of 40 me / l. Transfer 25 ml of stock solution into a 250 ml volumetric flask, and make up the volume with distilled water. This will give 4 me/l sodium solution. Transfer 0, 5, 10, 15, 20, 25, 50 and 75 ml of this solution to 100 ml volumetric flasks and make the volume with distilled water, iIt will give 0, 0.2, 0.4, 0.6, 0.8, 1, 2 and 3 me /l Na concentration.

Procedure

1. Removal of soluble salts:

Transfer 2-5 gm soils on a moistened filter paper fitted on a funnel and add 33 ml of 60% alcohol with a glass rod gradually on the soil just to moisten it and further pass the alcohol through the soil column with another two installments of 33 ml of alcohol till the soil is free from soluble salts. Check the ECe of the extract till it reaches to 40 micromhos per cm or less. Discard the leachate.

2. Extraction of exchangeable sodium:

After removal of free salts add 33 ml of ammonium acetate solution and collect the leachate in 100 ml volumetric flask. When the leaching is complete, add another 33 ml of the same solution to it and continue till 100 ml.

3. Estimation of sodium concentration by flame photometer

The standard solution of sodium was used for preparation of a standard curve for sodium with the flame photometer reading. The unknown concentration of the leachate was determined using sodium concentration in the standard curve

Calculation

$$\text{Exchangeable sodium (me/100gm soil)} = \frac{\text{Na concentration of extract in me /l x 10}}{\text{Weight of soil (gm)}}$$

$$\text{Exchangeable sodium percentage} = \frac{\text{Exchangeable sodium (me/100gm soil) x 100}}{\text{Cation Exchange Capacity (me/100 gm)}}$$

VI. Determination of cation Exchange Capacity

Apparatus:

Funnel, flame photo meter, volumetric flask, filter paper / centrifuge

Reagents:

1. **Neutral ammonium acetate (1N)**
2. **Ethanol: (60%)**
3. **Standard Sodium solution**: As given above.
4. **Sodium Acetate (1N)** Dissolve 136 gm of sodium acetate trihydrate in distilled water and dilute to a volume of 1 litre (adjust the pH 8.2 using dilute NaOH or CH_3COOH)

Procedure

Take 5 gm of soil in a 100 ml beaker and add 33 ml of sodium acetate and allow sufficient time to complete the reaction (preferably overnight). Transfer the soil on to the funnel fitted with a moist Whatman No. 42 filter paper. Add 33 ml of the NaOAc more on the filter paper and leach it through the soil. Repeat this process with 33 ml of NaOAc again to complete the leaching and discard the leachate. Add 30 ml of ethanol to the soil and leach it to remove excess sodium acetate. Continue the leaching till the ECe of the leachate reaches to 45-50 micromhos per centimeter and discard the leachate. Replace the adsorbed sodium on the exchange complex of the soil sample with three 33 ml portions of NH_4OAc solution and collect it in 100 ml volumetric flask. Make the volume of the flask to 100 ml and determine the sodium concentration by the flame photometer.

Alternate Method

Take 5 gm soil and in a 100 ml centrifuge tube and add 33 ml of sodium acetate and shake it for five minutes putting the stopper on the tube. Centrifuge it for 5 min and discard the clear supernatant. Repeat the procedure three times to saturate the exchange complex of the soil with sodium. Add 30 ml ethanol, shake for 5 min, centrifuge it and discard the centrifuged supernatant. Repeat the procedure for three times till the ECe of the supernatant reduced to the desired level. Replace the adsorbed sodium with three 33 ml portions of ammonium acetate solution and collect it in a 100 ml volumetric flask. Make up the volume to 100 ml with ammonium acetate and determine sodium by flame photo meter.

Calculation

$$\text{Cation Exchange Capacity (CEC) [cmol. (p+) /kg]} = \frac{\text{Na (me/l) from standard curve x 10}}{\text{Weight of the sample (5 gm)}}$$

Gypsum Requirement for Alkali Soil

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Alkali soils were characterized by the presence of excess "Exchangeable Sodium Percentage" (ESP) that resulted in high pH, poor physical condition and nutritional imbalances which adversely affects the plant growth. Leaching of excess soluble salts followed by addition of gypsum ($CaSO_4.2H_2O$) is recommended to replace the exchangeable sodium by calcium. Due to its easy availability, safe to handle and relatively low cost, gypsum is preferably used as an amendment for reclamation of alkali soil. Factors like exchangeable sodium percentage (ESP), cation exchange capacity (CEC), depth of soil to be reclaimed, amount of sodium carbonate and bicarbonate and soil texture are considered for finding the gypsum requirement of a soil. In general, calcium in gypsum replaces sodium from the soil exchange complex to form the soluble sodium sulfate (Na_2SO_4) that leached down with flushing water.

(Soil Exchange sites) $2Na^+ + CaSO_4$ = (Soil Exchange sites) $Ca^{++} + Na_2SO_4$

Thus application of gypsum transforms dispersed particles of soil to a favorable flocculating condition and reduces soil pH that further facilitates conversion of nutrients to its available form. Conventionally, gypsum of about 2mm particle (10 mesh) size has been used for the reclamation of alkali soils (Kovda *et a.,l* 1973). Khosla and Abrol (1972) observed maximum reactivity of gypsum at 0.59 mm (30 mesh) particle size, while further decrease in particle size brought about very small increase in reactivity. Gypsum is moderately soluble in water (0.25%) and is therefore a direct source of soluble calcium. Khosla *et al*. (1973) showed higher yield of shallow rooted crops like rice, wheat and barley obtained by mixing gypsum in the upper 10 cm of soil depth. The application of gypsum at shallow depth and lower dose (50%GR) were superior and economical than other treatments. Surface application of gypsum showed increase of the hydraulic conductivity than the mixed application. This in turn, improved physical soil condition and helped in leaching of soluble carbonates and bicarbonates thus increasing the reclamative efficiency of applied gypsum. The effective method of gypsum application should be broadcasting with optimum soil moisture condition followed by mixing it into the soil by shallow cultivation, planking and thereafter application of irrigation water for reaction with the soil particles. The correct time of application is very important for maximum efficiency of applied gypsum. It is recommended that the gypsum may be applied in the month of May or June followed by an irrigation that maintains 5-7 cm standing water for a period of 15 days and this may be followed by transplanting of paddy as the first crop in the end of June or first week of July (Yadav, 1977).

Although gypsum application is recommended worldwide for reclamation of alkali soils, studies carried out by different researchers showed that alternatively, changes in the land uses, use of salt tolerant varieties and organic amendments alone or in combination with gypsum proved efficient in reclamation of alkali soils. Growing rice favours in removal of exchangeable sodium by solubilizing calcium from calcium carbonate as result of increased hydrolysis and CO_2 liberated by plant roots (Chhabra and Abrol, 1977). Further studies showed that integrated use of chemical amendments and FYM, organic residues and green manuring help in increasing the productivity of such soils (Swarup and Yaduvanshi, 2004). The gypsum requirement is commonly determined in the laboratory by Schoonover's method as described by Richards (1954). The methodology is as follows:

Apparatus

1.	Conical Flask	250ml capacity
2.	Burette	50ml
3.	Pipette	5ml

Reagent

1. Gypsum saturated solution- Take 5gm gypsum in 1litre volumetric flask. Shake for an hour in 1000 ml distilled water and filter it.
2. Standard calcium chloride solution, 0.01 (N): Dissolve 0.5 gm of pure calcium carbonate in 10 ml of approximately 3 (N) hydrochloric acid and dilute to a volume of exactly one liter
3. EDTA (Ethylenediamine Tetra Acetic Acid*)*: 0.01 (N) Dissolve 2.00 gm of EDTA and 0.05 gm of magnesium chloride hexahydrate in water and dilute to a volume of one liter. Standardize the solution against standard calcium chloride solution to assess its exact strength.
4. EBT Indicator: Mix 0.5gm EBT with 100g NaCl to prepare the standard Erichrome Black T (EBT) indicator.
5. Buffer Mixture: Mix 67.5gm NH_4Cl with 570ml NH_4OH and make the volume to 1 litre and adjust the pH to 9.5 with NH_4OH

Procedure

Take 5gm soil in a 250ml conical flask and add 100ml gypsum solution to it. The suspension is shaken for half an hour and kept overnight. Filter the mixture. Take 5 ml aliquot (filtrate) in 100ml conical flask and 10 drops of buffer mixture, a few crystal of EBT indicator and titrate with EDTA till the colour changes from red to blue. Titrate a blank using 5ml gypsum solution to determine its Ca concentration.

Calculation

Volume (ml) of EDTA consumed for neutralizing 5 ml of gypsum solution = X ml
Volume (ml) of EDTA consumed for neutralizing 5 ml of filtrate solution = Y ml

$$\text{Mili} - \text{equivalent per liter of Ca in Gypsum} = \frac{\text{X x Strength of EDTA x}1000}{\text{Mililiter of aliquot taken}(5\text{ml})} = \text{S}$$

$$\text{Mili} - \text{equivalent per liter of Ca in filtrate} = \frac{\text{Y x Strength of EDTA x}1000}{\text{Mililiter of aliquot taken}(5\text{ml})} = \text{T}$$

Gypsum requirement (G. R.) (me /100gm) = 2(S-T)

Now, 1 Mili-equivalent of gypsum is 86 mg. One-hectare soil to a depth of 15 cm weigh 2×10^6 kg (approx.). Therefore, the quantity of gypsum required to reclaim one hectare of top (0-15cm) soil is as follows:

G. R. (tons/ha) = G. R. (me/100gm) x 10 x 2 x 10^6 x 86 x 10^{-6} kg
= G. R. (me/100gm) x 1720 kg
= G. R. (me/100gm) x 1.72 tons

Thus, 1720 Kg or 1.72 tons of 100 % gypsum is required for each me / 100 gm removal of sodium from the soil exchange complex for one hectare of land to a depth of 15 cm. This has to be multiplied by the purity factor of gypsum to arrive at the field requirement of the amendment. Normally the purity of agriculture grade gypsum is 70%.

Gypsum Requirement of Residual Sodium Carbonate Water

It is one of the methods to evaluate the sodicity hazards of carbonate and bicarbonate rich waters. The residual sodium carbonate may be calculated by subtracting the quantity of Ca^{++}+Mg^{++} from total of carbonate and bicarbonate determined separately in a given sample and expressed in me L^{-1}. Thus,

RSC = ($CO_3^{=}$ + HCO_3^{-}) – (Ca^{++}+Mg^{++})

Gypsum is used for improving the quality of irrigation water having high RSC or SAR for crop production in the arid and semiarid areas of Haryana and it's adjoining states. Continuous application of high RSC water tends to precipitate Ca and Mg and leads to increase SAR in the soil solution and result in the excessive saturation of sodium in the soil exchange complex. The adverse effect of such water could be eliminated to a considerable extent by treating water with gypsum prior to its application. The quantity of gypsum for neutralisation of 1meq L^{-1} of RSC is 86 kg per 1000m^3 of water (per hectare when the depth of irrigation is 10 cm). The agricultural grade gypsum is usually 70-80% pure. Application of gypsum has earlier been recommended when RSC of irrigation water is more than 2.5 meq L^{-1}. Field trails have shown that gypsum helps in maintaining yields of crops irrigated with sodic waters (RSC More than 5 meq L^{-1}) especially when paddy is taken in rotation and rainfall of the area is less than 50 cm.

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Technologies for Efficient Use of Sodic Water in Sustainable Crop Production

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Introduction

Anticipated global shortage of fresh water supply to agriculture sector in 21st century is likely to increase the utilization of relatively poor quality water for irrigation. Poor quality groundwater occur extensively (32-84%) in arid and semi-arid parts of India and its indiscriminate use poses serious threat to sustainability of natural resources and environment. Water quality researches over past few decades have enabled development of technological options to cope up with the problems of saline and sodic water use. Possibilities have now emerged to safely use the water otherwise designated unfit. These options primarily consist of: i) selection of crops, cropping patterns and crop varieties that produce satisfactory yields under the existing or predicted conditions of sodicity ii) appropriate irrigation scheduling and conjunctive use options with canal water; rain water management and leaching strategies to maintain a high level of soil moisture and low level of salts and exchangeable sodium in the rhizosphere and iii) use of land management practices to increase the uniformity of water distribution, infiltration and salt leaching besides the optimal use of chemical amendments including time and mode of their application with judicious use of organic materials and chemical fertilizers.

Consistent efforts made at different research centers in the country to devise the ways for safe utilization of sodic water in agriculture have resulted in fair understanding of basic principles of soil-water-plant systems. Based on understanding developed for preventing deterioration of soil to levels which limit crop productivity, specialized soil, crop and irrigation management practices are advocated. Some such management measures for controlling the build up of ESP and maintaining the physical and chemical properties of sodic water irrigated soils are discussed below.

Land Levelling and Rain Water Conservation

Proper land levelling and provision of 30-40 cm high bunds for retaining rainwater are essential prerequisites for managing sodic water irrigated land. Surface soil should be protected against beating of raindrops. This can be achieved by ploughing of fields in between rains which increases intake of rainwater and controls unproductive losses of water through weeds and evaporation. These practices also promote uniform salt leaching and self-reclamation through native $CaCO_3$ dissolution.

Crop Selection

The guiding principle for choosing the right kind of crops and cropping patterns suitable for particular sodic water is to select only those crops whose sodicity tolerance limits are lower than the soil sodicity (ESP) expected to build with use of that water. Under average conditions of water use, the expected root zone sodicity can be approximated by $1.5 \times SAR_{iw}$ in fallow- wheat, $2.0 \times SAR_{iw}$ in millet- wheat and $3.0 \times SARi_{w}$ in rice-wheat cropping sequences. Thus, based on the expected ESP to be developed, the suitable crops can be chosen from the list of sodicity tolerant crops given in table 1 & 2. Since use of sodic water requires repeated application of gypsum, it is advisable to select only tolerant and semi tolerant crops and their varieties having low water requirement such as barley, wheat, mustard, oat, pearl-millet and sorghum etc. The choice of promising cultivars can be made from the list given in table 4. The other guidelines pertinent to selecting crops suitable for sodic waters are:

Fields should be kept fallow during kharif in low rainfall areas (< 400 mm) where good quality water is not available. However, only tolerant and semi-tolerant crops like barley, wheat and mustard should be grown during rabi.

Jowar-wheat, guar-wheat, pearl millet-wheat and cotton-wheat rotations can be suceesfully grown in areas having rainfall > 400 mm/annum provided that sowing of kharif crops is done with rain or good quality water and only 2 to 3 sodic water irrigations can be applied to kharif crops. In rice-wheat belt of alluvial plains having rainfall ≥600 mm, rice-wheat, rice-mustard, sorghum-mustard, and dhainacha (GM)-wheat rotations can be sucessfully practiced with gypsum application. Sodic water should not be used for summer crops in the months of April to June.

Use of Amendments

Sodic water can be safely and economically used after treating with calcium carrying amendments like gypsum. Agricultural grade gypsum and acidic pyrite can effectively neutralize RSC of sodic water by adding them either to soil or in water through specially designed gypsum beds. The quantity of gypsum or pyrite to be applied depends on the RSC of water, extent of soil deterioration and water requirement of intended crops and cropping system. However, following guidelines can be of additional help in deciding the need and quantity of amendment required for use situations:

Table 1. Relative tolerance to sodicity of soils

ESP	Crops
10-15	Safflower, Mash, Peas, Lentil, Pigeon-pea, Urd-bean, Banana
16-20	Bengal gram, Soybean, Papaya, Maize, Citrus
20-25	Groundnut, Cowpea, Onion, Pearl-millet, Guava, Bel, Grapes
25-30	Linseed, Garlic, Guar, Palmarosa, Lemon grass, Sorghum, Cotton
30-50	Mustard, Wheat, Sunflower, Ber, Karonda, Phalsa, Vetiver, Sorghum, Berseem
50-60	Barley, Sesbania, Paragrass, Rhoades grass
60-71	Rice, Sugarbeat, Karnal grass

Generally gypsum is not needed on well-drained light textured soils in fallow-wheat rotation, however, application of gypsum @ 25% - 100% GR of water boosts crop yields (Manchanda *et al.* 1985) in double cropping. Yadav *et al.* 1991 reported that addition of gypsum @ 50% GR of a loamy sand soil was sufficient to grow even the sensitive kharif crops like pearl-millet, moongbean, urdbean, cowpea, clusterbean in areas receiving 600 mm rainfall.

In relatively high rainfall regions (> 600 mm), annual gypsum application equivalent to 50% GR of water was sufficient to sustain 8-9 Mg /ha of paddy and wheat yields (Sharma & Minhas 2001) in soils where pHs did not exceed 9.0.

Occasional application of gypsum @ 1-2 tons/ha before rainy season in heavy textured soils is also recommended to offset infiltration problems arising with use of high SAR saline water (SAR>20).

Table 2. ESP tolerance of crops in alkali soils and irrigated with alkali waters

Crop	Soil under reclamation			Alkali water irrigation		
	ESPt*	Slope	ESP75**	ESPt	Slope	ESP75
Cotton	--	--	--	14.9	1.3	34.1
Pearl millet	13.6	2.6	23.2	6.1	1.3	25.3
Rice	24.4	0.9	52.1	20.1	1.6	35.7
Wheat	16.1	2.1	28.0	16.2	1.9	29.4

Threshold ESP, ** ESP for 75 % yield

Method and Time of Gypsum Application in Soil

It is easier to apply gypsum in soil than through water. Required quantity of powdered gypsum should be broadcasted on previously leveled field and mixed with cultivator or disking in shallow depth of 10 cm. The best time for application of gypsum is after harvest of rabi crops, preferably in May or June, if some rains are received. Otherwise, its application should be postponed till the first good monsoon showers are received. Gypsum can be applied in the standing water also. The soil should be subsequently ploughed upon attaining proper soil moisture condition. Gypsum applied after harvest of rabi crops will also help in considerable improvement of the soil prior to the onset of kharif season. Pyrite has also been used for amending the deleterious effects of high RSC waters. Pyrite application once before sowing of wheat is better than its split application with all irrigations or mixing with irrigation water (Chauhan *et al.* 1986).

Gypsum Bed

Another way to reclaim sodic water is passing it through specially designed chamber filled with gypsum clods. The gypsum chamber is a brick-cement-concrete chamber. Size of chamber depends on tube well discharge and RSC of water. This chamber is connected to water fall box on one side and to water channel on the other side. A net of iron bars covered with wire net (2 mm×2 mm) is fitted at a height of 10 cm from the bottom of the bed. Farmers can also convert waterfall chamber of their tube wells into gypsum chamber with little modifications. Sodic water flowing from below dissolves gypsum placed in chamber and reclaims it. RSC of water from tube well discharge of 6 l sec-1 decreased from 5. 5 to 1.9 me l-1 by passing it through a chamber of size 2 .0 $\times$1.5 $\times$1.0 m in this method.

However, this method is not suitable for reclaiming very high RSC water (> 12 me l^{-1}) because the size of the chamber required to fill the huge quantity of gypsum needed to neutralize such high RSC becomes too large. It has also been observed that the gypsum bed water quality improvement technique does not dissolve > 8 me l-1 of Ca. The response of crops to the application of equivalent amounts of gypsum, either by passing the water (RSC 9 me l-1) through gypsum beds where the thickness of bed was maintained at 7 and 15 cm, or the soil application of gypsum is presented in Table 3. Though crops under both the rotations (paddy-wheat, sorghum-mustard) responded to the application of gypsum in either of the methods, overall response of crops was slightly more in case of sodic water which was ameliorated (3-5 me l-1) after passing through gypsum beds. Thus, it seems that gypsum bed technique can help in efficient utilization of gypsum.

Table 3. Average (1993-2003) paddy-wheat and mustard-sorghum yields (Mg/ha) and soil properties* with gypsum applied to soil or passing sodic water through gypsum beds

Treatment	Paddy	Wheat	pH	ESP	Mustard	Sorghum	pH_s	ESP
Control (T1)	3.08	2.68	9.6	66	2.27	1.18	9.5	61
Gypsum through beds								
3.3 meq/l (T2)	3.97	3.73	8.0	19	3.06	1.98	8.0	25
5.2 meq/l (T3)	4.24	3.93	8.0	18	3.18	2.13	8.0	24
Equivalent soil application								
As in T2 (T4)	4.31	3.71	8.2	20	2.86	1.92	8.0	26
As in T3(T5)	4.52	3.89	8.1	20	3.00	2.05	8.1	24
LSD(p=0.05)	0.43	0.46			0.38	0.24		

* At the harvest of rabi (2002-03) crops. (AICRP Saline Water 2002)

Irrigation Management

Conventional practice of basin irrigation should be adopted with emphasis to minimize the quantity of applied alkali irrigation water because deterioration of soil directly depends on it. The 'alkali hazard' is reduced considerably, if this water is used alternatively or mixed with canal water. Besides reducing the gypsum requirement of soil, conjunctive use of alkali and canal water also helps in bringing more area under protective irrigation and also in controlling rise in ground water table and associated problems. Canal water should preferably be applied during initial stages including pre-sowing irrigation to boost establishment of crops. Studies have sown that when sodic water was used in cyclic mode with canal water, yield of both the paddy and wheat crops were maintained equal to that with canal water except in the CW-2SW mode (Table 4).

Nutrient Management

Fertilizer Application

Since sodic water use cause rise in soil pH leading to higher nitrogen losses through volatilization and denitrification, extra nitrogen has to be added to meet the requirement of the crops. Similarly, the availability of zinc and iron also becomes low due to their precipitation as hydroxides and carbonates. Some beneficial tips for fertilizer management with sodic water use are:

- Application of 25% extra nitrogen as compared to the normal conditions.
- Zinc sulphate @ 25 kg ha should be added, particularly to the rabi crop.
- P, K and other limiting nutrients should be applied on soil test basis.
- Sodic water at some sites is rich in nutrients like N, P and S, and the doses of the nutrients should be adjusted accordingly as per their composition in such water.

Table 4. Effect of cyclic use of sodic and canal waters on soil properties and crop yields

Water quality/mode	adj. SAR*	pH	ESP	RIR	Average yield (Mg/ha) Rice	Wheat
Canal water (CW)	0.3	8.2	4	100	6.78	5.43
Sodic water (SW)	22.0	9.7	46	14	4.17	3.08
2 CW-1SW	8.9	8.8	13	72	6.67	5.22
1 CW-1SW	12.8	9.2	18	59	6.30	5.72
1 CW-2SW	18.5	9.3	22	34	5.72	4.85
Water quality	ECw (dS m^{-1})	Ca	Ca+Mg	RSC	SAR	adj SAR
		-----------(meq/l)---------				
CW	0.25	1.6	2.1	nil	0.3	0.4
SW	1.35	0.4	0.9	10.1	13.5	26.7

(Bajwa and Josan (1989), after 828 and 434 cm of irrigation and rainwater, respectively,)

Addition of Organic Materials

Addition of organic materials is observed to improve sodic soils through mobilization of inherent Ca2+ from $CaCO_3$ and other minerals by organic acids and increased pCO2 in soils. Solublized Ca^{2+} replaces Na^{+} from the exchange complex in soil. However, some disagreement on short–term effects of organic matter on dispersion of sodic soil particles in soils undergoing sodication exists in literature (Gupta *et al.* 1984). Nevertheless, majority of the available reports still suggest overall beneficial positive role of organic manures in improving soil properties and crop yields. Response of organic sources also varies with the nature of organic matter added. Sekhon and Bajwa (1993) recorded effectiveness of different organic materials in order of paddy straw > green manure > FYM. Moreover, with mobilization of Ca^{2+} during decomposition of organic materials, the quantity of gypsum required for controlling the harmful effects of sodic water irrigation can be considerably decreased.

Water Quality Guidelines

Based on field experience and results from different saline and sodic water use experiments, CSSRI, Karnal in consultation with Scientist from HAU, Hisar and PAU, Ludhiana has prepared some guidelines for efficient utilization of given poor quality water. These guidelines emphasize on long- term influence of water quality on crop production, soil conditions and farm management with assumption that all rainwater received in field is being conserved for leaching and desalinizing upper root zone.

Table 5. Sodic (alkali) water with RSC > 2.5 meq L-1 and ECiw < 4.0 dSm^{-1}

Soil texture (% clay)	Upper limits of SAR $(m\ mol\ L^{-1})^{1/2}$	RSC meq L^{-1}	Remarks
Fine (>30)	10	2.5-3.5	Limits pertain to kharif fallow – rabi crop rotation when annual rainfall is 350 –550 mm
Moderately fine (20-30)	10	3.5-5.0	When water has Na < 75%, Ca+Mg >25% or rainfall > 550mm, the upper limit of RSC becomes safe
Moderately coarse (10-20)	15	5.0-7.5	For double cropping, RSC neutralization with gypsum is essential based on quantity of water used during rabi season. Grow low water requiring crops during kharif.
Coarse (<10)	20	7.5-10.0	

Special Considerations

- Gypsum application is necessary for sensitive crops if saline water (SAR > 20 and / or Mg:Ca ratio > 3 and rich in silica) induces water stagnation in rainy season.
- Fallowing in rainy season under high salinity, SAR > 20 water use conditions is helpful for low rainfall areas.
- Fertilization with additional phosphorus is beneficial especially when C1:SO_4 ratio in waters is > 2.0.
- Canal water should be used preferably at early growth stages including pre sowing irrigation in conjunctive use mode.

- Putting 20% extra seed rate and a quick post-sowing irrigation (within 2-3 days) will help in better germination.
- Saline water irrigation just before onset of monsoon lowers soil salinity and raises antecedent soil moisture to leach more salt with rains when ECiw < ECe of 0-45 cm soil at harvest of rabi crops.
- Use of organic materials in saline environment improves crop yields.
- Accumulation of B, F, NO_3, Fe, Si, Se and heavy metals beyond critical limits with irrigation is toxic. Expert advice prior to use of such water is essential.
- For soils having (i) shallow water table (within 1.5 m in kharif) and (ii) hard sub-soil layers, the next lower ECiw/alternate mode of irrigation (canal/saline) is applicable.
- Textural criteria should be applicable for all soil layers down to at least 1.5 m depth. In areas where ground water table reaches within 1.5 m at any time of the year or a hard subsoil layer is present in the root zone, the limits of the next finer textural class should be used.

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Technologies for Efficient Use of Saline Water for Sustainable Crop Production

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Introduction

Availability of fresh water supplies to agriculture sector in future is likely to reduce world over and particularly in the Asian countries due to population pressure, improved living standards and inter-sector competition. The estimates for India show that reduction could be 10 to 12 % by 2025. In the back drop of this grim scenario, agriculture sector will be left with no alternative than to use poor quality water for its irrigation requirement. The ground water surveys in India indicate that different states use poor quality water in the range of 32 to 84% of the total ground water development. Many more areas with good quality acquifers are endangered with contamination as a consequence of excessive withdrawl of ground water. Groundwater of arid regions is largely saline and in semi-arid regions it is sodic in nature.

Indiscriminate use of poor quality water for irrigation deteriorates productivity of soils through salinity, sodicity and toxic effects. In addition to reduced productivity, it deteriorates the quality of produce and also limits the choice of cultivable crops. Nevertheless, concerted efforts at AICRP-Saline Water and other centers in different agro-climatic zones of the country have resulted in valuable concepts and viable technologies for the sustainable irrigation with poor quality water (Minhas, 1996). Possibilities have emerged for sustaining irrigation with water otherwise designated unfit, by selection of appropriate crops, improved water management and maintenance of soil structure/permeability. Technological and policy options for alleviating brackish water hazards and maximizing productivity are outlined here.

Classification of Irrigation Water

Irrigation water is classified based on electrical conductivity (EC), sodium adsorption ration (SAR) and residual sodium carbonate (RSC). However, from management point of view, the groundwater in different agro-ecological regions can be grouped into three classes i.e. (a) good, (b) saline and (c) alkali/sodic. Depending on the degree of restriction, each of the two poor quality water classes has been further grouped into three homogenous subgroups (Table-1).

Table1. Classification of poor quality ground water

Water Quality	ECiw (dS m^{-1})	SARiw (mmol-1)½	RSC (meq l-1)
a. Good	<2	<10	<2.5
b. Saline			
i. Marginally saline	2-4	< 10	<2.5
ii. Saline	> 4	< 10	<2.5
iii.High-SAR saline	> 4	> 10	< 2.5
c. Alkali waters			
i. Marginal alkali	<4	<10	2.5-4.0
ii. Alkali	<4	<10	>4.0
iii. Highly alkali	variable	>10	>4.0

Poor Quality Groundwater Resources

No systematic attempts have been made so far in the country to arrive at the estimate of poor quality ground water resources. However, some predictions about use of poor quality water in various states are given in Table 2. The CGWB (1990) approximated that the total area underlain with the saline ground water (EC>4 dS m^{-1}) is 193438 km^2 with the annual replenishable recharge of 11765 million m^3 Yr^{-1}, leaving aside minor patches.

Management Technologies for Saline Water Use

It has been established that the success with poor quality water irrigation can only be achieved if factors such as rainfall, climate, water table, and water quality, soils and crops are integrated with appropriate crop and irrigation management practices. The available management options mainly include the irrigation, crop, chemical and other cultural practices but there seems to be no single management measure to control salinity and sodicity of irrigated soil, but several practices interact and should be considered in an integrated manner. Some of management options have been described as under.

Crops Management

Semi-tolerant to tolerant crops like mustards, wheat, cotton etc. as well as those with low water requirement are recommended for cultivation with saline water use, while crops like rice, sugarcane and berseem, which require liberal water use, should be avoided. Mono–cropping is recommended for maintaining salt balances in low rainfall (<40 cm) areas. Salt tolerance limits of cereals, oil seeds, vegetables, and pulses developed for different ecological regions of India are available in Table 3. Following are some of the specific recommendations related to crop selection and management.

Table 2. Use of Poor quality groundwater (M ha-m Yr^{-1}) in states of India (Minhas *et al.*, 2004)

State	utilizable groundwater	Net draft	Groundwater (%) development	Poor quality water use	Km2 Saline >4dS m^{-1} groundwater area
Punjab	1.47	1.67	98	0.68	3058
Haryana	0.86	0.72	76	0.47	11438
U. P.	6.31	2.98	42	1.42	1362
Rajasthan	0.95	0.77	73	0.65	141036
Bihar	2.06	0.82	36	NA	NA
W. Bengal	1.77	0.63	32	NA	NA
Delhi	0.01	0.01	120	NA	140
Gujarat	1.56	0.85	49	0.26	24300
Karnataka	1.24	0.45	33	0.17	8804
Tamilnadu	2.02	1.40	63	NA	3300
M. P.	2.66	0.73	25	0.20	NA
Mharashtra	2.29	0.88	35	NA	NA
A. P.	2.70	0.78	26	0.25	NA
India	32.63	13.50	37		193438

Growth Stages

Germination and early seedling establishment are the most critical stages followed by the phase changes from vegetative to reproductive i.e. heading and flowering to fruit setting. So, irrigation with saline water should be avoided during initial growth stages.

Crop Cultivars

In addition to inter-generic variations, crop cultivars also vary in their tolerance to salinity. Such cultivars (Table 3) have been identified on their rating for high yield potential, salt tolerance and stability under saline environments.

Table 3. Promising Cultivars for saline and alkaline environments

Crop	Saline environment	Alkali environment
Wheat	Raj 2325, Raj 2560, Raj 3077, WH 157	KRL1-4, KRL19, Raj 3077, HI1077
P. millet	MH269, 331, 427, HHB-60	MH 269, 280, 427, HHB 392
Mustard	CS416,CS330,-1, Pusa Bold	CS15, CS52, Varuna, DIRA 336, CS 54
Cotton	DHY 286, CPD 404, G 17060, GA, JK276-10-5, GDH 9	HY6, Sarvottam, LRA 5166
Safflower	HUS 305, A-1, Bhima	Manjira, APRR3, A300
Sorghum	SPV-475, 881, 678, 669, CSH 11	SPV 475, 1010, CSH 1, 11, 14
Barley	Ratna, RL345, RD103, 137, K169	DL4, 106, 120, DHS 12

Cropping Sequences

The recommended cropping sequences for saline soils are pearl millet - barley pearl millet - wheat, pearl millet - mustard, sorghum - wheat or barley, sorghum - mustard, cluster bean - wheat or barley and cotton - wheat or barley. The pearl millet - wheat, pearl millet - barley, pearl millet - mustard, sorghum (fodder) - wheat and sorghum (fodder) - mustard cropping sequences are more remunerative in saline soils. Cotton based cropping sequences are not beneficial because the yield of winter crops that follow cotton are usually low. In saline areas, mustard could replace wheat in the cropping sequence since its water requirement is low compared to wheat.

Ionic Compositions Effects

Chlorides, being more toxic tend to reduce saline water tolerance limits of crops by 1.2 – 1.5 times as compared to sulphate rich waters (Manchanda, 1998). Similarly, more salts tend to accumulate in soils when irrigated with high SAR water and thus tend to reduce the limits of saline water use.

Tree Species

In conditions where crop production with saline water use is neither feasible nor economical, there such water can be used to raise tree species especially on lands those are already degraded. The preferred choice of species should *be Azadirachta indica, Acacia nilotica, A. tortilis, A. farnesiana, Cassia siamea, Eucaluyptus teretecornis, Feronia limonia, Prosopis juliflora, P. cineraria, Pithecellobium dulce, Salvadora persica, S. oleoides, Tamarix* etc.

Table 4. Salinity limits of irrigation waters for agricultural crops

Crops	Soil Texture	Pervious crop	ECiw (dS.m) for Yield (%)	
			90	75
Wheat	Silty clay loam	Sorghum	3.4	7.0
	Sandy loam	Bajra	6.6	10.4
	Loamy sand	Fallow	8.3	11.7
Barley	Sandy loam	Fallow	7.2	11.3
Rice	Silty clay loam	Rice	2.2	3.9
Maize	Slay loam	Wheat	2.2	4.7
Pearl-millet	Sandy loam	Wheat	5.4	9.0
Italian-millet	Sand	Sunflower	2.4	4.6
Sorghum	Sandy loam	Mustard	7.0	11.2
Sorghum Fodder	Sandy loam	Berseem	5.2	10.2
Mustard	Sandy loam	Sorghum	6.6	8.8
Safflower	Silty clay loam	Maize	3.3	6.8
Sunflower	Sandy loam	Mustard	3.5	7.2
Groundnut	Sand	Italian-millet	1.8	3.1
Soyabean	Silty clay loam	Mustard	2.0	3.1
Pigeon Pea	Sandy loam	Onion	1.3	2.3
Clusterbean	Sandy loam	Variable	3.2	4.5
Cowpea	Loamy sand	Variable	8.2	13.1
Berseem	Sandy loam	Sorghum	2.5	3.2
Onion	Sandy loam	Pigeonpea	1.8	2.3
Potato	Sandy loam	Okra	2.1	4.3
Tomato	Sand	Variable	2.4	4.1
Okra	Sandy loam	Potato	2.7	5.6
Chillies	Sand	Variable	1.8	2.9
Brinjal	Sand	Variable	2.3	4.1
Fenugreek	Sandy loam	Potato	3.1	4.8
Bitter gourd	Sand	Variable	2.0	3.4
Bottle gourd	Sand	Variable	3.2	4.5

Medicinal Plants

Some medicinal plants like Isabgol (Plantag ovata), Aloe and Kalmeg have also been found promising alternative to arable crops under saline irrigation conditions.

Irrigation and Leaching Management

Salt accumulate gradually in the root-zone of plants with each saline irrigation and ultimately reach detrimental levels causing reduction in crop yields if leaching does not take place. However, proper irrigation and leaching practices can prevent excessive accumulation of salts in the root zone. The following practices can be helpful. Arid areas need 15 to 20 percent more irrigation water for leaching of salts. Frequent light irrigations of saline water to maximize the benefits should aim to minimize the total water applied. Conventional irrigation practices with no extra leaching are usually sufficient for monsoon type climate areas receiving > 400 mm rainfall. Heavy pre-sowing saline water irrigation should be applied in sub-normal rainfall years so as to leach the salts accumulated during rabi season.

Micro-irrigation systems like drip and sprinkler hold promise for enhancing saline water use efficiency especially in high value crops because of their better control on salt and water distributions (Table-5). Pre-emergence sprinkler irrigation of saline water results in better establishment of crops because of low concentration of soluble salts in seedbed during germination. Some of the indigenous alternatives to drips on micro scale are the use of pitchers and specially designed earthen pots but their large scale feasibility remains untested. During rabi season sub surface drainage system can be used to reduce the irrigation requirement by inducing crop water use from shallow water-table through controlled drainage in rabi crops in saline water-logged soils.

Suitable Options for Conjunctive Use of Saline and Canal Water Should be Exploited

- First option is blending two supplies in such proportions that the salinity attained after mixing is within the permissible limits of crop tolerance. Mixing of canal and tube well supplies also helps in increasing the stream size and thereby application uniformity of irrigation especially in sandy soils.
- On demand separate application of two quality water can be done practiced in different fields, seasons or crop growth stages so that higher salinity water is avoided at sensitive growth stages/crops.
- Better quality water should be used for pre-sowing irrigation and at early crop growth stages as germination and seedling stages are most sensitive. Thereafter a switch over to poor quality water can be made when crops can tolerate higher salinity.
- In the seasonal cyclic use, fresh water is used for sensitive crops/initial stages of tolerant crops to leach the salts accumulated due to saline irrigation to previously grown tolerant crops. Cyclic uses i.e. irrigating with waters of different qualities separately offers both operational and performance advantages over mixing.
- Improved "Dorouv" system with specially designed sub-surface water harvesting system can irrigate up to 3-5 ha by skimming of fresh water floating over seawater in coastal sandy soils (Raghu Babu, 1999).

Nutrient Management

Fertilizers

Additional doses of nitrogenous fertilizers are recommended to compensate for volatilization losses occurring under saline environments Soils irrigated with chloride rich waters respond to higher phosphate application, because the chloride ions reduce availability of soil phosphorus to plants. The requirement of the crop for phosphoric fertilizers is, therefore, enhanced and nearly 50 per cent more phosphorus than the recommended dose under normal conditions should be added, provided the soil tests low in available P. For sulphate rich waters, no additional application of phosphate fertilizers is required and the dose recommended under normal conditions may be applied. For micro-nutrients such as zinc, the recommended doses based on soil test values should be applied.

Farmyard manure (FYM): FYM and other organic materials have not only the nutritive value, but play an important role in structural improvements, which further influences leaching of salts and reduce their accumulation in the root zone. The other advantages of these materials in saline water irrigated soils are in terms of reducing the volatilization losses and enhancing nitrogen-use efficiency and the retention of nutrients in organic forms for longer periods also guards against their leaching and other losses. Therefore, the addition of FYM and other organic/green manure should be made to the maximum possible extent.

Table 5. Yield and water use efficiency under different irrigation methods

Crop	Average yield (Mg ha^{-1}) for irrigation method			
	Surface method		Sprinkler method	
	CW	SW	CW	SW
Wheat (1976-79)	4.00 (97)	3.62 (83)	3.69 (107)	3.54 (97)
Barley(1980-82)	3.51 (147)	2.32 (98)	3.48 (159)	2.59 (117)
Cotton(1980-82)	2.30	1.71	2.28	1.34
Peal millet (1976-78)	2.38	2.07	2.54	1.50
	Drip Method			
	Surface	Subsurface	Furrow	
Raddish (ECw 6.5 dS m^{-1})	15.7 (17.5)	23.6 (26.2)	9.9 (8.7)	
Potato (4 dS m^{-1})	30.5 (93.5)	20.8 (78.5)	19.2 (53.6)	
Tomato (10 dS m^{-1})	59.4	43.9		
Tomato (4 dS m^{-1})	42.6	36.9		
(8 dS m^{-1})	28.0	24.5		

* Figure in parenthesis denote water use efficiency (Kg/ha-cm). Source: AICRP (2002)

Cultural Practices

Owing to reduced germination, there is often a poor crop stand in fields irrigated with saline water. Thus to ensure better populations following measures are suggested. Reduce inter/intra row spaces and use 20-30% extra seed than under normal conditions. Dry seeding and keeping the surface soil moist through sprinkler/ post-sowing saline irrigation helps in better establishment of crops. Modifications in seedbed e.g. sowing near the bottom of the furrows on both sides of the ridges and applying irrigation in alternate row and to seed on the north-east side of the ridges, is recommended. For the larger seeded crops, the seeds can be planted in the furrows.

The furrow irrigation and bed planting system (FIRB) has been found better than conventional planting in cotton /pearl millet –wheat rotations. Adoption of measures for better intake of rainwater (tillage to open up soil) and its conservation in soil via checking unproductive evaporation losses (soil/straw mulching) is recommended during monsoon season

Table 6. Guidelines for using saline irrigation water (RSC < 2.5 meq/l)

Soil texture (% clay)	Crop tolerance	Upper limits of ECiw (dS/m) in rainfall regions		
		350	350-550	550-750 mm
Fine (> 30)	S	1.0	1.0	1.5
	ST	1.5	2.0	3.0
	T	2.0	3.0	4.5
Moderately Fine (20-30)	S	1.5	2.0	2.5
	ST	2.0	3.0	4.5
	T	4.0	6.0	8.0
Moderately Coarse (10-20)	S	2.0	2.5	3.0
	ST	4.0	6.0	8.0
	T	6.0	8.0	10.0
Coarse (< 10)	S	- -	3.0	3.0
	ST	6.0	7.5	9.0
	T	8.0	10.0	12.5

S, ST and T denote sensitive, semi-tolerant and tolerant crops.

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Remote Sensing and GIS for Delineation and Characterization of Poor Quality Waters

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Introduction

Irrigation water is extracted from various sources such as river, spring, canal and tank, and groundwater for boosting agricultural production to feed the burgeoning population of the country. The chemical quality of irrigation water, therefore, differs from one source to other. River, spring, canal and tank waters are usually of good quality except in some cases, these are saline or alkali whereas groundwater over the major portion of the country is generally of good quality except it is alkali, saline or saline-alkali of various degrees in arid and semi-arid regions. Groundwater has been a major source of irrigation and drinking water and occurs in unconfined and confined aquifers in different physiographical regions. EC, SAR, RSC and specific ions of groundwater indicate its suitability for irrigation and drinking purposes. Poor quality waters having EC >4.0, SAR>10 or RSC>2.5 exist extensively in the arid and semi-arid regions to the extent of 32-84% of total groundwater development. Information on extent and distribution of poor quality groundwaters in the country is essential for developing management strategies for their utilization for irrigation to meet the shortage of good quality water.

Groundwater exploration by traditional method of drilling has low success rate and after successful drilling, borewells/tubewells have dried up in a short period of time. Of late, remote sensing and geographical information system (GIS) techniques are being applied to groundwater resource mapping and management. Exploration procedures can ideally adopt remote sensing and GIS as the first step to be followed by field geological studies, geophysical prospecting and test drilling. This helps in focusing the field efforts in areas where greater potential of groundwater exists and in eliminating non-potential zones, thus reducing the cost and time involved in exploration procedures. Remote sensing and GIS techniques for groundwater exploration at district scale are quick and inexpensive technique for getting information on the occurrence of groundwater and for selecting promising areas for further groundwater exploration thus reducing field work and provides information on prospects in a single map. This type of information is very helpful in the areas where more emphasis is on groundwater development for the irrigation and drinking purposes. Inclusion of subsurface information inferred from geoelectrical survey through GIS can give more realistic picture of groundwater potentiality and quality of an area. This lecture attempts to describe poor quality waters and to delineate and characterize zones of poor quality groundwater in the country using integrated approach of remote sensing, geoelectrical and GIS techniques.

Water Quality of Different Sources

Water quality parameters such as pH, EC, Ca, Mg, Na, K, CO_3, HCO_3, SO_4, Cl and specific ions are determined using standard methods and procedures (APHA, 2005). Four hazards such as salinity, sodicity, alkalinity and specific ion toxicity hazard (fluoride, nitrate and boron) for irrigation and public health are determined from water quality parameters. Salinity hazard on the basis of total concentration of soluble salts is the single most important criteria used for determining quality of irrigation water. It is measured in terms of electrical conductivity (EC) in deciSiemen per metre (dS/m). Water which may be suitable for irrigation on the basis of EC may not be suitable if the concentration of sodium is high and leads to sodicity hazard to soil. Sodicity hazard is measured in terms of SAR (sodium adsorption ratio) of the water using equation 1. Alkalinity hazard to soils is expected when irrigation water containing sum of bicarbonate and carbonate higher than the sum of calcium and magnesium ions. It is measured in terms of RSC (residual sodium carbonate) using equation 2. It leads to development of alkali soils upon long-term irrigation. Specific ion toxicity hazard is assessed for individual ion and is considered for fluoride, nitrate and boron ions of interest to agriculture and public health.

$$SAR = \frac{Na}{\sqrt{\frac{(Ca + Mg)}{2}}} \quad \ldots (1)$$

and $$RSC = (HCO_3 + CO_3) - (Ca + Mg) \quad \ldots (2)$$

Where, ions in the equations are expressed as milli equivalent per litre (me/l).

Rainwater is the purest form of water having lowest salt content. Generally, the quality of rainwater varies widely and is dependent on the distance from the sea. Most of the river and spring waters in the country under natural conditions contain bicarbonate and sulphate, and calcium and sodium as the predominant cations and anions, respectively. These ions tend to precipitate on evaporation in the quantities of one third to one half of the total salts as calcium carbonate. This, however, leads to decrease in actual salinity, but causes alkalization in due course of time. In north Indian rivers, calcium, magnesium and bicarbonate are dominant ions whereas in south Indian rivers, sodium dominates over calcium and magnesium ions. EC and RSC values of south Indian river waters along with Yamuna river water are relatively higher. The waters from the Tungbhadra and Cauvery rivers in Tamil Nadu are relatively more alkaline and contain RSC up to 2 meq/l. Similar is the case with waters of the rivers draining in the Rann of Kuchchh. The water quality may further deteriorate on course due to pollution from the industrial and sewage waters. Canal waters originating from the rivers or their reservoirs represent the quality of parent rivers unless contaminated on course. Therefore, canal waters are usually as good as river waters. Canal waters in Uttar Pradesh and Haryana have low EC (< 0.5 dS/m) and are free from SAR, RSC or toxic elements whereas canal waters in Rajasthan are of good quality with pH, EC, SAR and RSC as 7.8, 0.4, 6.0 and 1.36, respectively. On conversely, EC of canal waters in the Sunderban area of West Bengal varies from 17 to 26 dS/m and is not suitable for irrigation. However, this is due to the proximity to the sea coast. Tanks form an important source of irrigation in rainfed agriculture in southern India particularly and their quality is variable. Some tanks contain good quality waters which are suitable for irrigation whereas others contain saline or alkaline waters. The quality of inland lake waters varies from most good to most saline.

Groundwater occurs in regionally extensive aquifers constituting over 97% of earth's good quality water. According to an estimate by CGWB, only 58% of available ground water resources in the country have so far been developed, being highest of 109% in Haryana. The salt content of groundwater depends on the source of water and path/course over which it travelled. Mineralization of groundwater is governed by laws of dissolution. Changes in the salt content in the recharge process result from reduction in base exchange medium, transpiration, evaporation, and precipitation. While groundwater is flowing, soil and rocks act as ion exchange and cations in the water reach equilibrium with the soil cations. General salt content increases due to evapotranspiration or dissolution and is mostly affected by the climate. While deep groundwater does not have seasonal fluctuation of salt content, the salt content of shallow groundwater changes as a function of evaporation, rainfall, drainage and irrigation practices. The groundwater over major portion of the country is of good quality. The marginal and poor quality groundwater constitutes a greater part in the states of arid and semi arid regions of the country. Estimate of groundwater in the states of Rajasthan, Haryana and Uttar Pradesh reveals that 25 to 84% waters are of marginal or poor quality. Moderate to high salinity groundwater also occurs in the northern Karnataka, eastern Andhra Pradesh, and northern and central parts of Tamil Nadu. Some groundwater could be more saline than the sea water.

Classification of Groundwater for Irrigation

Classification criteria for assessing the suitability of irrigation water must include those chemical characteristics of waters which affect soils and crop yield and quality upon their long term use. Several criteria have been devised on the basis on single parameter such as EC, SAR or RSC; two parameters such as EC and SAR, and SAR and RSC. USSL diagram, Rhoades diagram and FAO guidelines are based on both EC and SAR whereas adjusted SAR parameter is based on both SAR and RSC. Water quality is further grouped into three major classes such as good, marginal and poor quality on the basis of EC, SAR and RSC and the guidelines for suitability of irrigation are developed (Table 1).

Table 1. Classification of groundwater for irrigation

S No	Water quality class	EC (dS/m)	SAR $(m\ mol/l)^{1/2}$	RSC (me/l)
1.	**Good**	< 2	< 10	< 2.5
2.	**Marginal**			
	• Marginally saline	2-4	< 10	< 2.5
	• Marginally alkali	< 4	< 10	2.5- 4.0
3.	**Poor**			
	• Saline	> 4	< 10	< 2.5
	• High SAR saline	>4	> 10	< 2.5
	• Alkali	< 4	< 10	> 4.0
	• Highly alkali	Variable	> 10	> 4.0

Traditional and Remote Sensing Approaches

Traditional approach of collection of groundwater information by drilling is time consuming and expensive. It provides reliable and accurate first hand information on water quality and depth. Remote sensing can be exploited to provide timely information but it needs some form of ground truth data as a check to make it reliable. Satellite remote sensing with limited field work has been successfully used for groundwater mapping at a variety of spatial and temporal scales. It is a cost effective alternative and major source of timely and reliable information, because of repeated observations in relatively short period, and synoptic and multispectral coverage. Multispectral classification techniques for ground surface feature mapping have been proved to be promising as a key spatial input data to several groundwater studies.

Remote Sensing refers to the technology of acquiring information about the earth's surface using electromagnetic radiation as a medium of interaction from sensors onboard airborne or spaceborne platforms. Remote sensing employs passive or active sensors. Passive sensors sense natural radiations either reflected or emitted from the earth features whereas active sensors emit their own electromagnetic radiation. Remote sensing can be broadly classified as optical, microwave and hyperspectral. In optical remote sensing, sensors detect solar radiation in the visible, near-, middle- and thermal-infrared wavelength regions, reflected/scattered or emitted from the earth features, forming images resembling photographs taken by a camera/ sensor located high up in space. Different land use and land cover features, such as water, soil, vegetation, river and rocks reflect visible and infrared light in different ways. Interpretation of optical images requires the knowledge of the spectral reflectance patterns of various materials (natural or man-made) covering the surface of the earth. In case of green vegetation, there is low reflectance in the blue and red region and relatively high reflectance in green and a marked increase of leaf reflectance in the near infrared region. In the visible and near infrared regions, soil reflectance shows a generally increasing trend with wavelength. Water absorbs most of the radiation in the near IR and middle IR regions.

Microwave remote sensing is highly useful as it provides observation of the earth's surface, regardless of day/night and atmospheric conditions. Microwaves have electromagnetic frequencies between10^9 and 10^{12} Hz. Radar is an active microwave remote sensing system. Radar illuminates the terrain with electromagnetic energy, detects the scattered energy returning from the terrain (called radar return) and then records it as an image. Intensity of radar return, for both aircraft and satellite-based systems, depends upon radar system properties and terrain properties. Hyperspectral remote sensing deals with imaging at narrow spectral bands over a contiguous spectral range and produces spectra of all pixels in a scene. Hyperspectral signature can detect the individual absorption features, since all the materials are bound by chemical bonds, thus they can be identified by their spectral characteristics more accurately as compared to broadband multi-spectral imagers. Hence, hyperspectral data is being used to detect the subtle changes in water, soil, vegetation and mineral reflectance.GIS helps in the integrating remotely sensed derived data with ancillary data to have more precise and correct information in the groundwater prospecting.

Integrated Approach of Groundwater Resource Mapping

Field data on groundwater quality are generally collected by traditional method of drilling with a sampling scheme. Area estimates of various water qualities by traditional survey are unbiased but suffer from high sampling errors due to small number of samples. Area estimates by satellite image classification have no sampling errors but usually suffer from biased (misclassification). These two techniques complement each other and are, therefore, combined to obtain improved estimates, which are more accurate than either of the two approaches to be used (Fig. 1).

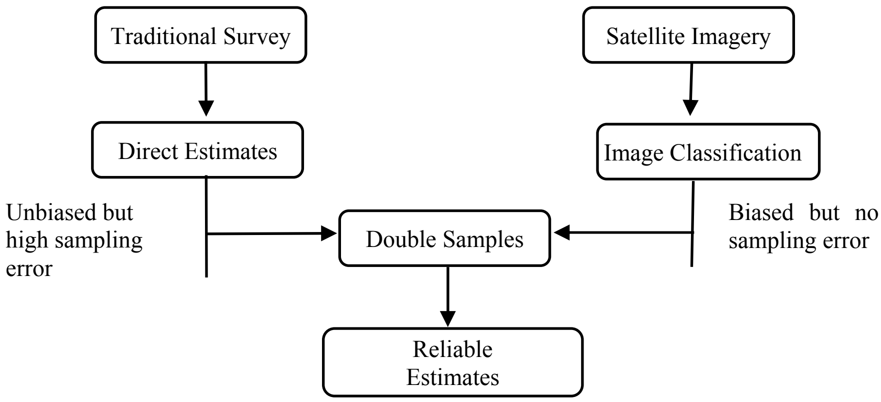

Fig. 1. Integrated methodology of groundwater prospecting and quality survey

Spaceborne Sensors

Data from spaceborne sensors are globally available for an area of interest at a specific time while data from airborne sensors are not available globally though they have better resolution and geometric accuracy. Various spaceborne sensors have been launched in the country and the world under various remote sensing missions. Multispectral data can be selected and obtained for an application on the basis of spatial resolution and swath of a satellite sensor (Table 2).

Multispectral data from LISS-III & IV cameras are widely used for generating thematic maps for groundwater studies in the country. These are multispectral high resolution cameras with spatial resolution of 23.5 m and 5.8 m at nadir. The LISS-IV sensor consists of three linear odd-even pairs of charge coupled detector (CCD) arrays, each with 12000 pixels. The odd and even pixel rows are separated by 35 microns, which correspond to five scan lines. Also the placement of the three CCDs in the focal plane is such that their imaging strips on the ground are separated by 14.25 km in the along-track direction. The camera can be operated in two modes: Panchromatic and multispectral. In the multi-spectral mode, data are collected in three spectral bands: 0.52 to 0.59 micron metres (green); 0.62 to 0.68 micron metres (red) and 0.76 to 0.86 micron metres (near infrared). These bands can be used for various principal applications (Table 3).

Table 2. Spatial resolution and swath of various satellite borne sensors

Sensor	Satellite	Resolution (m)	Swath (km)
Indian space borne sensors			
PAN Stereo	Cartosat-1 & 2	0.8 & 2.5	9.6 & 30.0
PAN	IRS-1C & 1D	5.8	70.0
LISS-IV (Multispectral)	Resourcesat-1 (IRS P6)	5.8	23.9
LISS-IV(Mono)	Resourcesat-1 (IRS-P6)	5.8	70.0
LISS-III	IRS-1C, IRS-1D, IRS-P6	23.5	141.0
LISS-II	IRS-1A & 1B	36.3	148.0
International space borne sensors			
Pan & Multispectral	IKONOS	0.82 & 2.5	16.0
Pan & Multispectral	Quickbird	0.61 & 2.5	16.0
High Resolution Visible	SPOT-5	2.5, 5.5, 10	60.0
Pan & Multispectral	GeoEye-1	0.41 & 1.65	15.2

(Note: PAN stands for Panchromatic; LISS: Linear imaging self scanning sensor)

In the multispectral mode, the sensor provides data corresponding to pre-selected 4096 contiguous pixels, corresponding to 23.9 km swath. In panchromatic (mono) mode, the data of full 12,000 pixels of any one selected band, corresponding to a swath of 70 km, can be transmitted. Nominally, red band data are preferred in this mode. The LISS-IV camera has the additional feature of off-nadir viewing capability by tilting the camera by +/- 26 degrees for revisiting and obtaining a stereo pairs. This way, it can provide a revisit of 5 days for any given ground area.

Table 3. Principal applications of the LISS spectral bands

Band	Wavelength (μm)	Principal applications
Pan	0.51-0.73	Fine geometrical detail mapping, cadastral and cartographic mapping, waterbody identification, DEM generation
Green	0.52-.59	Cultural feature identification iron content in rocks and soils, vegetation discrimination, vigour assessment,
Red	0.62-.68	Cultural feature identification, plant species differentiation,
Infra red	0.76-.86	Water body delineation, soil moisture discrimination, vegetation type discrimination & vigour assessment

Table 4. Data Formats and Products

No	Product type	Level of correction	Area covered (km x km)	No of bands	Output product
1	Scene based	Standard/ georeferenced	23 x 23	3 Mx	Digital/photographic
			70 x 70	Mono	Digital/photographic
2	Mapsheet based	Geocoded	7.5' x 7.5'	3Mx	Photographic/digital
			7.5 'x 7.5'	Mono	Photographic/digital
			15' x 15'	Mono	Photographic/digital
3	LISS-III+IV (Mono)	Merged data	15'x 15'	3	Photographic/digital
		Geocoded	70 x 70	3	Photographic/digital

(Note: Mx stands for multispectral)

Data Source and Product

Archive and planned remote sensing data from satellite borne sensors are available. These data can be obtained in various data formats and products (Table 4) for further processing for groundwater resource studies (Fig. 2). Field data from geophysical sensors can be collected. Ancillary information such as topographic maps, soils, and groundwater depth and quality data can also be obtained from concerned agencies.

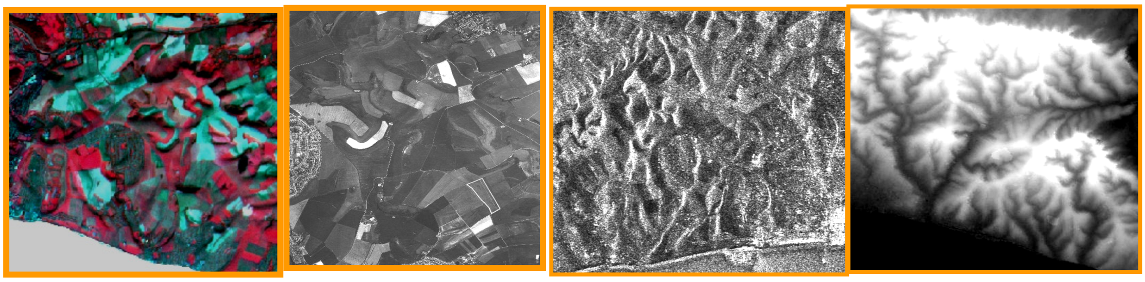

Fig.2. Multiple sources of image data from left to right (aerial photograph, multispectral image, radar image and digital elevation model

Data Processing Techniques

Many steps of digital image processing and modelling are required in order to extract useful information from the image data. Suitable techniques are adopted for a given theme, depending on the requirements of the specific problem. Since remote sensing may not provide all the information needed for a full-fledged assessment, many other spatial attributes from various ancillary sources are needed to be integrated with remote sensing data. This integration of spatial data and their combined analysis is performed using GIS. A digital image processing and GIS software can be chosen considering application and budgetary constraint (Table 5). Digital image processing comprises the following four basic steps:

- *Image correction/restoration*: Image data recorded by sensors on a satellite contain errors related to geometry and brightness values of the pixels. These errors are corrected using suitable mathematical models, which are either definite or statistical models.
- *Image enhancemen*t: Image enhancement is the modification of image by changing the pixel brightness values to improve its visual impact. These techniques are performed by deriving the new brightness value for a pixel either from its existing value or from the brightness values of a set of surrounding pixels.
- *Image transformation*: Multispectral character of image data allows it to be spectrally transformed to a new set of image components or bands with a purpose to get some information more evident or to preserve the essential information content of the image (for a given application), with a reduced number of transformed dimensions. The pixel values of the new components are related to the original set of spectral bands via a linear operation.
- *Image classification*: The overall objective of image classification procedures is to automatically categorize all pixels in an image into land cover classes or themes. A pixel is characterized by its spectral signature, which is determined by the relative reflectance in different wavelength bands. Multi-spectral classification is an information extraction process that analyses these spectral signatures and assigns the pixels to classes based on similar signatures.

Table 5: List of industry leading software and hardware for digital image processing, GIS and GPS

Data source	Widely used software and hardware
Optical remote sensing	ERDAS Imagine 9, PCI Geomatica 9, ENVI 4.2, IDRISI Kilimanjaro
Radar Remote Sensing	ERDAS Imagine IFSAR module, ArcView-SARscape, Geomatica Radar, Phoenix SAR/InSAR Toolkit
Aerial Photography	ERDAS Imagine Photogrammetry Suite, PCI Geomatica 9 OrthoEngine
GIS	ESRI ArcGIS ArcInfo 8.x, ArcView 3.2, GeoMedia Professional, PCRaster, GRAM++
GPS	Trimble Pathfinder ProXRS with post processed phase diff. correction, Garmin etrex-Vista & GPSII & 12

A scheme of image processing and GIS techniques using image registration, false colour compositing, overlaying, vegetation indices, density slicing, and supervised classification are applied on LISS-III or IV data. Various zones to be identified within landform and terrain maps should have conformity with ground water salinity and depth contours. Vegetation indices viz. normalized difference vegetation index (NDVI), green vegetation index (GVI), normalized difference salinity index (NDSI), waterlogging index, etc. are generated by transforming the image data.

Delineation and Characterization of Poor Quality Groundwater Zones

Preparation of Hydrogeomorphological and Other Thematic Maps

Synoptic view, repetitive coverage and capability to view the scene in several spectral bands of visible and NIR portions, are special characteristics that have made remote sensing an effective tool in groundwater exploration. Groundwater can be distinguished in the near infrared wavelength due to low reflection of water. Spatio-temporal distribution of groundwater depends on the underlying rock formations, their structural fabric and geometry, and surface expression. Remotely sensed data in conjunction with sufficient ground truth information provide information on the geology, geomorphology, structural pattern and recharge conditions which ultimately define the groundwater prospects. The surface expressions of aquifers are the basis of clue to groundwater prospecting which can be discriminated by remote sensing techniques.

A standard or geocoded scene in form of false colour composite (FCC) image of the selected sensor of the study area is obtained on CD-ROM from the National Remote Sensing Centre (NRSC), Hyderabad. In case of standard scene, the scene is to be rectified and georeferenced using suitable ground control points obtained from Survey of India topographic maps or GPS survey. Visual or digital interpretation of a FCC of multi spectral data is carried out by taking into consideration various image interpretation and terrain elements for preparation of various thematic maps. Significant hydrogeomorphic (landform) units are demarcated based on tone, texture, shape, size, pattern, association, etc. Delineation of all linear features on the FCC image is carried out and these linear features are further classified into fractures, faults, shear zones, straight lithocontacts with available information. Delineation of landforms including hydrogeomorphologically significant landforms viz. valley fills, alluvial fans, piedmont zones, alluvial plains, braided channels, abandoned channels, palaeochannels, flood plain etc. are carried out in the area covered by unconsolidated sediments. All the delineated hydrogeomorphic landforms are suffixed with lithology type. On the basis of image characteristics, soils, hydrology, land use and land cover, etc. maps are prepared through onscreen interpretation/digitisation of the imagery using flow diagram (Fig. 3). Vegetation indices viz. normalized difference vegetation index (NDVI), green vegetation index (GVI), normalized difference salinity index (NDSI), waterlogging index, etc. are also generated from LISS data.

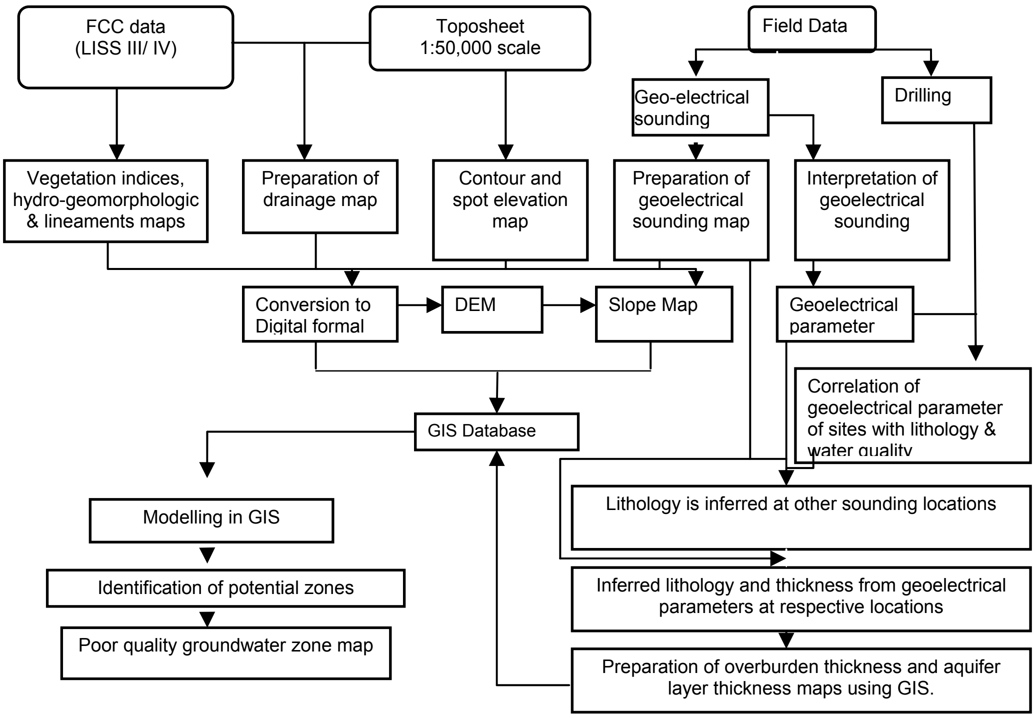

Fig. 3. Flow diagram of locating poor quality groundwater zones

Land use and land cover map is prepared using multispectral classification technique. Digital elevation model can be generated from the digitization and spatial interpolation of contour lines and spot elevation from topographic map or using stereogrammetry of satellite stereo data. Slope and aspect maps are derived from a DEM whereas drainage map is prepared from interpretation of the FCC and DEM. The interpreted all thematic maps are checked during the ground truth collection. Interpreted maps are modified by taking into consideration the ground observations to prepare a hydrogeomorphological map of the study area. All maps are imported to GIS software viz. ArcGIS 9.1 for integrating ancillary data for further analysis. Groundwater depth and quality data and maps are also digitized in GIS software. After digitisation, error removal and attributation of ancillary maps, groundwater prospects and quality maps are thus prepared to develop groundwater prospective zone map at district scale. The groundwater prospective zone map is draped on digital elevation model (DEM) to develop a map of further groundwater development.

Delineation of Groundwater Potential Zones Based Hydrogeomorphic Units

It is necessary to carry out rapid geophysical scanning in an area by ground penetrating radar, electrical resistivity, borehole logging, electrical resistivity, geoelectrical sounding and groundwater quality sample information to integrate thematic maps with subsurface water quality data in order to acquire comprehensive knowledge on groundwater prospects and quality of an area. The impervious clay thickness and aquifer depth and quality information are integrated to GIS in order to demarcate the groundwater potential zones.

Table 6: Feature class with weightage and score for groundwater prospecting

Theme	Weightage (%)	Feature class	Score
Hydro-geomorphology	45	Alluvial plain	25
		Residual hill complex	8
		Residual hill	5
		Residual mound	1
		Pediment	10
		Valley fill	17
		Valley flat	20
		Floodplain	23
		Water bodies	25
Geology	35	Sandy silty alluvium	25
		Brown sand	22
		Laterite	6
		Lignite-gritty sandstone	20
		Dolerite	1
		Pegmatite and quarts veins	1
		Garnet biotite gneiss	4
		Cordierite gneiss	2
		Charnockite	4
		Quartzite	1
		Coastal sand	23
Slope	15	0-7	25
		8-15	18
		16-25	10
		26-35	04
		>35	01
Land use/land cover	5	Paddy field	25
		Wheat field	23
		Mixed crop	11
		Plantation/forest	6
		Reclaimed alkali field	15
		Urban area	2
		Barren land	7
		Water body	20

The hydro-geomorphological, geology, slope and land use and land cover maps are suitably subdivided into feature classes in GIS (Table 6) according to feature class, score and weightage are assigned. A GIS based groundwater potential map is thus prepared using the equation (3). The details of delineated geomorphic units with groundwater prospects in Haryana are given in Table 7.

Groundwater Potential Map (GPM)

GPM = (Geomorphology) x 0.45 + (Lithology) x 0.35 + (Slope) x 0.1 + (Land use/land cover) x 0.05 …..…. (3)

VIBGYOR colour code is used in denoting degree of groundwater prospect in GIS (Fig. 4). While violet indicates high prospect for groundwater occurrence, red colour region shows no prospect for groundwater. Groundwater prospect map shows probable regions where borewells can be drilled. These maps have facilitated identifying sources of drinking water for deprived villages. Following national level hydrogeomorphic mapping showing groundwater prospect areas on 1:250,000 scale, more detailed maps for few priority states on 1:50,000 scale are generated in GIS environment under the Rajiv Gandhi National Drinking Water Mission. The feedback has shown above 90% success, when wells were drilled on the basis of groundwater prospect maps generated using integrated approach of remote sensing and GIS (Table 8).

Table 7: Groundwater prospects of various geomorphic (landform) units

Geomorphic units	Description	Water prospects
Fluvial origin alluvial plain	Gently undulating plains consisting of clay, silt, fine to coarse sand of varying lithology	Excellent
Alluvial plain with sand cover	Undulating plains comprising sand, silt and clay. Sand is dominant but stabilized.	Good
Palaeo channel /abandoned channel	Channels which are cut off from main course of the river, buried or abandoned. Comprises of fluvial deposits (sand, silt and clay particles)	Very good
Denudational origin pediment	Occurring near to structural hills gently slopping area comprising colluvial material and medium to fine grained sand and silt. This unit has higher thickness near ridges and laterally merge with alluvial plain.	Moderate to good
Inter-montane valley/basin	Depression between mountains, formed as broad basin consisting of colluvial deposits covered with alluvium.	Excellent
Valley fill	Unconsolidated material coarse to fine sand, silt and clay	Good
Residual hills	Isolated low relief hill formed due to differential weathering consisting of metasediments.	Poor
Structural origin structural hills	Structurally controlled steep sides hills associated with folds, faults, fractures and joints, these are meta sediments of Delhi super group (moderate along fault planes)	Poor to moderate
Linear ridges	Long narrow low lying linear to arcate hills rising from alluvial plains acting as barriers of groundwater flow.	Poor

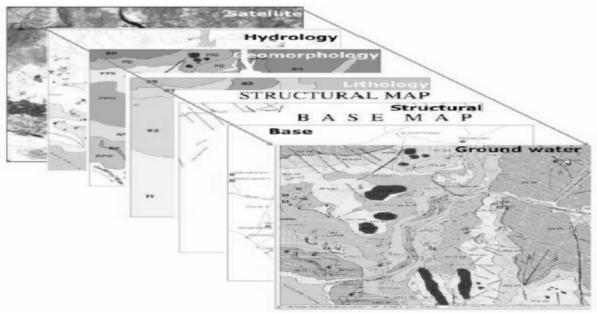

Fig. 4. Groundwater prospect map generated in GIS environment

Table 8: Success rate of remote sensing based groundwater prospect mapping under Rajiv Gandhi National Drinking Water Mission (RGNDWM)

State	No. of wells drilled as per groundwater prospect maps	Success rate (%)
Andhra Pradesh	29,873	90
Chhattisgarh	19,503	90
Gujarat	34	100
Karnataka	5213	93
Madhya Pradesh	7730	92
Kerala	10,430	90

Source: Navalgund *et al*. 2007

Table 9. Reflectance response zones on the basis of GVI image interpretation

Zone	Reflectance zone	Image indication	Hydrogeological conditions
1	Low salinity	Large bright patches representing dense vegetation	Deep water table depth, normal salinity, low salt content
2	Low to medium salinity	Scattered small bright patches with sparse vegetation	Moderate water table depth, moderate salt content
3	High salinity	Dark patches due to absence of dense vegetation	Shallow water table, high salt content

The growth and condition of vegetation are also indicators of groundwater quality for an area prone to waterlogging and salinization. The reflectance response in the green vegetation index (GVI) image of remotely sensed data with the vegetation characteristics and hydrogeological conditions are used for identification of different salinity zones (Table 9).

Groundwater prospect and quality information maps are integrated to GIS with water table depth and other thematic maps to prepare groundwater quality zone maps on the basis of EC, SAR and RSC for mapping the extent and distribution of poor quality groundwater zones in the country. In a study of Haryana state, groundwater quality map with three zones on the basis of EC only such as good (EC < 2.0 dS/m); low/marginal (EC from 2.0 to 4.0 dS/m) and high/poor (EC > 4.0 dS/m) is prepared in GIS environment with water table depth information (Fig. 5).

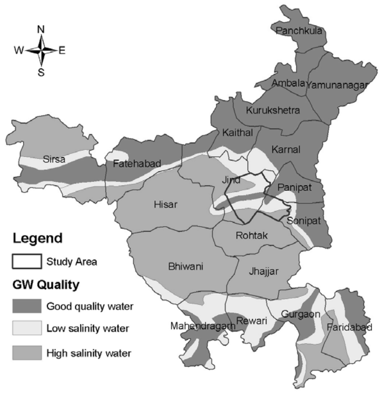

Fig. 5. Groundwater quality zonation Map of Haryana

Concluding Remarks

An integrated approach of remote sensing, geophysical scanning survey and GIS is useful for the preparation of groundwater prospecting and poor quality groundwater zonation maps on a scientific basis. The information generated on prospects, quality and depth in a single map will help the planners, decision makers and development agency for developing plans for further groundwater development and for devising feasible management strategies for conjunctive use of poor quality waters for ensuring sustained agricultural production.

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Irrigation Water Quality and Release of Ions from Soil Mineral Weathering

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Introduction

In irrigated agriculture, the hazard of salt water is a constant threat particularly in arid and semiarid regions. The major cations of the dissolved mineral salts are Na^+, Ca^{2+}, Mg^{2+}, and K^+, and anions are Cl^-, HCO_3^-, CO_3^{2-}, SO_4^{2-}, and NO_3^-. Soluble salts originate from the disintegration (weathering) of minerals and rocks as a part of ongoing geochemical processes. From weathering sites, salts move into the deeper soil layers, groundwater, water bodies and finally into oceans. In arid environments where rainfall is limited salts may accumulate in the root zone, soil surface, landscapes with particular relief and geologic conditions and adversely affect the plant health. In addition to total salinity, water rich in carbonate and bicarbonates of sodium generates excessive level of exchangeable sodium which adversely affects physico- chemical properties of soil. The salts present in sodic lands of the Indo Gangetic alluvial plains were the result of weathering. The useful parameters for expressing the sodium hazards of irrigation waters are sodium adsorption ratio and residual sodium carbonate.

Sodic Hazards and Mineral Weathering

The sodic hazards of applied waters can be predicted from the SAR of the saturation extract, because of its relation with ESP of soil exchange complex. But is applicable only at the steady state condition where the SAR of soil solution is more or less the same as that of applied water. Because of release of ions from *in situ* soil mineral weathering processes, the chemical composition and SAR of the applied irrigation waters may differ from that of soil solution. In particular it is applicable when the applied waters are having bicarbonates because of precipitation of Ca as $CaCO_3$. Affinity and release of ions into the soil solution from soil depend upon the salinity of irrigation water, cation exchange capacity (CEC), nature of exchangeable cations and soil mineralogy (Oster and Shainberg, 1979; Frenkel *et al*., 1983; Endo *et al.*, 2000). In the bed load sediments of high land rivers of India (upper reaches of the Ganga, the Yamuna, the Baramputra etc.) where illite is the dominant mineral (80%) and carbonate weathering (Ca+Mg) and HCO_3^-) accounting for about 80% of cations and anions was dominant whereas in the low land rivers (the Chambals, the Ken, the Betwa), smectites accounts for about 80 percent of clays and HCO_3^- excess over Ca+Mg and relatively high contribution of Na+K to the total cations showing silicate weathering and/or contribution from alkaline/saline soils and groundwater could be the important sources of major ions to these waters (Sarin *et al.*, 1989). These changes in soil water caused by mineral weathering are important in deciding the suitability of water for irrigation usage, as it is the composition of the resulting soil solution (SAR, EC, RSC) rather than that of irrigation water, which controls exchange reactions *vis-a-vis* sodification of soils. Therefore study of amounts and kind of ions brought in to the solution by mineral weathering, the mineral responsible for ion release and putting it into the water quality evaluation phenomenon are vital for utilization of poor quality waters.

Release of Ions Under Saline and Sodic Irrigation

The application of 1000 mm of water containing, 1000 mgL^{-1} total dissolved solids, to a hectare of land, applies 10 t of salts. In India, water quality in 32 to 84% of the aquifers surveyed has been observed to be saline/alkali (Minhas, 1996). In many such areas the good quality surface water supplies are either inadequate or not available at all and the farmers are left with no option but to use poor quality waters for irrigation. Quality of irrigation water (salinity and sodicity) would strongly influence the release of kind and amount ions from soil weathering. Frenkel *et al*. (1983) were also of the opinion that chemical composition of the solution could affect the rate of soil hydrolysis and in turn release of ions from mineral weathering in the presence of $CaCO_3$ or Ca-silicate. In contrast to the acid and normal soil, the release of Na is expected to be the dominant compared to Ca+Mg in alkali soils, thus affecting the sodic hazards of irrigation water accordingly, which need to be studied.

To find the kind and amount of ions released from alkali soil under saline environment and consequential changes in chemical composition of soil solution, a column study using a sandy loam alkali soil of Bhaini Majra, Kaithal (Haryana) was conducted at CSSRI, Karnal using irrigation water with three levels of total electrolyte concentration (TEC: 10, 20 and 40 m.e. L^{-1}), four levels of SAR (10, 20, 30 and 40) and two levels of RSC (0 and 5 m.e. L^{-1}) (Lal *et al.*, 2007). The results indicated that the total salt concentration of the leachate was higher than that of applied waters because of release of ions except in treatment having TEC 40 m.e.L^{-1}, SAR 10 and RSC 5 m.e. L^{-1} where it was lowered (denoted by – sign) by 1.4 m.e. L^{-1}. The increase in cation concentration (sum of Ca+Mg and Na released in the effluent) ranged from 4.0 to 7.0 m.e. L^{-1}, with the major cation released being Na (2.9 to 4.2 m.e. L^{-1}) and Ca+Mg accounting for the remainder (1.0 to 3.3 m.e. L^{-1}) (Table 1). The major anionic increases were accounted for CO_3 and HCO_3 (1.3 to 5.2 m.e. L^{-1}) The release of Ca+Mg was significantly reduced with increase in either EC or RSC of irrigation water.

Table 1. Quality parameters of irrigation water and release of ions in the effluent

Water no.	Composition of applied water			Release of ions in the leachate						
	TEC	RSC	SAR	Ca+Mg	Na	Cl^-	HCO_3+ CO_3	RSC	$\sum C^+$	$\sum C^-$
	m.e.L^{-1}									
I	10	0	10	3.0	3.5	2.0	4.5	0.0	6.5	6.5
II	10	0	20	3.2	3.0	1.6	4.8	1.1	6.2	6.4
III	10	0	30	3.3	3.0	2.2	4.3	0.8	6.3	6.5
IV	10	0	40	2.9	4.1	2.4	4.6	1.6	7.0	7.0
V	20	0	10	2.3	3.6	1.8	4.8	0.0	5.9	6.6
VI	20	0	20	3.2	3.3	2.0	4.9	0.0	6.5	6.9
VII	20	0	30	3.0	3.4	1.6	5.2	1.4	6.4	6.8
VIII	20	0	40	2.7	3.3	1.8	4.6	1.4	6.0	6.4
IX	40	0	10	1.5	3.7	1.6	4.2	0.0	5.2	5.8
X	40	0	20	2.1	3.4	1.8	4.0	0.0	5.5	5.8
XI	40	0	30	2.2	3.0	2.1	3.8	0.0	5.2	5.9
XII	40	0	40	2.2	3.1	1.8	4.0	0.0	5.3	5.8
XIII	10	5	10	2.0	3.5	2.0	3.7	6.7	5.5	5.7
XIV	10	5	20	2.5	2.9	2.8	3.3	5.8	5.4	6.1
XV	10	5	30	2.6	4.1	2.7	3.7	6.1	6.7	6.4
XVI	10	5	40	2.4	4.2	2.8	3.8	6.4	6.6	6.6
XVII	20	5	10	1.5	2.5	2.7	1.3	4.8	4.0	4.0
XVIII	20	5	20	2.1	3.2	2.4	2.8	5.7	5.3	5.2
XIX	20	5	30	2.4	3.4	2.4	3.1	5.7	5.8	5.5
XX	20	5	40	2.6	3.9	2.4	4.0	6.4	6.5	6.4
XXI	40	5	10	-4.7	3.3	2.1	-3.6	6.1	-1.4	-1.5
XXII	40	5	20	1.0	3.1	2.0	1.8	5.8	4.1	3.8
XXIII	40	5	30	1.4	3.2	2.3	2.3	5.9	4.6	4.6
XXIV	40	5	40	2.0	2.9	2.0	2.2	5.2	4.9	4.2
Mean				2.1	3.4	2.1	3.4	3.2	5.4	5.6
CD(5%)				0.4	0.5	NS	0.8	NS		

The effects of increased total electrolyte concentration (40 m.e. L^{-1}) might be due to increased relative preference for Ca over Na (Poonia *et al.*, 1984). Due to comparative higher release of CO_3 + HCO_3 than Ca + Mg, an increase in RSC of effluent varied from 0.2 to 1.7 m.e. L^{-1} was observed more so at 10 m.e. L^{-1} TEC level. The SAR values of effluent ranged from 8.0 to 29.8 (mmol L^{-1}) which were much lower (6 to 72%) than that of applied both RSC and non-RSC irrigation waters (Fig. 1). Because of release of Ca+Mg from soil, there was a proportionate relative gain in Ca+Mg: Na content in effluent as compared to applied water, thereby reducing the potential sodium hazards.

The reduction in SAR was more pronounced where waters of low TEC and high SAR were used. SAR of effluent was more where RSC waters were used compared to non-RSC waters. In use of RSC waters at TEC level of 40 m.e. L^{-1} and 10 SAR of applied water, SAR of the effluent was increased by 38% due to precipitation of Ca in presence of carbonates and bicarbonates, the aspect considered in the calculation of adjusted SAR. These results indicated that non-RSC water of high SAR but low TEC will pose less detrimental effects than the expected. It is not applicable in RSC waters because RSC of such waters was further increased due to higher release of CO_3+HCO_3 than Ca+Mg, which will be harmful for soil quality. Such reduction in SAR of saturated extracts of soils from rice fields under similar conditions after seven years of rice – wheat cropping system could be due to the dissolution of Ca from $CaCO_3$ and dilution due to rainfall.

At steady state (the equilibrated conditions when the columns presaturated with different quality waters were leached with a uniform quality water) also, a continuous release of sodium in to the soil solution varied from 3.5 to 6.8 whereas Ca+Mg release varied from 0.8 to 1.2 m.e. L^{-1} (Table 2).The composition of applied waters had no effect on the release of Ca+Mg and Na in the soil solution at steady state composition. The cumulative release of Ca+Mg and Na in eight displacements ranged from 2.8 to 10.3 and 28.9 to 50.0, respectively.

The release of Na in soil solution in fact was not as high as it seemed because as the composition of solution phase changes it leads to corresponding adjustment on the exchange complex. Thereafter, there was a net retention of Ca+Mg in the soil, which was accounted for by its increased amounts in exchangeable and soluble forms. The ESR-SAR relationship by using the equation (ESR = 0.01475 SAR – 0.0126) of U.S. Salinity Laboratory Staff (1954) showed that 0.5 to 2.5 m.e. L^{-1} of Na in soil solution at steady state could be accounted by its release from exchange complex. From break through curves (Fig. 2), it was found that the relative release of

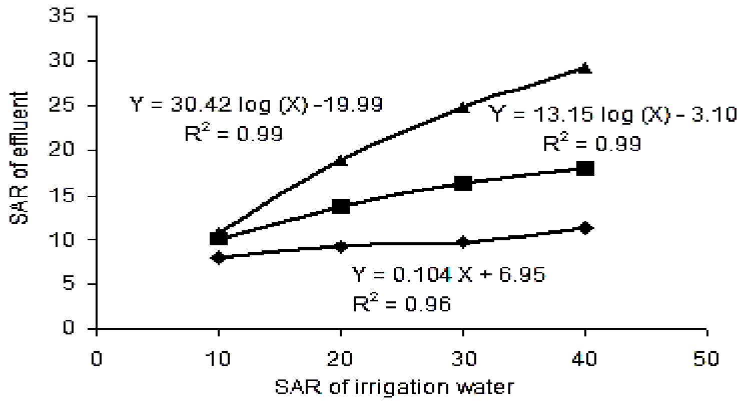

Fig. 1. Relationship between SAR of effluent and applied non-SAR irrigation water

Na in soil solution from soil, saturated with waters of different SAR and TEC both of RSC and non-RSC was higher and continued for longer duration than Ca. Though more Na was released than Ca+Mg but ratio of Na: Ca+Mg ions released in to soil solution varied only from 3.5 to 6.8 which would reduce the sodic hazards (SAR) of irrigation waters having SAR > 9.6. The release of Ca+Mg reduced sodic hazards of high SAR irrigation water, which will not be as high as suggested by their chemical composition. It was found that $CaCO_3$ was one of the major sources, which released calcium and carbonate & bicarbonate ions in the solution. $CaCO_3$ content was found to be higher in soil samples where RSC waters were used compared to non-RSC waters. If the release of Ca+Mg continued @ 0.9 m.e. L^{-1} as found at the steady state in soil solution then 0.8 % $CaCO_3$ left in the soil will last on an average for 518 irrigation of 7.5 cm depth each. The findings were of practical importance for using high SAR and low electrolyte non-RSC irrigation water on alkali soils rich in Ca+Mg minerals like feldspars, $CaCO_3$ which could maintain proportionately higher Ca+Mg: Na ratio than in the applied irrigation water. Sodic soils of Indo-Gangetic plains invariably contain free $CaCO_3$ concretions, which releases Ca in soil solution and reduces sodicity hazards of high SAR water irrigation. These ions might also be coming out from dissolution of silicate minerals (plagioclase feldspars) or $CaCO_3$ because of metastable form, which was more soluble than pure components present in the soil (Levy, 1980; Curtin *et al.,* 1995). Mineralogical analysis of the soil also showed the presence of significant amount of feldspars and indicated that Ca, Mg feldspars and calcite were the sources responsible for the release of Ca and Mg whereas sodium was released from dissolution of Na_2CO_3 and sodium feldspars.

Table 2. Release of cations into the soil solution at steady state composition when the previously saturated columns were leached by common water.

Water no.	Ca+Mg	Na	SARss	(Na/Ca+Mg) release ratio
	m.e.L^{-1}			
I	0.9 (10.3)	4.3 (32.5)	4.1	4.8
II	1.1 (10.2)	4.7 (37.7)	4.3	4.3
III	0.9 (9.5)	5.4 (34.7)	4.8	6.0
IV	0.8 (10.0)	4.5 (34.5)	4.3	5.6
V	0.8 (7.5)	4.5 (36.4)	4.3	5.6
VI	0.8 (8.3)	5.2 (42.5)	4.7	6.5
VII	1.1 (9.4)	5.0 (40.8)	4.4	4.5
VIII	1.1 (9.4)	3.9 (39.7)	3.8	3.5
IX	1.0 (3.7)	4.1 (42.3)	3.9	4.1
X	1.2 (6.9)	5.8 (45.6)	4.9	4.8
XI	1.0 (7.3)	6.8 (47.5)	5.6	6.8
XII	0.9 (8.2)	5.3 (46.5)	4.7	5.9
XIII	1.0 (8.5)	4.4 (35.4)	4.1	4.4
XIV	0.8 (10.8)	4.2 (28.9)	4.1	5.3
XV	0.8 (9.0)	4.1 (33.6)	4.0	5.1
XVI	1.0 (9.3)	4.2 (29.9)	4.0	4.2
XVII	0.8 (6.4)	4.5 (35.4)	4.3	5.6
XVIII	0.8 (6.7)	5.4 (41.1)	4.8	6.8
XIX	0.8 (6.9)	5.0 (40.4)	4.6	6.3
XX	0.8 (7.5)	5.0 (42.9)	4.6	6.3
XXI	0.8 (2.8)	5.1 (47.6)	4.6	6.4
XXII	0.9 (5.7)	5.1 (51.8)	4.6	5.7
XXIII	0.8 (4.6)	5.4 (50.0)	4.8	6.8
XXIV	0.9 (5.5)	5.5 (48.9)	4.9	6.1
Mean	0.9 (7.7)	4.9 (40.3)	4.5	5.5
CD (5%)	NS	NS	NS	

(SARss SAR of soil solution & Figures in parenthesis indicate the cumulative release of ions in m.e.L^{-1} in eight displacements)

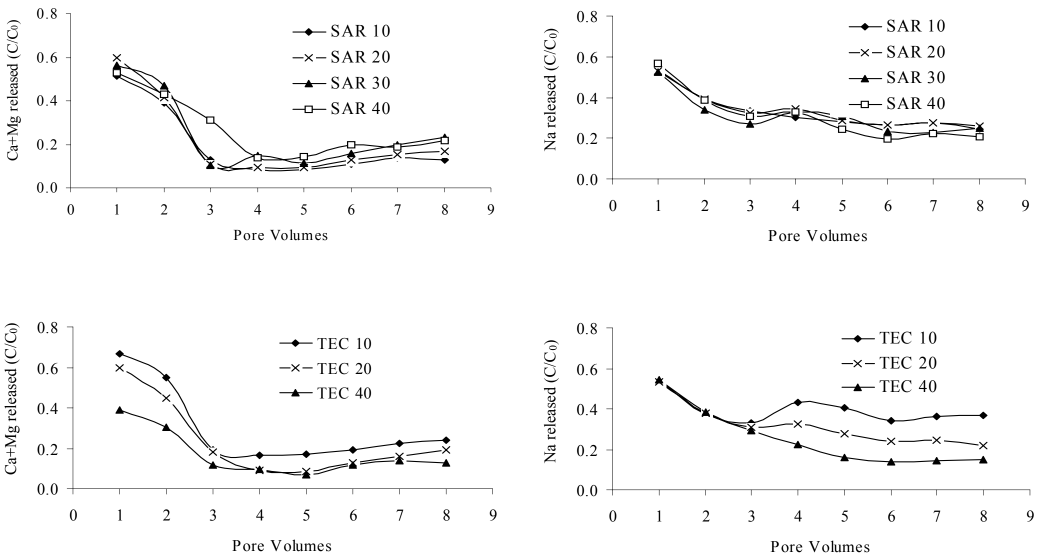

Fig.2. Effect of SAR and Total Electrolyte Concentration (m.e. L^{-1}) of applied non-RSC waters on Ca+Mg and Na release in soil solution

Table 3. Average increases in effluent concentration

Sr. no.	Soil properties pHs	$CaCO_3$	CEC	OC	Clay %	Average increases in effluent concentration (meq L^{-1}) Ca+Mg	Na	$\sum C^+$	HCO_3	$\sum C^-$
1	7.1	Tr	10.0	0.85	6.4	2.3	0.4	2.7	2.2	2.8
2	8.0	1.2	11.0	0.40	8.6	2.5	1.0	3.5	3.1	3.6
3	7.4	0.2	18.0	0.73	16.8	3.0	0.8	4.7	3.8	4.7
4	7.4	0.7	25.8	0.89	28.2	3.5	1.3	4.7	3.8	4.2
5	6.2	Tr	13.8	2.24	6.8	4.3	1.1	5.4	2.6	5.5

Rhoades *et al.* (1968) also observed release of 3-5 meq L^{-1} salt in acid to normal pH soils of USA in which Ca+Mg was recorded to be higher than that of Na from soil minerals, which significantly reduced 30 to 90 per cent in SAR of the applied irrigation water (Table 3). The changes in composition of soil solution and release of Ca+Mg and HCO_3 as a consequence of soil mineral weathering was verified by studying weathering behaviour of minerals Ca-Mg silicate feldspars, hornblende and other heavy minerals like magnetite, hematite, zircon which were present in the significant quantity on the experimental soil. The mineral weathering processes of hydrolysis and carbonation was found to be responsible in specimen minerals and soil which can be expressed by the following equation:

$$Ca_2\text{-silicate} + H_2O + 4CO_2 \longrightarrow H_4\text{-Al silicate} + Si(OH)_4 + (SiO_2)n + 2Ca^{+2} + 4HCO3^-$$

Mineral Weathering Correction

The SAR of soil water could be affected by both the release of Ca+Mg from soil mineral weathering and loss of Ca as a result of lime precipitation. These two processes are difficult if not possible to separate because the Ca and HCO_3^- released to solution from weathering processes enter into cation exchange and precipitation reactions as well. The net effect of these two opposite processes depends upon the pHc of the applied water and studied by Rhodes (1968) by studying the impact of HCO_3 containing waters in soil and lime separately.

$$pHc = (pK_2 - pK_c) + p(Ca+Mg) + palk$$

Where p(Ca+Mg) and palk are negative logarithms of the major concentration of Ca+Mg and of the equivalent concentration of titrable base (CO_3+HCO_3) respectively. pK_2 and pK_c are the negative logarithms of second dissociation constant of H_2CO_3 and solubility constant of $CaCO_3$ respectively both corrected for ionic strength (Bower *et al.,* 1965). A decrease in Ca+Mg and HCO_3 contents accompanied by the increases in SAR value, were observed for waters having pHc values <8.4. This is expected for waters having such lime precipitation indexes. On the other hand in waters with pHc > 8.4, increase in Ca+Mg and HCO_3 concentrations with a commensurate decrease in SAR values was recorded. The separate contribution of soil mineral weathering to the changes observed in the soil solution can be estimated by subtracting the solution composition obtained after equilibration with lime from the soil water effluent compositions. Generally since the increases in Ca +Mg content produced by mineral weathering processes were greater than the decreases produced by lime precipitation, net solution changes resulted in increase in Ca+Mg and HCO_3 concentration.

To incorporate the mineral weathering component in evaluation of the sodic hazards of irrigation water the basic concept put forth by Bower *et al*. (1968) was followed as given below.

$$ESP = 2\ SAR_{iw}\ [1+ (8.4 - pH_c)].$$

The term $(8.4- pH_c)$ is Langelier index and 8.4 the approximate pH reading of a nonsodic soil in equilibrium with $CaCO_3$. The coefficient 2 was empirically found to be the best fit for Punjab soil for which the equation was originally developed. The SAR of drained water SAR_{dw} can be substituted against ESP because of their 1:1 relationship.

$$SAR_{dw} = \frac{1}{\sqrt{LF}} SAR_{iw}$$

Since the SAR values increase with the square root of the concentration, which is increased in the drained water according to the concentration factor, 1/LF. SAR_{dw} resulting from SAR_{iw} also depends upon $CaCO_3$ therefore; lime saturation index (8.4 - pHc) was incorporated in the equation.

$$SAR_{dw} = \frac{1}{\sqrt{LF}} SAR_{iw}\ [1+ (8.4 - pHc)]$$

SAR_{dw} is related to SAR_{iw} via leaching fraction. For the best fit the value of the coefficient was found to be $y^{(1+2LF)}/\sqrt{LF}$ and y was found to be 0.70 and regression coefficient was found to be 0.9 For waters not containing HCO_3, equation may be replaced by .

$$SAR_{dw} = \frac{1}{\sqrt{LF}} SAR_{iw}$$

Inclusion of soil mineral weathering coefficient to evaluate the sodic hazards improves the quantitative correspondence between observed and predicted SAR values of drainage water.

Effect of Exchangeable Cations on Mineral Weathering

The kinetics of dissolution of soil minerals ($CaCO_3$ and Ca silicate) is a function of ionic composition of exchange phase and found to be a two step reaction. The initial reaction is fast and completed in less than 1 hour and linearly related to exchangeable sodium. The second phase is slower and depends upon the total mineral surface available for weathering and is diffusion controlled (Frenkel *et al.*, 1983). Both mechanisms increase the Ca+Mg concentration in solution and in the exchanger phases. The total amount of Ca+Mg contributed by weathering increases as the amount of exchangeable Na increases.

Mineral Weathering and Soil Physical Properties of Sodic Soil

The differences in rates of mineral dissolution may be responsible for the observed differences in their susceptibility to hydraulic conductivities mainly because of release of salts from mineral weathering. Soils containing minerals $CaCO_3$ and feldspars) readily releases soluble electrolytes will not readily disperse at moderately ESP because of maintenance of salts. Conversely, the concentration of salts in the soil solution of soils that do not contain readily weatherable minerals will be below the threshold concentration (the flocculation value) and the soil will be more susceptible to clay dispersion (Shainberg *et al.*, 1981). The results are especially of importance in crust formation under rainfall conditions.

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Mitigating the Influence of Poor Quality Waters through Agronomic Manipulations

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Introduction

Water is the major issue confronting world today. The world faces number of challenges affecting sustainability of fresh water for posterities. Today the share of fresh water to agriculture is around 70%, so the water available to agriculture in future would be of rather poor quality. Whatever be the source of irrigation water, *viz*., river, canal, tank, open well or tube well, some soluble salts are always dissolved in it, but the concentration and composition of dissolved salts depend upon the source of the irrigation water. Use of saline water for irrigation is a subject of increasing interest because of increasing water requirement for irrigation and the competition between human, industrial and agriculture use. Amongst the various categories of poor quality waters, the sodic water bears a good irrigation potential by virtue of its amenability to reclamation through treatment with calcium or acidic amendment.

Salt Problems in Irrigation Water: Nature and Extent

The properties of soil are profoundly influenced by quality of irrigation water, hydrological conditions and cultural practices. The most common salts in irrigation water are table salt, gypsum, Epsom salt and baking soda. Among the soluble constituents, calcium, magnesium, sodium, chloride, sulphate, bicarbonate and boron are of prime importance in determining the quality of irrigation water and its suitability for irrigation. Irrigation water can contribute a substantial amount of salt to a field over a season. For example a water source with an EC of 1 dS/m, a quality suitable for irrigating most of the crops, contains nearly 1 tonne of salt in every acre-foot of water applied.

The most common problems that results from using poor quality irrigation water are:

- **Salinity:** A salinity problem occurs if the total quantity of salts in the irrigation water is high and the salts accumulate in the crop root zone to the extent that yields are adversely affected. Due to this the crops has the difficulty to extract enough water from the salty soil solution.
- **Permeability**: When the rate of water infiltration into and through the soil is reduced by the effect of specific salts or the lack of salts in the water to such an extent that the crop is not adequately supplied with water and yields are reduced.
- **Toxicity:** A toxicity problem occurs when certain constituents in the water are taken up by the crop and accumulate in amounts that result in reduced yields. This is related to one or more specific ions in water, namely, boron, chloride or sodium.
- **Miscellaneous:** these includes excessive vegetative growth, lodging and delayed crop maturity resulting from excessive nitrogen in the water supply, white deposits on fruits or leaves due to sprinkler irrigation with high bicarbonate water.

Characterizing Salinity

There are two common water quality assessments that characterize the salinity of irrigation water:

Total dissolved solids (TDS): Its unit is mg of salts/l or ppm. The higher the TDS, the more will be the salinity.

Electrical conductivity (EC): EC can be reported based on the irrigation water source (EC_w) or on the saturated soil extract (EC_e). Conversion factor depends upon both the salinity and the composition of water. For eg.

TDS (mg/l)= 640 X EC_w (ds/m) when EC_w <5 ds/m

TDS (mg/l)= 8000 X EC_w (ds/m) when EC_w >5 ds/m

Salinity measurements are important aspects of soil, crop and environmental protection, research and management. A salinity meter has been manufactured by ICT International provides a highly accurate, low cost, plug and play solution to measure salinity in the field. The system consists of a meter with LCD display and spreadsheet software.

Origin of Salts in Irrigation Water

The weathering of parent material of soil or rocks, which includes hydrolysis, hydration, solution, oxidation and carbonation, is the primary source of salts in irrigation water. Salinization is a process of those results from:

- High levels of salts in the soil
- Use of saline irrigation water
- Seepage from the canal
- Landscape features that allows salts to become mobile (movement of water table)
- Climate trends that favor accumulation
- Human activities such as land clearing and aquaculture activities
- Disrupting drainage pattern
- Continuous high water table
- Back water flow or intrusion of sea water in coastal water

Effect of Salinity on Plants

Excessive saline water reduces the yield of many crops. This may range from a slight loss to complete failure depending upon the crop and the severity of the salinity problem. Irrigation with poor quality water deteriorates soil properties and creates conditions unfavorable for economic growth of crops with normal farming practices. Amount and kind of salts in irrigation water determines the nature of crop growth hindrance. Increased ESP and pH adversely affect the soil tilth, water infiltration and soil aeration (Datta and Jong, 2002). It also increases soil crustation resulting in poor root growth, poor crop stand, bare soil spots and retardation of crop growth and yield. The specific toxicity symptoms like scorching, leaf burning etc are observed in early stage of crop growth. The level of soluble salts above 4ds/m in soil moisture inhibits the seed germination and growth of most commercial crops. This adversely affects the biomass production and economic yield. The following table illustrates the various saline conditions and category of crop tolerance.

Table 1. Salinity standards of irrigation water for agricultural crops

Sr. No.	EC (dS/m) at 25^{o}C	SAR Value	Category
1	<0.75	<10	No hazard to crops, acceptable
2	0.75-3.0	10-25	Increasing hazard, intermediate
3	>3.0	>25	Severe hazard, excessive

Principles of Salinity Control

The aim of salinity control is to prevent soil degradation by salinization and reclaim salty soils that have been formed due to continuous use of saline water. Soil reclamation is also called soil improvement, rehabilitation, remediation, recuperation or amelioration. Basically management of saline irrigation water involves two fold strategies:

- Agrochemical strategies
- Bioreclamation

The former involves maximizing crop production and includes recommendations on pre-reclamation management, amendment use, choice of variety and inter-cropping. The later is based on cultivation of salt tolerant and planting of trees and grasses.

Drainage

While irrigating with saline water if the water table rises within 60 cm to 1 meter from the surface, lands often go out of cultivation because of the rapid accumulation of salts in the root zone. Hence, through drainage the water should be kept at levels such that the roots are beyond the zone of capillary action.

Several treatments and management practices can reduce the salt level in the soil. However there are some situations where it is neither possible nor economically practical to attain desirable low salinity levels. In that case choosing a suitable salt tolerant crop can minimize crop loss caused by the salinity.

Principles of Crop Selection

- Crop selection should be based on profitability rather than relative yield losses.
- Crop also varies in their ability to tolerate salinity at different stages of growth. Germination and early seedling stages are the most sensitive stages and their tolerance increases with age.
- Nutrient responsive crops and their varieties should be selected for higher initial vigor.
- Salt tolerant crop group should also include water stress day index (WSDI) for the tolerant group of crops like wheat and sugarbeet (Katerji *et al*, 2000).

High yielding salt resistant varieties of rice like CSR 10, CSR 23, CSR 27, CSR 36, and CSR 30, two salt tolerant varieties of wheat named KRL 14 and KRL 19 and two mustard varieties, CS 52 and CS 54 have also been released by CSSRI, Karnal

Table 2. Salt resistant varieties of important field crops

Crop	Varieties
Rice	Jaya, IRS-68, IR-8, Pusa2-21, Padma,
Wheat	K-65, Sonalika, Hira, HD-2177, HD-2238,
Barley	RS-6, Jyoti, DL-3, Ratna
Pea	Bounewille
Rai	CS-52, CS-54, Varuna, Sulphala,
Safflower	N-18, US-10
Sorghum	SP-771, SP-146,
Sugarbeet	Erotype, margo Magnopoly
Bajra	IP-68, Syn-3, Syn. 2
Cotton	Atala-1517
Sugarcane	CO-205, CO-286, CO-280, POJ 2878, CO-975

(Paliwal and Yadav, 1976)

Cropping System

The adoption of suitable cropping system hastens the reclamation process. Growing of rice promotes a more favorable physical condition. In Deccan Plateau, *Dhaincha*-sugarcane-cotton has been found the best cropping system. In Punjab and adjoining areas, *Dhaincha*-rice- berseem and *Dhaincha* –rice-sugarbeet are the suitable cropping systems for sodic soils. In UP, rice-barleyor berseem and *Dhaincha* –rice-barley or berseem are reported to be better cropping system during initial years of reclamation.

Soil Management Practices

In order to adopt irrigation with poor quality water on a long term basis it is of utmost importance to have the detailed soil analysis including its structure, texture, pH, lime content location and amount of gypsum and total soluble salts. Gypsum requirement should be estimated. Data on the climatic parameters as amount of rainfall, its intensity, distribution and evaporation are to be obtained, as these controls the periodic as well as annual salt build up in an irrigated area.

Land leveling: A field infested with the problem of salinity should be leveled carefully. This will help in uniform spread of water and facilitates its downward movement otherwise at high spots (if salts are not leached) it will lead to salt accumulation and will cause heterogeneity in salt concentration.

Deep ploughing: medium textured soils pose a problem of sodicity. Such soils can be managed better by deep ploughing with incorporation of *Dhaincha*.

Seed Rate and Plant Population

Due to poor physical conditions of sodic and saline soils mortality of young seedlings occur and tillering and branching in the crop is relatively reduced. Problem soils need higher seed rate and closer spacing to maintain proper plant population. In case of transplanted crops seedling should normally be raised in normal soils. About 25% higher seed rate over recommended seed rate ensure good crop stand.

Seed Placement

Obtaining a satisfactory stand of crop on saline soils or with poor quality water is important. Planting seeds in the centre of a single row raised bed will place the seed exactly in the area where salts concentrate. A double row raised planting bed by comparison offers an advantage. The two rows are placed so that each is near a shoulder of accumulation. By this method higher salinity can be tolerated than with the single row planting because the water moves the salts through the seed area to the centre of the ridge. Seed bed design and seed placement should be done to minimize exposure of seeds and roots to salt particularly in the early sensitive stages of growth.

Age of Seedling and Time of Transplanting

Young seedlings are very sensitive hence older seedlings are recommended for transplanting. Transplanting should be done when the seedlings are 35-40 days old as compared to 25-30 days old as in case of normal soils. The optimum time for transplanting of high yielding and medium duration varieties of rice is from 25 June to 10 July. From the middle of July to end of July, medium duration varieties should be transplanted.

Planting Pattern and Method of Sowing

For close growing crops flat sowing or drilling is recommended. The best method for ride is transplanting. Forage crops like berseem, lucern etc. should be broadcasted in standing water. Sowing of crops on ridges should be on the side of the ridge so that salts accumulating on the top of the ridge may be excluded.

Time of Irrigation

A heavy pre-sowing irrigation to leach these surface salts will improve germination and early growth. It is made further in advance of the desired planting date to allow for cultivation to remove weeds and prepare the seedbed.

Quantity of Water

The maximum attainable efficiency is nearly 60%. Very few water is evaporated and most of it is stored underground. Many aquifers cannot absorb this and the water table rises leading to water logging. Hence, excessive field irrigation should be discouraged. Since, concentration of salts in the soil solution near the root zone determines the degree of adverse effect on crop growth rather than the salt concentration of irrigation water alone, it is essential to adopt irrigation practices such that the salinity in the root zone is kept least. For this purpose the quantity of water and the frequency of irrigation water should be such that they could meet the leaching requirement of the soil and the consumptive use of the crop grown.

Conjuctive Use of Water

To mitigate the adverse effect of soil salinity on crop yield the farmers irrigate frequently by mixing canal water and ground water. In most crops subjected to irrigation with saline waters, germination and early seedling stages are generally the most sensitive and their tolerance increases with age (Swarajlakshmi *et al*, 2003).

Method of Irrigation

The soil's EC is associated with irrigation method. In case of surge flow irrigation water is applied intermittently. This discourages continuous submergence and reduces the salt build up. Alternate furrow irrigation is also advantageous. If the beds are wetted from both sides the salts accumulate in the top and the centre of the bed but if alternate furrows are irrigated the salts can be moved beyond the single seed row thus reducing the extent of salt accumulation. Increasing the depth of water in the furrow can also improve germination.

Nutrient Management

Generally soils irrigated with poor quality waters are also low in their fertility status. Better crops can be grown by raising fertility status. The efficiency of fertilizers on soils irrigated with saline water depends largely on the interactive effects of salts, exchangeable sodium and fertilizers.

- Amongst the fertilizers nitrogen is better than phosphorus followed by potash. Up to moderate levels of salinity P and K application may be profitable only in the presence of N. Application of urea should be avoided due to its higher rate of nitrogen loss in the gaseous form under saline-alkali soils.
- Use of organic sources i.e. FYM, compost, sludge, green manure, crop residue are always beneficial and should be encouraged.
- After 3-5 years of reclamation and continuous cropping, soil fertility goes down. Fertilizers should be added in the soil test basis to sustain crop yields and better quality.

Conclusion

High crop yields can be obtained from saline irrigation water by adopting suitable cultural and agronomic practices. The suitable management practices for optimal crop production with saline water irrigation helps in preventing the build up of salinity and toxic ions in the root zone controls the salt balances in soil –water system as well as minimize the damaging effect of salinity in crop production.

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Nutrient Stress Management for Sustaining Crop Productivity under Irrigation with Saline and Sodic Waters

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Introduction

A shift towards the rice based cropping systems in the semiarid parts of north western India has forced the farmers to exploit ground waters to the maximum for supplementing the limited surface water resources. This over-mining of groundwater is causing decline in ground water levels at alarming rates in better ground water quality zones while in other areas, farmers are left with no option but to use poor quality underground waters. Experimental evidences show that to overcome salinity/sodic hazards accruing upon irrigation with brakish waters, specialized soil–water-crop management practices should be followed. However, researchers face a dilemma as to whether rice-based cropping system is sustainable and be recommended for irrigation with sodic water. The critiques of such a system rely completely on literature. But our experiences on working under field situations force us to seek some clarification on what scale of experimentation such results have come and whether the sodic water used was represented by pure ionic compositions.

Salinity and sodicity of underground irrigation water coupled with nutrient deficiencies and/or specific ion toxicity pose a serious problem for sustaining crop productivity in the country. Use of poor quality ground water constitutes about 30-80 per cent of total ground water development. The management practices for optimal crop production with saline and sodic water irrigation must aim at preventing the build-up of salinity/sodicity and toxic ions in the root zone to levels that limit the productivity of soils, control the salt balances in soil-water system as well as minimize the damaging effects on crop growth. Efficient, balanced and integrated nutrient management strategies are extremely important to increase yields to match the potential yields obtained under good quality irrigation water. Therefore, we focus on the ionic interactions and nutrient dynamics as influenced by salinity/sodicity of irrigation water and discuss how these issues relate to the nutritional problems and suggest long-term remedial measures to utilize poor quality waters for improving and sustaining crop productivity.

Nutrient Management Strategies for Using High RSC/Sodic Waters

In many arid and semi arid regions of the world sodic groundwater is the main or only source of irrigation and its continued use poses a threat to improve crop production. Application of gypsum as soil or water amendment is commonly recommended to offset the deteriorating effects of these types of water. However, organic amendments have also been used to alleviate the adverse effects of soil sodicity on crop growth. Long-term nutrient management strategies developed so far for improving rice-wheat production on sodic lands are potentially applicable to areas primarily met with good quality under ground irrigation water. (Swarup 1994, 2004). Since rice-wheat is the most commonly practiced crop rotation in the Indo-Gangetic plains, improving its productivity particularly in the areas having poor quality groundwater is a major challenge. Development of site specific integrated plant nutrient supply (IPNS) and management strategies is therefore a viable option for sustaining the productivity of this system. The basic concept underlying IPNS is the maintenance or adjustment of soil fertility and nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of the benefits from all possible sources of plant nutrients in an integrated manner. IPNS is an approach ecologically, socially and economically viable, and environmentally un-hazardous. Keeping these facts in view field investigations were carried out (Swarup and Yaduvanshi, 2004, 2004a; Yaduvanshi and Swarup 2005) to evaluate the long-term effects of sodic irrigation water (residual sodium carbonate (RSC) 8.5 mel^{-1} and sodium adsorption ratio (SAR 8.8) with and without gypsum as soil amendment and organic (farmyard manure (FYM) and pressmud) and inorganic fertilizer use (N,P,K and Zn) on soil properties and yields of rice and wheat. Lessons learnt from these experiments are summarized below:

- Nitrogen continues to be the most limiting plant nutrient in soils irrigated with sodic water. The continuous use of fertilizer N alone (120 kg ha^{-1}) significantly improved grain yields of rice and wheat over control (no fertilizer) (Table 1). The mean yields increased by 53.9 per cent in rice and 72.9 per cent in wheat.

- Next to N, phosphorus limits crop productivity from the very beginning. The soils test low to medium in Olsen's P. Phosphorus applied at the rate of 26 kg P ha^{-1} each to rice and wheat significantly improved the yields, the mean increase being 0.72 and 0.65 t ha^{-1}, respectively.

- The soils irrigated with sodic water generally test high in available K. Potassium applied at a rate of 42 kg ha^{-1} to both crops had no significant effect on yields.

- Zinc application improved the yields of rice but the effects were significant only in 1997 and 1998 rice.

- The NPK fertilizer with either 10 t ha^{-1} FYM, 5 t ha^{-1} gypsum or 10 t ha^{-1} pressmud (T6, T7 and T9) recorded significantly higher yields over the years as compared with NPK alone (T4). The residual effect of FYM, gypsum and pressmud was significant on wheat yields since 1997. Though yields of both crops improved further when gypsum was applied with FYM or pressmud (T8 and T10), but the differences were not significant over the treatments T6, T7 and T9. The differences in rice and wheat yields over the years have arisen primarily because of erratic rainfall and its impact in influencing SAR of soil (Table 1). Continuous cropping with sodic water and inorganic fertilizer use for ten years slightly decreased the soil pH and SAR from the initial value of 8.6 and 29.0 to 8.50 and 18.7 respectively. However, treatments involving the use of gypsum, FYM and pressmud significantly decreased the soil pH and SAR and improved soil organic carbon and available N, P, K and Zn over inorganic fertilizer treatments and control (Table 1).

- With the application of fertilizer N alone (T2) or in combination with P and K (T3, T4), the soil available N (SAN) in the surface soil layer increased slightly from initial level of 125 kg ha^{-1} to 140 kg ha^{-1} (Table 1). However, in control (No fertilizer) it declined significantly as compared to all the N treated plots. Addition of inorganic P fertilizer (T3) resulted in considerable build up in soil available P (SAP). Further significant improvement in available soil P occurred when FYM and SPM were used. The increase in P status due to addition of FYM and SPM can be attributed to the high content of these nutrients in the manure. When N alone was applied, available soil P declined from the initial level of 14.8 to 8.1 kg ha^{-1}. The results conform to the findings of Swarup and Singh (1989). The soil available K (SAK) content of the soil showed an increase by 2.2% in plots treated with K fertilizer and by 6.9% in plots receiving amendment/organic manures use over its initial level of available K. Continuous cropping depleted available soil K from the initial level of 275 kg ha^{-1} to 237 kg ha^{-1} in the treatments which did not receive K fertilizer (Table 1). The build up of soil available K due to FYM or SPM application may be due to (i) the additional K applied through it and (ii) the solubilizing action of certain organic acids produced during FYM or SPM decomposition and its greater capacity to hold K in the available form. There was significant improvement in DTPA extractable Zn in plots treated with Zn fertilizer (T5) or FYM/SPM.

- The rice-wheat productivity and soil fertility on long-term basis can be sustained by integrated use of gypsum or FYM with recommended NPK dose in areas having sodic ground water. Pressmud, a byproduct of sugar factory and also economically cheap as compared to gypsum offers alternate opportunities to the farmers of the Indo-Gangetic plains for efficiently using the poor quality groundwater and improve rice-wheat productivity and soil fertility.

Table 1. Effect of integrated nutrient management on yield of rice-wheat system and soil properties under sodic water irrigation

Treatments (10 year) 1994-95 to 2003-04		Mean grain yield of crops (Mg ha^{-1})		Soil properties after 10 years rice-wheat sequence					
Rice	Wheat	Rice	Wheat	Organic carbon (g kg^{-1})	Soil pH	Available nutrients (kg ha^{-1}) N	P	K	SAR
$N_0P_0K_0$	$N_0P_0K_0$	2.60	1.70	2.5	8.51	85	10.6	215	18.8
$N_{120}P_0K_0$	$N_{120}P_0K_0$	4.00	2.94	2.6	8.53	140	8.1	242	13.4
$N_{120}P_{26}K_0$	$N_{120}P_{26}K_0$	4.72	3.59	2.6	8.49	139	18.8	234	13.5
$N_{120}P_{26}K_{42}$	$N_{120}P_{26}K_{42}$	4.79	3.69	2.6	8.52	141	22.6	287	14.3
$N_{120}P_{26}K_{42}$ + Zn	$N_{120}P_{26}K_{42}$	4.99	3.87	2.5	8.51	140	21.0	275	14.1
$N_{120}P_{26}K_{42}$ + FYM	$N_{120}P_{26}K_{42}$	5.29	4.16	4.3	8.38	163	22.5	301	12.0
$N_{120}P_{26}K_{42}$ + gypsum	$N_{120}P_{26}K_{42}$	5.23	4.10	3.7	8.18	146	19.0	299	11.6
$N_{120}P_{26}K_{42}$ + FYM + gypsum	$N_{120}P_{26}K_{42}$	5.35	4.22	4.2	8.28	164	23.8	300	10.1
$N_{120}P_{26}K_{42}$ + SPM	$N_{120}P_{26}K_{42}$	5.31	4.46	4.2	8.29	159	24.1	304	11.4
$N_{120}P_{26}K_{42}$ + SPM + gypsum	$N_{120}P_{26}K_{42}$	5.41	4.52	4.0	8.28	160	24.0	301	10.0
LSD (P=0.05)		0.42	0.34	0.65	0.08	8.5	2.3	18.5	0.75

Nutrient Management Strategies for Using Saline Waters

The accumulated salts in saline soils can affect the nutrient availability for plants in following ways: by changing the forms in which the nutrients are present in soils; by increasing the losses through leaching when the saline soils are leached heavily or as in nitrogen through denitrification or by precipitation in soils; through interactive effects of cations and anions; and through the effects of complementary (non-nutrient) ions on nutrient uptake. By and large most soils in India are deficient in nitrogen, which need to be supplemented through fertilizer sources. Urea is by far the most widely used N source for crops. Urea is first hydrolysed to ammonia and carbon dioxide by the enzyme urease and the process has the most commonly expressed disadvantage of loss of N via NH_3- volatilization. (Kumar *et al.,* 1995; 2000). Following the application of N through inorganic fertilizer sources, there is a sudden burst in microbial activity and a large pool of NH_4^+ is generated. Thus, ammonia volatilization is extensive in salt affected soils which lead to low N-use efficiency by crops. Proper splitting of fertilizer N doses so as to meet crop demands, deep incorporation, slow release N-fertilizers, application of urease inhibitors and use of organic-N sources have all been reported to increase N-use efficiency by reducing the N-losses.

Interactions between fertilizers and salinity have been studied at large. However, the evaluation of the concept of alleviating salinity stress through enhanced fertility brings out that such a strategy of additional application of fertilizer nitrogen to reduce/overcome the adverse effect of salts may not pay off well. In general, when salinity is not a yield limiting factor, the applied nitrogenous fertilizers will increase the yield of crops, proportionately more than when the salinity become the limiting factor. (Dayal *et al.*, 1994; Swarup and Yaduvanshi, 2004a). A better strategy for improving N-use efficiency therefore, seems to be to substitute a part of inorganic fertilizer requirements through organic materials. Experiments on the use of organic materials have been conducted in the network trials on different crops and the results have been summarized in Table 2. At a given salinity level, increasing application of organic materials improved yields of all the tested crops. However, when salinity of the irrigation water was higher, the percent response was reduced when referenced to yields where no organics were applied. It seems that addition of organic materials temporarily immobilize the NH_4^- N and subsequently release the organically bound N to crops during the growth season. Increased responses to N-fertilizers in the presence of organic materials suggest its role in reducing the volatilization losses and enhance the N-use efficiency under saline environment. A combination of organic and inorganic sources saved N or 50% in rabi and 25% in kharif.

Table 2. Effect of nitrogen levels and organic materials on yield of crops (t ha^{-1}).

Kharif	Rabi		Agra			Gangawati		
Inorg. N	Inorg. N	Org.Mat ------(%RDN)------	Mustard	Sorghum	OC(%)**	Wheat	Maize	OC(%)**
Nil	Nil	Nil	0.66	17.4	0.25	0.96	1.16	0.40
50	50	Nil	1.45	23.9	0.33	1.96	2.21	0.48
100	100	Nil	1.93	28.4	0.34	2.39	3.27	0.50
125	125	Nil	2.17	30.6	0.34	2.52	3.52	0.48
75	Nil	GM_1(10t ha^{-1})	1.39	26.8	0.42.	1.56	3.15	0.54
75	Nil	GM_2(10t ha^{-1})	1.30	27.2	0.43	1.47	3.10	0.56
75	Nil	OM_1(15t ha^{-1})	1.40	29.6	0.54	1.47	3.25	0.56
75	Nil	OM_2(5t ha^{-1})	0.89	24.3	0.39	1.22	3.07	0.57
50	50	GM_1	1.93	28.1	0.43	2.35	3.37	0.51
50	50	GM_2	1.76	28.7	0.42	2.21	3.19	0.51
50	50	OM_1	2.04	31.5	0.54	2.31	3.23	0.54
75	50	OM_2	1.46	25.7	0.42	1.99	2.98	0.54
	LSD(P=0.05)		0.26	3.7		0.41	0.52	

GM_1 Dhaincha, GM_2 Subabuul for Agra and Glyricidia at Gangawati; OM1 FYM, OM_2 Paddy straw
*75% at Gangawati; ** Organic carbon determined after 5-6 years

On the other hand, increasing the level of phosphorus over the recommended dose seemed to mitigate the adverse affects of salinity. Type of salinity has also been observed to influence the response of crops to phosphorus application. When wheat and barley crops were irrigated with chloride dominated waters, the yield response to phosphate application was higher as compared to sulphate dominated waters. Results show the application of phosphatic fertilizers most likely will improve the threshold limits of crops to the use of chloride dominated saline waters (Manchanda *et al.*, 1982; Chauhan *et al.*, 1991). The generalization of results with fertilizer use under saline conditions seems difficult but it can be stated that in most cases moderate levels of salinity can perhaps be compensated by increased fertilizer doses so long salinity levels are not excessively high and the crops under consideration are salt sensitive.

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Managing Soil Health under Poor Quality Irrigation Water

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Introduction

Soil health refers to the fitness of soil for any specific purpose determined by the factors chosen for soil classification, soil suitability and land capability. It examines spatial and temporal variations induced by land use policy or management. Soil organic carbon (SOC) is the most reliable, versatile and easily assessable indicator, encompassing interactive effect of several factors. Plateuing or decreasing trends of crop yields at current level of management indicates declining soil health. Erosion, drought and desertification, irrigation induced salinity and sodicity, paradigm shift in land use, nutrient depletion and intensive cultivation are the cause of soil health deterioration. Erratic rainfall and exploitation of land, water and vegetation resources by ever increasing human and livestock population further accentuate the problem of soil health. Increasing salinity, residual carbonate, alkalinity and contamination of surface and ground water through heavy metals, nitrates, fluoride and arsenic are the reflection of deteriorating soil health.

Recycling of contaminated or poor quality water through irrigation is further escalating the problem of soil health. Recent estimates indicated that about 32 to 84 % of wells are having poor quality water, dominantly occurring in arid and rain-fed agro ecosystems; covering more than 65 % (92 m ha) of cultivable land in India and spreads over in 18 states and 12 agro-ecological regions. High salinity groundwater is reported in arid agro ecosystem while alkali water predominats in semi arid parts of India receiving 500 to 700 mm rainfall. High RSC water with low salinity is common in central and southern part of rain-fed agro-ecosystem (Gupta *et al.*, 1994). Ground water is contaminated with toxic level of B, F, NO_3^-, Se and As in some parts of the region.

Declining water table as a consequence of high withdrawal for intensive cultivation is another important issue. An alarming rate of decline in groundwater, more than 4 meters during 20 years (1981-2000) in some parts of arid and rain-fed ecosystems depict gravity of situation and a sizeable area turns to gray zone. About 60 % blocks of Rajasthan have been reported in gray zone. Water quality deterioration is attributed partly to increased salt concentration and partly to intermixing of poor quality water strata.

Thus the entire arid and rain-fed ecosystem is dominantly affected with poor quality of water. Its continuous use is the major threat to soil health. Organic carbon decomposition, inorganic carbon buildup, secondary salinization and sodification are the immediate impact. Inadequate fertilization, drought and desertification with poor quality water add other dimension. These altogether call for immediate attention for the sustainability of agriculture. The present paper deals with the issues associated to deteriorating soil health in the region of poor water quality; agro-techniques that counter the impact of poor water quality are elaborated. The paper also highlights the strategy for harnessing the optimum benefit of agro-technique for mitigating the impact of poor water quality and for providing cleaner water and fresh environment to the people deriving their livelihood on the earth.

Poor Water Quality Induces Salinity and Sodicity

The poor quality water enhances salinity and sodicity, which expedites the process of SOC decomposition **(**Eswaran *et al*. 1999) and affects micro floral composition adversely. Loss of biological productivity ranged from 10 to 25 % and 25 to 50 % in Inceptisols and Alfisols affected with medium to high sodicity, while decrease of productivity has gone up to 25 to 50 in Inceptisols and Alfisols and >50 % in Vertisols affected with same level of sodicity **(**NBSS&LUP, 1990). The magnitude of biological productivity loss could be imagined from 10.1 million hectare saline and sodic land apart from 2.2 million hectare saline flats **(**Sehgal & Abrol, 1994**).**

Inorganic Carbon

The soils irrigated with brackish water have appreciable amount of inorganic carbon/ pedogenic carbon, which is the cause of SOC decomposition, soil salinity development and increase of bulk density (Singh *et al.*, 1999). Pedogenic carbonate alone or in combination with other factors restrict root proliferation, immobilize soil plazma and prepare ground for secondary salinization. The increase of inorganic carbon by 64, 44, 14 and 3.1 to 5.5 and 3.2 g/m^2 was reported in Malkosani, Pipar, Bhagasani, Chirai and Bap variant series of Jodhpur, respectively with simultaneous rise of soil pH by 0.2 to 0.4 units in a span of 27 years from 1975 to 2002 (Singh *et al.* 2008).

Temporary Drought and Desertification

A high solute potential because of salinity and sodicity reduces availability of water. The problem is more acute in the year of low rainfall or in drought years. These altogether heighten the influence of drought or create drought like situation which adversely affect the biological productivity and its input in soils.

About three to four months after Rabi harvest and before Kharif sowing, land fallowing is common in India, which adversely affects the soil health. Doran and Ziss (2000) estimated SOC loss by summer fallowing as 320 to 350 kg in semi arid tropics. Commonly practiced cropping sequence in arid region such as pearl-millet- fallow- pearl-millet rotation might be the cause of declining SOC.

Soil Erosion

Salinity and sodicity on account of regular irrigation with poor quality water adversely affects the soil fabric and expedite the process of soil erosion. Erosion is mostly active on surface soils, erode SOC and nutrients. Loss of biological productivity is reported to the tune of 25 to 50 and >50 % in severely and very severely water eroded Inceptisols and Vertisols, respectively. SOC depletion was reported about 50% higher from wind eroded cultivated soils and cultivable wasteland than their non-eroded counterpart (Narain, 2000).

N**utrient Depletion**

Nutrients depletion from the agriculture field is the severe threat to the soil health. Sub-optimal nutrient application together with poor quality water results in sparse plant cover and low vegetative inputs into the soils. In arid and rain-fed areas removal by crop was far more than the added through fertilizers (Katyal, 1997). Alfisols, Ultisols and Oxisols with low cation exchange capacity were the heaviest looser. Soil organic carbon loss ranged from 0.22 to 6.0 % over the initial in different cropping sequences of India due to inadequate fertilization, whereas depletion of SOC was far less 0.22 to 2.92 % under balanced fertilization (Anonymous, 2002-03). Inadequate fertilization with high RSC (residual sodium carbonate) depleted phosphorus and potassium by 7.7 and 13.4 %, respectively in arid soils of India from 1975 to 2002 (Singh *et al.,* 2007).

The abrupt change in land use by introducing high water requiring crops further heighten the problem of nutrient depletion. Traditional farming system was extensive with low yields which was sustainable in harmony with the carrying capacity set by the nature. Low productivity system has lost relevance in view of increasing demand of food, fiber and wood. Since 1951- 52 there has been an increase of 36, 22 and 54 million hectare irrigated, net sown and double cropped area respectively on the cost of fallow, pastures and grazing lands and tree grooves. High intensity farming system supports high productivity, they appear non sustainable in absence of holistic land management which satisfies needs of stakeholders in an economically favorable way and simultaneously contains curative action for preserving the soil health and prevents soil degradation.

Agro-Techniques Counter the Influence of Poor Quality Water

Whether soils are naturally high or low in SOC, adding new organic matter every year is perhaps the most important way to improve/ maintain soil health with minimum use of irrigation. Regular additions of organic matter improve soil structure, enhance water and nutrient holding capacity, protect soil from erosion and compaction and support a healthy community of soil organisms. Good soil physical properties also prevent ground water contamination by improving filtering capacity of soils.

Adequate Preventive Measures for Erosion Control

Protecting soils at the place is the most important for reducing the risk of SOC depletion. Stubble mulching with the residue of pearl millet, alternate strip of erosion susceptible and erosion resisting crops, sand dune stabilization with vegetative cover, shelterbelts plantation are the effective measures for controlling wind erosion. In an experiment of wind erosion during 1994 to 1999, an increase of SOC from 850 to 1400 kg/hectare was reported beneath the shelterbelts. An increased level of nitrogen, phosphorus and potassium has also been reported. (Solanki *et al.*,1999).

Moisture Conservation

Increased good quality irrigation water enhances SOC by increasing period of vegetative cover and vegetative input to the soils. These altogether increase water stable aggregates that offer protection to SOC against sun beating and erosion. Rain water storage in tanks, subsurface barrier for ground water recharge and khadin management are some of the techniques that can be helpful for increasing the availability of fresh water for irrigation. *In situ* moisture conservation including inter row water harvesting, field bunding, mulching, deep ploughing and other agronomic practices such as drought tolerant cultivars, optimum plant density, and proper sowing time, balance fertilization, use of sprinklers and drips for irrigation on the undulated topography may prove beneficial for moisture storage and soil organic carbon build up.

Correcting Water Quality

Gypsum application is very important in reducing the adverse impact of high RSC water used for irrigation. Gypsum application @ 50 and 100% of the total requirement effectively reduces the carbonate and bicarbonate salinity in irrigation water and enhanced soil health as evident from reduced soil pH by 0.3 to 0.4 units, increased nutrient availability and depressed SAR by 6.4 to 10.7 (Joshi and Dhir., 1994).

Integrated Nutrient Management

Integrated nutrient management including chemical fertilizers, manures and bio-fertilizers such as Azospirillum, Rhizobium, blue green algae, phosphate solubilizing micro organisms and VAM fungi enhanced vegetative cover and over all biomass production. These ultimately results in vegetative input to the soils and a higher SOC which in turn improve aggregate stability (Masri *et al.*, 1996), enhance total nitrogen content (Harris *et al.*, 1995), increase mineralization potentials and stabilize SOC (Ryan 1997).

Legumes Based Cropping System

Legumes fix atmospheric nitrogen and in addition to this legumes also improve soil structure, reduce soil pH and increase the availability of native phosphorus. This could be seen from a long-term trial conducted at CAZRI Jodhpur with Pearl millet-moth bean cropping sequence in a rotation of four years. The sequence maintains initial SOC of 0.22 and 0.14% in surface and subsurface horizons during the period. Another sequence with legume-legume-legume-pearl millet increased SOC. In contrast rice based cropping sequence together with recommended dose of fertilizers produced higher yield on the cost of declining soil health.

Legume Based Forage Production

Growing grasses is well known for improving SOC and binding soil particles. Inclusion of leguminous grasses with traditional forage in arid region is found more beneficial. This type of rotation induces high residue, which increases SOC, aggregate stability, biological diversity, water movement, aeration, porosity and reduces bulk density**.** A study conducted in the arid region indicated that intercropping of *Cenchrus cilliaris* and *Clitoria ternatia and Cenchrus cilliaris* and *Lablab purpures* added higher SOC both at the surface and in the subsurface as compared to the pasture with *Cenchrus cilliaris* alone (Tripathi *et al.*, 2002).

Silvipasture and Silviculture Based Agriculture

Plantations (silviculture) alone or in combination with grasses are another very important practice for improving SOC. Plantations with *Acacia tortelis*, *Colophospermum mopane, Hardwickia binata* and *Cenchrus ciliaris* are noted for increasing SOC, available nitrogen, phosphorus and micronutrients in arid region. Silvipasture and plantations have 185 and 141% higher potentiality of SOC sequestration than traditional pearl millet-fallow system. These could sequester 9.6 and 7.4 kg/m^2 higher CO_2 than pearl millet-fallow system approximately in the same period (Singh *et al.*, 2007). Therefore, silvipasture and plantations should be integral part of agriculture particularly for improving the severely eroded areas, community land and wasteland.

Agro-forestry

Growing of crops with shrubs, herbs and grasses is the old age practice for providing fodder to the animals, timber to the farmers and shades to the soils. The practice simultaneously could enrich the soils by sequestering 121% higher SOC than the pearl millet-fallow system. Growing of trees with crops could sequester 6.29 kg/m^2 higher atmospheric CO_2 than the cultivation of crops alone (Singh *et al.*, 2007). This could be possible because of higher biomass production and higher soil moisture profile beneath the agro-forestry system. Extensive research revealed that agro-forestry including moth, cluster bean and local variety of pearl millet as a crop component with *Calligonum polygonoides* and *Lasiurus sindicus* as perennial trees and grass are more successful in areas receiving 100 to 250 mm rainfall, while plantation of *Prosopis* and *Ziziphus species* in the field and *Capparis decidua* on the boundary with pearl millet, moth bean, sesame and cluster bean is beneficial in 250 to 350 mm rainfall areas. However, growing of *Prosopis cineraria* and *Tecomella undulata* with pearl millet, green gram, moth bean and cluster bean is advantageous in the area of 250 to 450 mm rainfall on the desert margin. In the irrigated area of arid region plantation of *Prosopis cineraria* and *Acacia nilotica* with wheat, barley, mustard and gram in winter cotton, sorghum, pearl millet and sesame in summers are expected to improve SOC.

Agriculture Diversification

Diversified farm means growing of variety of crops in a rotation together with animals. These are economically sustainable and resilient. Soil organic carbon depletion not only occurs because of growing of annual crops requiring specific and high management but also keeping land out of agriculture. Diversification integrating both crops and livestock in the farming system may be beneficial to each other because latter may supplement manure to the soils for increasing/ maintaining soil organic matter. Pasture and forage crops included in rotation may also contribute significantly in raising soil organic carbon and reducing erosion.

Conservation Agriculture

Tillage operations disturb soil structure and redistribute energy rich organic substances in the soils. Researchers have shown that the use of mould board plough reduced SOC by an average of 256 lb/acre/year (Reicosky *et al.*, 1995). Conservation agriculture is an umbrella covering a wide range of diverse tillage practices that have as common characteristics, the potential to reduce soil and water loss relative to conventional tillage. A well accepted definition of conservation agriculture is planting and tillage combination that retain a 30 % or higher crop residue on the soil surface. Conservation agriculture also increases SOC, improves nutrients, water use efficiency and physical properties besides restricting soil erosion.

Gene Mining for Drought Avoidance

It is the other important practice to develop drought hardy plants. There are several species in sub-Saharan Africa and other desert, which have very extensive root system for mining water from large volume of soils, such as Prosopis Juliflora serving in the rainfall zone ranging from of 200 mm in Bhuj to 1000 mm around Ramnathpuram in east coast. Short duration crop of moth bean is another classical example of deep root system. Genetic and molecular characterization of such plants can help to introduce new genotype in the plants through genetic engineering. Thus genetically modified plants can manage a biotic stress of droughts, salinity, heat and cold waves and such attempts may be beneficial for averting the impact of fallowing on SOC depletion.

Strategies for Optimizing the Influence of Agro-techniques

Strategies for optimizing the influence of agro-technique in terms of improving soil health encompasses long term planning with minimum use of irrigation which consists of selection of ideal land use and management. Agro-eco-zoning and segmentation of land based on the land quality class are the effective methods for compartmentalization of land depending upon quality and constraints. A matching exercise between the land use requirement and available resources should be the next step for obtaining the best possible land use. The associated management practices should also be the part of land use optimization programme. A contingency crop planning should also be framed on the event of severe drought and complete failure of monsoon. The entire soil health improvement plan should be monitored on a specific time frame.

Agro-Eco-Zoning for Regional Planning

Agro-ecological zoning separates areas into the region at the apex level and agro-eco unit at the bottom. The agro-ecological region identifies the natural resources in terms of problems, potentialities and constraints and their extent with respect to land utilization types and groups them in uniform units. Digital database in GIS and application of logic through decision support system (DSS) further enhance the process and precession of agro-ecological delineation. The sub agro ecological regions are further subdivided into agro-ecological zones based on landforms, soil association and land use. The agro ecological zones have further taken down to sub zones depending on terrain characteristics, parent materials, soil texture, depth, salinity, surface and ground water potentiality and cropping pattern. The latter is considered ideal for management at the regional level (Faroda *et al.*, 1999).

Land Quality Class for District and Farm Planning

Foregoing discussion indicated that alternate land use systems including agro forestry, silvipasture, and silviculture are established techniques for improving soil health. Land quality class (LQC) separates the area for alternate land uses from that area capable of producing crops. The proportion alternate and cropland may range from 30 % on the soils of land quality class (LQC) I to 95% with the soils of land quality class of IX (Eswaran *et al.* 2000). Marginal shallow soils (LQC IV and V), sand dunes, rocky surfaces, saline flates, shallow and miscellaneous (LQC VI, VII, VIII and IX) should be placed under alternate land use systems. Growing of crops on these marginal lands aggravate wind erosion which affects the adjoining agriculture land of LQC I to III. Alternate land use systems on this kind of land not only improves the soil health by controlling soil erosion, adding organic carbon and providing canopy cover to the soils but also provides fodder to the animals. This acts as a bigger agro forestry system without affecting the area presently used for agriculture. Allocation of marginal land under alternate land use systems also acts as cushion for the farmers for raising animals during the drought years.

Right Choice of Species for Agro-Eco-Zones/ Land Quality Class

Land suitability evaluation depending on the rainfall, temperature, humidity, soil morphology and fertility helps to identify the right type of cultivars, grasses and trees for each land quality class/ each agro-eco sub-zones. Optimum soil organic carbon density which is a total reflection of soil health can also work as a tool for selecting right type of cultivars. For optimizing SOC density, a soil suitability cumulative index for each land use was derived by allocating the numerical value ranging from 20 to 80 to each soil characteristics depending upon the land use requirement (Sys *et al.*, 1991). Numerical value of each soil characteristics was normalized on the scale of 100 before their addition for cumulative soil suitability index. For giving the regional look normalized soil suitability cumulative index was further normalized on the scale of 0.2 to 1.0 with respect to the best soils of the region. The latter was regressed against soil organic carbon density (0-100 cm soil depth) for developing second order polynomials. These were differentiated twice for calculating optimum value of SOC density for different land use. The soils with SOC density of above 3.0 kg/m^2 could be used for growing cowpea, cluster beans and wheat while soils with SOC density of 2.56 kg/m^2 may be utilized for sesame, moth beans and pearl millet. *Lasiurus sindicus* could be grown successfully in the soils,having soil organic carbon density 2.03 kg/m^2 .

Technological Support

Right type of land use for an area should have technological support which includes development of agri-silvipastoral system for erosion control using combination of trees, shrubs and grasses as shelter belt. Crop improvement for drought mitigation, integrated nutrient and water management, residue management for enhancing soil fertility are the other technique should come after the selection of ideal land utilization types. The combined effect of all factors may lead to the desired goal of soil organic carbon improvement in arid regions of India.

Contingency Planning for Drought Mitigation

Keeping land without vegetative cover because of low rainfall punctuated with high drought frequency is the major reason for deteriorating soil health in the arid region. Therefore, a sound contingency planning is needed to provide vegetative cover to the soils during the drought and the planning should be job and income oriented. The land use planning may include short duration varieties of pearl millet and legumes. Mixed cropping with pearl millet, moth bean, moong bean, cluster bean, sesame, kachri may be one of the viable options. Cash crops requiring limited water and soils of lower fertility such as isabgol, cumin, spices and condiments may be the part of contingency planning. Shrubs like *Lawsonia alba*, *Capparis deciduas, Cassia angustifolia*, *Commiphora wightii* are drought hardy and may be planted in the field and on the field boundary with short duration varieties of crops. The inclusion of medicinal plants in the crop curriculum may be explored in drought prone areas (Kumar *et al.* 2005).

Monitoring

Monitoring of the soil organic carbon dynamics is essential to assess the sustainability of the soil resource in response to human induced pressures such as land use and soil contamination. Monitoring is defined as the repeated inventory of an item to determine trend and status. One method of monitoring soils is benchmark sampling. The basic principle of benchmark sampling is to sample at the same location year after year. Benchmark sites are representative of larger areas and are usually about a quarter acre (0.1 ha) in size. Sampling with this method is less expensive and time consuming than traditional grid sampling and is more consistent because it assumes the benchmark area is less variable than the larger area which it represents.

Conclusions

Severe erosion, force fallowing, inadequate nutrient application, insufficient moisture, lack of soil aggregation, mono-cropping, irrigation induced salinity and sodicity, gradual building of inorganic carbon, excessive tillage and use of marginal land for cropping are some of the factors that threat to the soil health. Regular irrigation with poor quality water further expedites the process of soil quality deterioration. A holistic approach dealing with agro-eco-zoning, evaluation of land for ideal land utilization types, optimization of land use may improve soil organic carbon and soil health. Provided, these are supported with agro techniques which includes adequate area allocation for alternate land use, agro-forestry, agro horticulture, integrated nutrient, water and pest management, conservation tillage, moisture conservation, water harvesting and special allowance for drought mitigation.

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Saline Water Irrigation and Its Influence on Produce of Horticultural Crops

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Introduction

The continuous increase in earth's population while fresh water resources are finite requires more water for domestic, industrial, and agricultural needs. More water to irrigate crops for food and fiber production to meet the requirement of the expanding population is required. Hence, good quality water is becoming scarce not only for raising crops but also for drinking and other lively hood requirement. Water availability for irrigation could be enhanced through judicious and proper use of saline water and the recycling of drainage waters for irrigation. Waters generally classified as unsuitable for irrigation can, in fact, be used successfully to grow crops without long-term hazardous consequences to crops or soils, with the use of improved farming and management practices. The development of crops with increased salt tolerance and the adoption of new crop and water management strategies will further enhance and facilitate the use of saline waters for irrigation and crop production, while keeping soil salinity from becoming excessive. Pre-harvest treatments (water and nutrient management) have significant effects on post harvest behavior of produce. Irrigation water quality, timing, amount and frequency affect the yield, taste and keeping quality. It has been known for several years that saline water irrigation of crop improves fruit quality in terms of taste, colour and concentration of soluble solid, especially sugar and acids. Unfortunately, the improvement in quality usually is accompanied by reduced yields, mainly as a result of a small fruit size.

Effect of Saline Water Irrigation on Quality Attributes of Different Crops

Information on the effect of water salinity and soil salinity on crop quality is very scant although such effects are apparent and have been noticed under field condition. In general, soil salinity, either caused by saline irrigation water or by a combination of water, soil and crop management factors, may result in reduction in size of produce; change in colour and appearance; and change in composition of the produce. Saline water may affect the yield or quality of the produce, which is evident from the findings of various workers. For example, Shalhevet (1969) reported a reduction in seed size in ground nut after irrigating the crop with marginal quality water. However, there was an increase in the oil content with increasing salinity up to a certain point. In an another study,

Shalhevet and Yaron (1973) observed that for every increase in 1.5 ds/m in ECe, there was 10% reduction in yield, but there was marked increase in soluble solids. Fruits from higher salinity treatments were less liable to damage and number of spoiled fruits was also less. Mizrahi and Pasternk (1985) studied the effect of salinity on quality of various vegetable crops and reported that the fruits from processing tomato cultivars those were exposed to various degree of salinity had higher total soluble solids (TSS) and acidity than those irrigated with normal water (control). Although, fruit yield with saline water irrigation was lower, but this effect was offset by the higher fruit quality. Melon fruits from plants subjected to saline water had better taste than their controls. After 3-4 weeks of storage at room temperature, there was no longer any difference in taste score. Mizarahi *et al.* (1988) have observed that salinity improved flavor and increased percent total soluble solids and sugar concentration of tomato fruit. Also, it reduced color, flavour and thus improved the overall quality of fruit. Rhoades *et al.* (1989) recorded an increase in the quality of wheat, melon and alfalfa with the use of saline irrigation water. Shelf-life was not affected by saline treatments, whereas the yield and fruit size were generally lower than fruits those from the control treatments. Further, increase in salinity increased the soluble solids concentration and slightly improved the appearance of muskmelons (Mendlinger, 1993). Lurie *et al.* (1991) described that saline water slightly reduced the yields of pomegranate but did not affect fruit quality or storage potential. Similarly, it had no effect on bearing, but fruits had less black heart and superficial scald after storage than fruits from trees irrigated with fresh water. In taste also, pomegranate and pear fruits from trees irrigated with saline water were reported to better than those harvested from control plants. Grape yields are markedly reduced by irrigation with saline water but fruits were sweeter. Oron *et al.* (2002) studied the effect of salinity on quality of pear and reported higher proportion of healthy fruits, higher overall quality under saline water condition. Damico *et al.* (2003) observed that increasing water salinity reduced crop water consumption, plant growth and crop yield, but increased fruit quality. Similarly, in tomato, titrable acidity, osmotic pressure and concentration of sodium, sugars and organic acids were increased in treated plants than those harvested from control plants. Hepaksoy (2004) described the effect of salinity on some fruit quality attributes and sugar composition of Sutsuma mandarin. Titrable acidity of fruit juices decreased with decrease in salinity level. Similarly, sugar composition of fruits varied with variation in salinity level.

A very few work on use of saline water for crop production has been done in India but that too were reported on field crops as under Chouhan and Chouhan (2000) studied the effect of different quality water on yield of sunflower and mustard. Different quality water was prepared with canal and saline water. They observed significant difference in the plant irrigated with saline water. However, no significant difference was observed with 1: 1 ratio and 2:1 ratio of canal and saline water. Naresh *et al.,*(1993) reported decline in yield of wheat with saline water. Minhas (1993) also reported the similar results for wheat, when irrigated with drainage water.

Water Quality

Irrigated agriculture is dependent on an adequate water supply of usable quality. Water quality concerns have often been neglected because good quality water supplies have been plentiful and readily available. This situation is now changing in many areas. Intensive use of nearly all good quality supplies means that new irrigation projects and old projects seeking new or supplemental supplies must rely on lower quality and less desirable sources. To avoid problems when using these poor quality water supplies, there must be sound planning to ensure that the quality of water available is put to the best use.

Water quality refers to the characteristics of a water supply that will influence its suitability for a specific use, i.e. how well the quality meets the needs of the user. Quality is defined by certain physical, chemical and biological characteristics. In irrigation water evaluation, emphasis is placed on the chemical and physical characteristics of the water and only rarely is any other factors considered important.

Using Saline Water for Irrigation

Utilization of saline water for irrigation is associated with salt accumulation in the soil, which might be harmful to plants, and diminishing yields. The salt effects on physiological process result from lowering of the soil water potential and the toxicity of specific ions. On the other hand it has been reported that non-toxic highly saline water has an agricultural potential. If, irrigation can be managed in such a way that provides high soil moisture content and, consequently, high soil water potential within the whole root zone, the osmotic effects will be damped (Michelakis *et al*., 1993). Moreover, when saline water is skillfully used for irrigation, it can be beneficial for agricultural production, particularly in orchards (Hoffman *et al.*, 1986). Saline water use for agricultural production offers several additional benefits:

(i) Re-use (instead of disposal as with fresh water) during the entire year, with minimal environmental risk of ground water deterioration (Oron, 1993); and (ii) A premium market price for the fruits and vegetable products because of a high content of total soluble solids and an extended shelf life, due to the adaptation of the plant to the stressful growing conditions (Mizrahi & Pasternak, 1985).

Classification of Saline Water for Irrigation

The suitability of saline water for irrigation is dependent upon the conditions of use, including crop, climate, soil, irrigation method and management practices. Hence, water quality classifications are not advised for assessing water suitability for irrigation. However, for the purpose of identifying the levels of water salinities for which these guidelines are intended, it is useful to give a classification scheme. Such a classification is given in Table 1 in terms of total salt concentration, which is the major, quality factor generally limiting the use of saline waters for crop production.

Table 1. Classification of saline waters

Water class	Electrical conductivity dS/m	Salt concentration mg/l	Type of water
Non-saline	<0.7	<500	Drinking and irrigation water
Slightly saline	0.7 – 2	500-1500	Irrigation water
Moderately saline	2 - 10	1500-7000	Primary drainage water and groundwater
Highly saline	10-25	7000-15000	Secondary drainage water and groundwater
Very highly saline	25 -45	1 5 000-35 000	Very saline groundwater
Brine	>45	>35 000	Seawater

The development of appropriate practices for the use of saline water for irrigation requires an adequate understanding of how salts affect waters, soils and plants. But, the sustainability of a viable, permanent irrigated agriculture, especially with the use of saline irrigation waters, requires much more. It requires constant monitoring of salinity levels to ensure salts stay within the acceptable range, and farmer need to be prepared to accept lower-than-average yields.

How Does Saline Water Irrigation Affect the Plant?

Plant roots generally take up moisture by a type of osmosis through membranes in root cells. Osmosis is a natural process where water, passing through a semi-permeable membrane, moves from a solution of low levels of dissolved salts to one with a higher salt level. This process allows water to move from a solution of relatively low concentration (the irrigation water) into a solution of relatively high concentration (in the plant root cells) in an attempt to establish equilibrium in the two solutions. This continues until the plant cells become full, or turgid.

If the irrigation water is moderately saline, the plant has to work harder to absorb water from the soil. With lack of water, the plant soon begins to wilt, and growth is slowed, with reduced yields. If highly saline irrigation water is used, the process of osmosis can become reversed. Where the solution outside the plant roots is higher in salt concentration than that of the root cells, water will move from the roots into the surrounding solution.

The plant loses moisture, and so suffers stress. This is why symptoms of high salt damage are similar to those from high moisture stress. For example i) leaf tip dieback ii) margins yellowing, scorched and turning brown or black, followed by iii) Leaf fall of dead leaves.

If water is sprayed directly on leaves, it can cause salt scorch and leaf damage even at lower salinities. If irrigation water is only moderately saline, but it contains high concentrations of specific ions, it can still damage the crop. For example

i) high chloride or sodium ion levels (the most common) cause symptoms similar to high salinity.

ii) high bicarbonate levels can make calcium and magnesium unavailable to the plant. Some effluent waters that may be used for irrigation can have high boron levels.

Acceptable Salinity Levels for Horticultural Crop

There will be some variation in salinity affects depending on crop, variety, rootstock, leaching ability of the soil and also method of irrigation (spray, drip or furrow). Most crops, including salt-sensitive crops, should accept salinity levels of up to 0.7dS/m without loss of yield. With salinities over 0.7dS/m, we could expect to see reduced yields from some salt-sensitive plants.

Most grapevines should accept salinity levels of up to 1.0 dS/m without loss of yield. Above this figure, yields generally start to decline, and we could expect up to 10% yield loss at 1.7 dS/m.

Management Options for Saline Irrigation Water for Horticultural Crops

Monitoring Salinity Levels

Regular monitoring of salinity level within the root zone of the crop is must and make sure salt stay below the harmful level. The main method of reducing the effect of saline water is to apply extra water to leach salts below the rootzone. Leaching often occurs with rainfall. In other cases, irrigation water beyond the crop's water requirement may need to be applied. The extra irrigation water needed to leach salts is termed the leaching fraction**,** and this can be calculated for various crops and soil types. If additional leaching water is applied, good subsoil drainage is must to ensure the leached saline water can regularly be removed from the soil.

Mulching

As saline water evaporates from the soil it leaves behind salts. Good mulch helps reduce surface evaporation, maintains moisture near the soil surface and lessens the buildup of soil salinity.

Crop Tolerance to Salinity

All plants do not respond to salinity in a similar manner; some crops can produce acceptable yields at much greater soil salinity than others. This is because some are better able to make the needed osmotic adjustments enabling them to extract more water from a saline soil. The ability of the crop to adjust to salinity is extremely useful. In areas where a build-up of soil salinity cannot be controlled at an acceptable concentration for the crop being grown, an alternative crop can be selected that is both more tolerant of the expected soil salinity and can produce economical yields.

There is an 8 to 10-fold range in salt tolerance of horticultural crops. This wide range in tolerance allows for a much greater use of moderately saline water much of which was previously thought to be unusable. It also greatly expands the acceptable range of water salinity (ECw) considered suitable for irrigation. The relative salt tolerance of most horticultural crops is known well enough to give general salt tolerance guidelines.

Timing of Irrigations

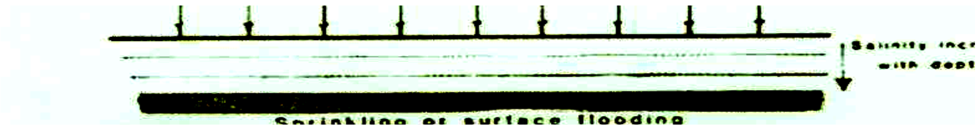
The key to the effective use of saline irrigation waters and salinity control is to provide the proper amount of water to the plant at the proper time. The ideal irrigation scheme should provide water as nearly continuously as possible, though not in excess, as needed to keep the soil water content in the rootzone within safe limits. However, carefully programmed periods of stress may be needed to obtain maximum economic yield with some crops; cultural practices also may demand occasional periods of dry soil. Thus, the timing and amount of water applied to the rootzone should be carefully controlled to obtain good water use efficiency and good crop yield, especially when irrigating with saline water.

Timing of irrigation may include increasing the frequency of irrigation, irrigating prior to a winter rainy season, and using pre-plant or other practices to aid in germinating the crop. The goal of irrigation timing is to reduce salinity and avoid water stress between irrigations. Water stress between irrigations can often be eliminated by increasing the frequency of irrigations, thereby preventing excessive root zone depletion caused by too long an interval between irrigations. By decreasing the interval between irrigations, higher soil-water availability is maintained.

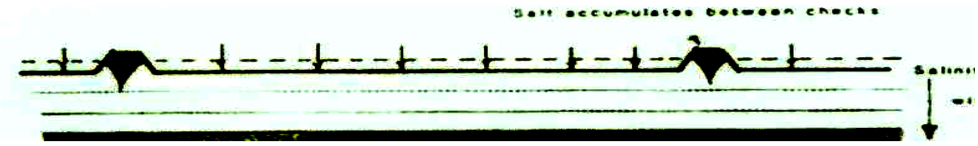
Irrigation Methods

The method of irrigation directly affects both the efficiency of water use and the way salts accumulate. The main ways to apply water are basin flooding, furrow irrigation, sprinkling, sub irrigation, and drip irrigation. Flood irrigation is good for salinity control when using saline waters if the land is level, though aeration and crusting problems may occur. Aeration and crusting problems are minimized by using furrow irrigation, but salts tend to accumulate in the beds. If excess salt does accumulate, a rotation of crops and periodic irrigation by sprinkler or flooding should be used as salinity-control measures.

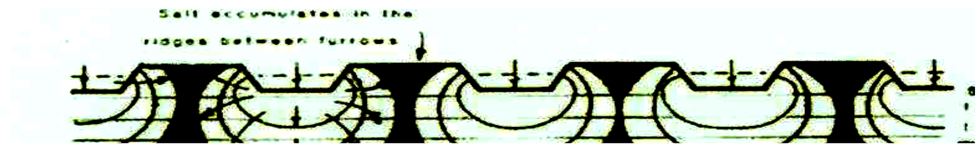
Flood and sprinkler irrigation are designed to apply water evenly over the entire irrigated area. This results in most of the salts accumulating in the lower root zone. The degree of accumulation depends upon the leaching fraction. Fig. 1 illustrates several typical salinity profiles resulting from surface flooding or sprinkler irrigation at leaching fractions varying from 0.1 to 0.4. Fig. 1 shows the salt accumulation patterns for surface flooding or



Sprinkler or surface irrigation



Border check basin irrigation



Furrow irrigation

Drip irrigation

Fig. 1. Salt accumulation pattern in soil under different irrigation systems

sprinkler irrigation which apply a uniform depth of water across the entire field as contrasted to the salt accumulation patterns from furrow or localized (drip or trickle) irrigation which applies water to only part of the field surface. In the case of furrow irrigation, salt builds up with depth in the soil similar to flood irrigation, but salt also accumulates in the areas not covered by water. Salt moves with the water to the high points where the water evaporates most rapidly and is leached to greater depths as water drains by gravity. For localized irrigation, salts accumulate at the edges of the soil wetted from the emitter. This results in a wetted spherical shape with salinity highest at the outer edges of the sphere.

Because soluble salts reduce the availability of water in almost direct proportion to their total concentration in the soil solution, irrigation frequency should be increased so that the moisture content and salinity of irrigated soils are maintained as high and low, respectively, as is practicable, especially during seedling establishment and the early stage of vegetative growth, if it can be done without resulting in excessive leaching or insufficient depth of rooting. The most practical way to accomplish this is through use of drip irrigation because drip applies water on a daily or near daily basis at a very low application rate (2-8 litres per hour per emitter). The near daily replenishment of the water used by the crop keeps the soil moist and very near to or slightly above field water holding capacity. The irrigations should maintain a slight but nearly continuous downward movement of moisture and salts for excellent short-term salinity control. Irrigation efficiency can be close to 100 percent during the cropping period, meaning that the crop evapotranspiration demand can be met essentially without losses due to runoff or deep penetration.

Effect of Marginal Quality Water Irrigation on Pomegranate – A Case Study

Experiment was conducted to study the impact of saline water irrigation on pomegranate yield and its quality at Central Institute of Post Harvest Engineering and Technology, Abohar, Punjab located at 30^o 09' N latitude and 74^o 13' E longitude and an altitude of 185.6 m above mean sea level. Abohar is situated in the south-west part of Punjab falls under semi-arid region and is known for cotton growing belt. Groundwater is saline and rainfall is very low and erratic. Agriculture is completely dependent on canal water supply. Efforts had been made to utilize saline groundwater by blending it with canal water and apply with drip irrigation system to horticultural crop like pomegranate. By blending saline groundwater with good quality canal water, marginal water of different magnitudes was prepared and applied through drip irrigation system. The ratio of under groundwater and canal water in different prepared water was 0:100; 25:75; 50:50; 75:25 and 100:0. Pomegranate was also grown with traditional system as farmer's practiced in this region and considered as control for this study. Irrigation amount of 1.25 times of evapotranspiration was applied in each irrigation. Pomegranate trees were 6 years old and irrigated with drip system from very beginning, while for the last two years when this experiment was started, they were irrigated with different quality water as per different treatments. Observation and outcome of this study are presented as under

Irrigation Water Quality

Different constituents present in various type of water used for irrigating pomegranate with drip system are presented in Table 2. Slight increase in pH value for different quality water was recorded when proportion of under groundwater (tube well water) increased from zero to 100%, which were originally highly saline. Test report indicates that pH value of tube well water (T_5) is not varied substantially. However, other constituents like Ca, Mg, Na and K increased significantly with the increase in proportion of tube well water in irrigation. Electrical conductivity increased from 0.38 (T_1) to 19.50 (T5) ds/m, which is higher side in normal condition. But, if irrigation is managed properly even higher salinity level of irrigation can be applied for moderately salinity sensitive plants.

Table 2. Quality of water of used under different treatments

Treatment	pH	EC (dS/m)	$Ca^{2+} + Mg^{2+}$ (me/l)	Na^+ (me/l)	K^+ (me/l)	SAR
T_1	7.61	0.38	2.40	1.60	0.17	1.46
T_2	7.66	6.30	19.00	12.24	0.49	3.97
T_3	7.77	9.10	29.00	14.40	0.64	3.78
T_4	7.84	14.70	48.80	21.84	0.88	4.42
T_5	7.79	19.50	67.20	29.12	1.09	5.02

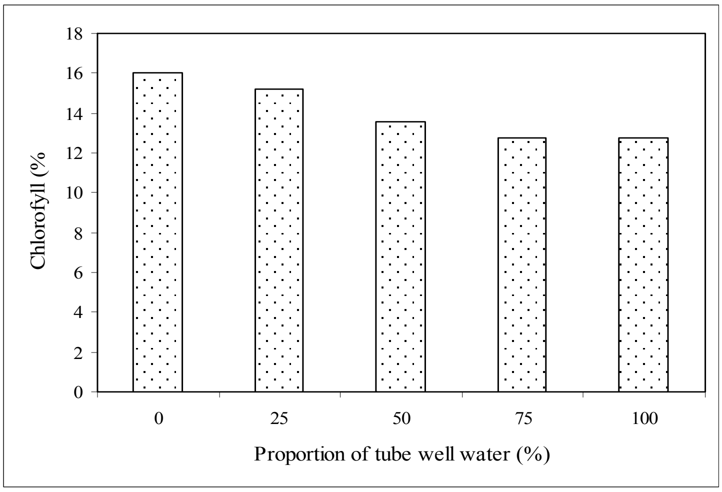


Fig. 2. Chlorophyll percentage in pomegranate leaves measured

Chlorophyll Content

Analysis of chlorophyll content in leaf indicated that as salinity level in irrigation water increased chlorophyll level in leaf decreased significantly (Fig 2). It decreased from 16.06 mg/FW (0% salinity) to 12.750 mg/FW (100% salinity). The decreased in chlorophyll level may be recorded due to dryness of plant leaves from tip and around due to soil moisture stress experienced by the plant because of osmotic pressure generated by salt present in root zone. Interestingly, once rain started, no visual difference was observed between the different treatments. It is might be due to the fact that during rainy period plant root zone was free from harmful salts in all treatments because of leaching of salts with rain water. However, difference in growth was observed because of the variation of dry season.

Yield and Tield Attributes

Fruit per plant, average fruit weight, yield/ha, TSS and reducing sugar were recorded to asses the impact of different magnitude of saline water. No definite trend for fruit per plant was found with different treatments. The average fruit weight was reduced with the increase in proportion of under groundwater in irrigation (Fig. 3). However, drip irrigation with 50 percent of under ground water in irrigation also produced higher fruit weight as compared to conventional system. Yield of drip irrigated tree were significantly higher in 0 and 25% of tube well water in irrigation than the control. Interestingly, total soluble solids (TSS) increased with the salinity in irrigation water and it was maximum with the water having 75% or more under ground water in irrigation. Similar trend was observed for reducing sugar also (Fig. 4).

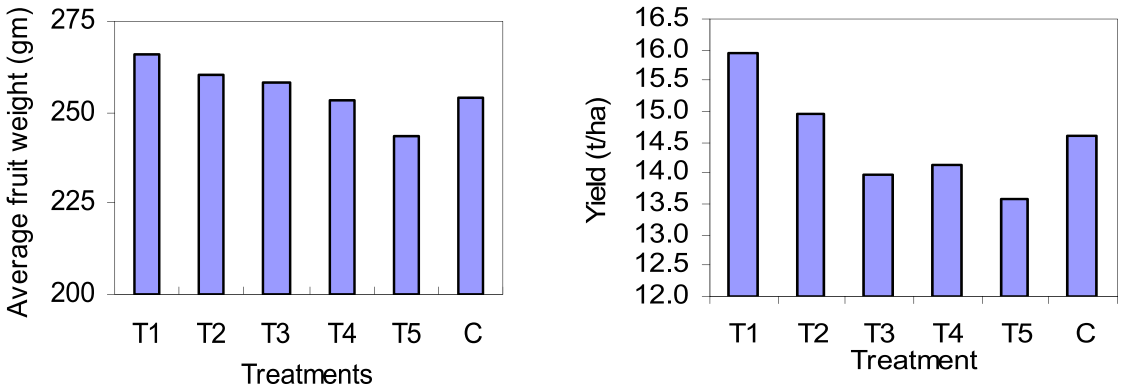


Fig. 3. Average fruit weight and yield under different treatments

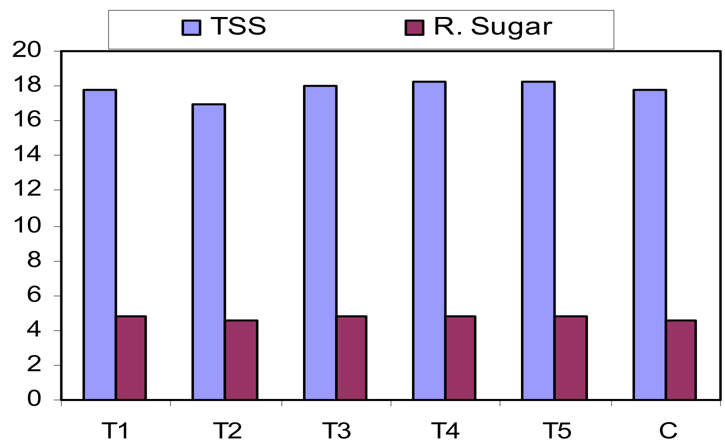


Fig. 4. Total soluble solids and reducing sugar percentage under different treatments

Conclusion

The technology of growing fruit crops with saline water is the need of hour as successful utilization of saline water in agricultural sector could save significant amount of good quality water for other sectors where marginal quality water can not be used. It also provides opportunity to produce quality raw material for processing industry and to enhance the shelf life as well. Study clearly reveled that irrigation water having under ground water up to 25 per cent (EC= 6.30 dS/m) may successfully be used through drip irrigation system for pomegranate cultivation if soil is light in texture and adequate soil moisture is maintained.

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Conjunctive use of Saline Drainage Water and Canal Water for Crop Production and Agronomic Management Practices

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Introduction

Irrigation and drainage play very critical role in meeting the food requirement of ever increasing population of the world on sustainable basis. More than one third of the global food is harvested from 260 m ha irrigated lands, which is only one sixth of the total cultivated area. There are several concerns about the sustainability of irrigation and drainage projects because of quality problems for disposal of drainage water. Problems of land degradation are also encountered due to irrigation-induced salinity and water logging but drainage is a vital component of agricultural production system. In humid regions, agricultural drainage is required to remove excess soil water from plant root zone. Drainage is critical in controlling salinity and water logging of irrigated agriculture. In order to enhance the net benefits of drainage system, more attention will have to be given to the management of drainage water. Drainage water reuse and its disposal are comparatively new areas of management but considerable experience exits in saline irrigated agriculture that can be used in making decisions. However, it must be recognized that each drainage site is and will be unique. Various strategies have been proposed to use drainage water for irrigation. (Rhoades, 1984, 1987; Boumans *et al*., 1988; Sharma *et al*., 1994; 2001; 2005a, b; Sharma and Rao, 1998; Sharma and Tyagi, 2004, Yadav *et al*. 2007). Selection of a particular strategy depends upon the quality of drainage water, soil type, crops to be irrigated and the agro-climatic conditions. Saline drainage water reuse might be more practical in areas where non-saline water is available during early growing season but limited in supply to meet the crop water requirement for entire irrigation season. Reuse of saline drainage water may be useful for crop production in arid and semi-arid regions where underground water is of poor quality and supply of fresh water is not sufficient to meet irrigation requirement of entire area. This lecture illustrates the potential of drainage water for irrigation along with management strategies for arid and semi-arid regions.

Scarcity of Water Resources

Fresh water supply, an essential ingredient for the economic development of society is just not enough to meet the requirement of all sectors of economy. Presently, agriculture being the major user consumes 89% good quality water resources of the country, but estimates suggest that more water will be needed for the growing demands of municipalities, industries and energy generation. These sectors will require about 22% (23.4 m ha-m year^{-1}) of the total water resources (105 m ha-m year^{-1}) by 2025 AD. In India consumptive use far outweighs non-consumptive uses (industrial and domestic uses) but non-consumptive use is also on the increase. Population will not stabilize by 2025, and would continue to grow and so will the water demand. Under these circumstances, the future water demands can be met only through judicious planning giving due priority to water conservation, recycling and reuse of low quality water.

Management of Waterlogged Saline Soils

Management of waterlogged saline soils involves basically the lowering of water table below root zone and leaching of excess salts. Leaching is essentially the displacement of saline soil solution with good quality water or with water of lower salt concentration. The salts displaced during leaching need to be removed by subsurface horizontal drainage system if the natural drainage of soil is impaired. Subsurface drainage has proved successful in the rehabilitation and conservation of irrigated lands in arid and semi-arid regions (Rao *et al.*,1988; Sharma & Gupta 2006). However, such drainage systems produce poor quality drainage waters and disposal of such waters is a serious problem in the absence of natural outlets. This problem has imposed restrictions on the reclamation plans using subsurface drainage system for potentially productive waterlogged saline area in the country. In order to enhance the net benefits of drainage system, more attention should be given to the management and disposal of drainage water.

Reuse of Blended Drainage Water for Irrigation

Drainage water of higher salinities cannot be reused directly for crop production. Blending involves mixing two waters of different qualities to obtain water that is suitable for irrigation. The salinity attained after mixing should be within the permissible limits, based on soil type, crop to be grown and climate of the area. To use the blending strategy, a controlled way of mixing the water supplies must exist.

Table 1. Mean relative grain yield of wheat as affected by different salinity levels of blended drainage water for post-sowing irrigation and succeeding pearl millet and sorghum crops

EC (dS/m) of irrigation water	Wheat	Pearl millet	Sorghum fodder
0.5 (Canal water)	100	100	100
Blended drainage water			
6.0	95.8	98.0	96.1
9.0	90.3	94.1	90.1
12.0	83.7	86.3	80.3
18.8	77.8	77.3	70.4

Blended drainage water reuse was studied at Sampla location (Haryana) where a subsurface drainage system was installed at a depth of 1.75 m. Blended saline drainage water of different salinities (0.5, 6, 9, 12 and 18 dS/m) was used for all and only for post-plant irrigations of wheat. The results are summarized in Table 1. Considering the yield obtained with the use of canal water as the potential (100%), the mean relative yields of wheat with the use of blended drainage water of EC 6, 9, 12 and 18.8 dS/m were 95.8, 90.3, 83.7 and 77.8%, respectively. The pooled data of this experiment were used to work out the response of wheat to saline drainage water quality (0.5 to 18.8 dS/m) with piecewise linear regression. The analysis indicated that comparatively higher salinity irrigation waters (up to 9 dS/m) could be used for 90% wheat yield in those soils, which are provided with subsurface drainage system (Fig. 1). The mean relative yield of succeeding pearl millet and sorghum fodder decreased significantly only in those plots where higher salinity water (> 12 dS/m) was applied to previous wheat crop. The mean relative yield green forage yield of sorghum in 12 and 18.8 dS/m treatments was 80.3 and 70.4%, respectively indicating that sorghum is slightly less tolerant to salinity than the pearl millet. Our results in a monsoon climate are consistent with the concept that both salt sensitive and salt tolerant crops can be grown in rotation if the non-saline water is used for irrigating the succeeding crops.

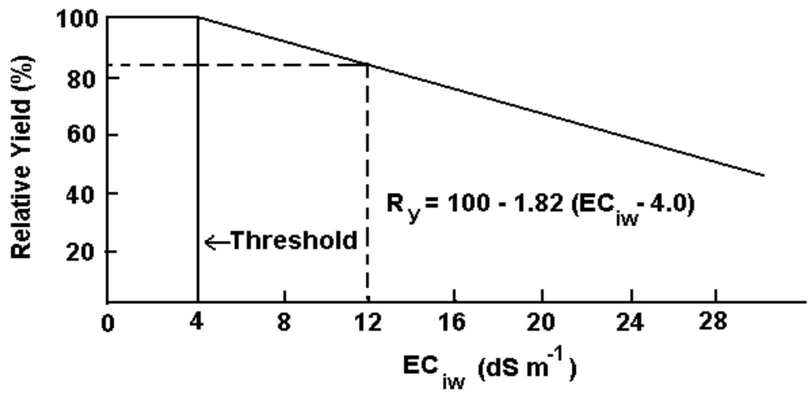

Fig. 1. Relative yield of wheat with different salinity water irrigation

Cyclic or Rotational Use of Drainage Water

The cyclic use, also known as sequential application or rotational mode is a technique, which facilitates conjunctive use of fresh and saline drainage effluent. In this mode, canal water is replaced with saline drainage water in a predicated sequence/cycle. An advantage of the cyclic strategy is that steady state salinity conditions in the soil profile are never reached. Rhoades *et al.* 1992 have also advocated the seasonal cyclic use, called "Dual Rotation", strategy where non-saline water is used for salt sensitive crops/initial stage of tolerant crops to

Table 2. Effect of various cyclic modes of post-plant irrigations with canal water and drainage water on mean relative (%) yields of wheat and succeeding pearl millet and sorghum crops

Mode of water application	Wheat	Pearl millet	Sorghum fodder
4 CW	100	100	100
CW : DW (alternate)	94.4	97.0	91.8
DW : CW (alternate)	91.3	95.5	91.1
2 CW + 2 DW	94.3	96.4	92.8
2 DW + 2 CW	88.2	94.9	91.1
1 CW + 3 DW	83.6	91.9	87.2
4 DW	73.7	85.0	78.7

CW = Canal water; DW = Drainage water

leach out the accumulated salts from the irrigation with salty waters to previously grown tolerant crops. This strategy may work better in arid climates with very low rainfall but it is of natural occurrence under the monsoon climate. Experiments by Sharma *et al.*, (1994), where combined use of saline drainage water (EC_{iw} 10.5-15.0 dS/m) and canal waters were used in pearl millet/sorghum-wheat rotation support the suitability of cyclic use strategy where canal water was used for pre-plant irrigation. Pearl millet and sorghum crops received no further irrigation except the monsoon rains during the growth period (Table 2).

Management of Shallow Water Table

A potential solution for reducing drainage volumes could be to promote exploitation of water table for meeting a part of crop water requirement. Subsurface drainage over a period of time leads to improvement in the quality of sub-soil water in drained field. The upper few centimeters of subsoil water had very little salinity, and may be used by the plants by manipulating the drainage system operation. Thus plants would meet part of their evapotranspiration needs directly from soil water. Shallow water table at 1.0 m with salinity in the range of 3.0 to 5.5 dS/m facilitated the achievement of potential yield even when surface water application was reduced to 50 per cent (Rao *et al.*, 1992). These fields have been provided with subsurface drainage. The salinity build up was negligible and the little amount of salts accumulated, were leached in the subsequent monsoon season. These results indicate that an operational strategy of intensive operation of drainage system in the soil reclamation stages and less intensive just to meet the annual leaching requirements in the later stages may be an useful strategy in maintaining the productivity of land and water at optimum.

Salt Build-up in the Profile

When using saline drainage effluent for irrigation, the salt concentrates in the soil solution due to evapotranspiration and may accumulate in the soil. But if the salt accumulation does not exceed the threshold value of crop salt tolerance in the root zone, the crops will grow normally. Soil salinity was monitored in different studies, indicated that soil profile salinity increased with the increasing salinity of irrigation water (Sharma and Rao, 1998). Observations indicated that salt build up did not occur over the years and much of the salts that were added during irrigation are leached out of the soil profile with the monsoon rains (Fig.2). This downward leaching of salts reduced the salinity levels within acceptable limits for good germination of next wheat crop. The leaching of soluble salts under the prevailing conditions was brought about by rainwater and a pre-plant irrigation and no extra irrigation water was applied for leaching of salts. If the monsoon rainfall is not sufficient for leaching the salts in the profile, in such cases a heavy (7-10 cm) pre-plant irrigation with canal water should be applied.

Long-term Effects on Soil Properties

Several studies have suggested that irrigation water containing salt concentrations exceeding conventional suitability standards can be used successfully on many crops for at least 6-7 years without a loss in yield. However, uncertainty still exists about the long-term effects of these practices. Long-term effects on soil could include soil dispersion, crusting, reduced water infiltration capacity and accumulation of toxic elements. The magnitude of these effects will, however depends on the quality of drainage water. Effects of irrigation with high salinity drainage effluent as available at Sampla drainage project area were monitored for six years on some soil

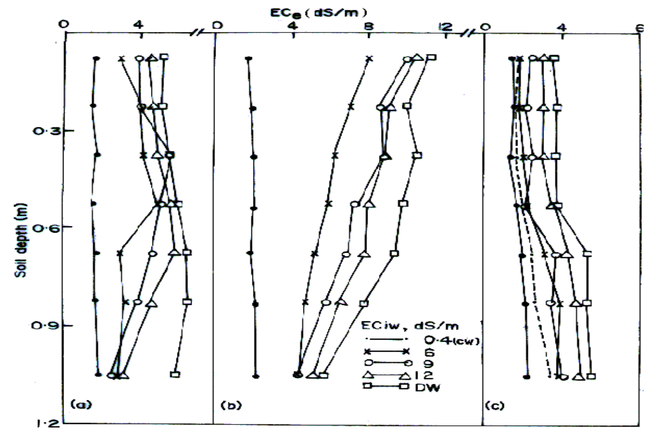

Fig. 2. Soil salinity profile in different treatments (a) at wheat sowing, (b) at wheat harvest, (c) after monsoon leaching.

properties. Since the SAR of saline drainage water was more (12.3 - 17.0) than that of canal water (0.7), hence its use increased soil SAR_e (Sharma and Rao, 1998; Fig. 3). Leaching of salts by monsoon rains reduced SAR_e and the remaining SAR_e values did not cause any alkali hazard to the succeeding crops. Similarly, no significant adverse effects were observed on saturated hydraulic conductivity and water dispersible clay after the monsoon rains. A slight decrease in hydraulic conductivity after monsoon leaching will not be a problem during the irrigation season since the negative effects of high SAR of drainage water is offset by the high salinity of the drainage water. Only slight variation in water dispersible clay after 6 years of irrigation with drainage water indicates minimum structural deterioration in soils irrigated with high salinity drainage water. Although, no potential adverse effects were observed in these studies at Sampla farm, we caution those considering the reuse of drainage water, first , to evaluate their specific conditions carefully.

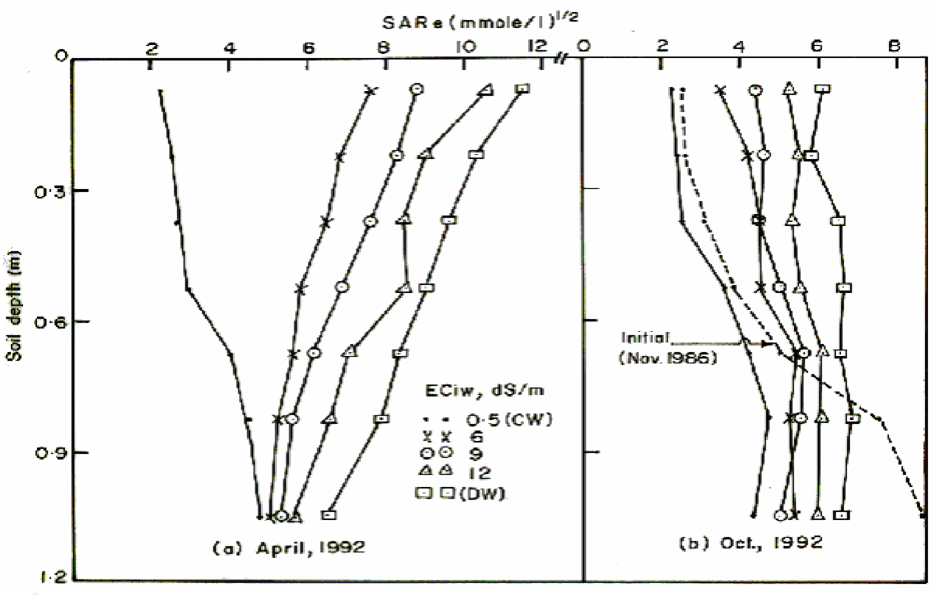

Fig. 3. Sodium adsorption ratio (SAR_e) profile in different treatments (a) at wheat harvest, (b) after monsoon leaching.

Agronomic and Management Practices for the Use of Saline Drainage Waters

When using saline drainage water for irrigation many suitable management practices should be considered. An approach with rigid criteria will not be practical, since most management decisions are subjective and innumerable combinations exist. The management practices which are to be followed for optimal crop production, must aim at preventing the build up of salinity, sodicity and toxic ions in the root zone to level that limit the productivity of soils, control the salt balances in soil-water system as well as minimize the damaging effects of salinity on crop growth. The following practices are suggested:

Drainage Water Availability

The availability of the drainage water should be determined. Based on the drain discharge in different seasons, it is possible to estimate the volume of available drainage water for disposal or irrigation for a particular area. A system for the collection and redistribution of drainage water must be developed to avoid the need for storage reservoir. A network blending system must be installed if the blending strategy is adopted. The quantity of water from the subsurface drainage is limited and available only when the water table is above the drains. However, the volume of return flow (drainage water) depends on the drain depth and spacing, depth and methods of irrigation, leaching requirements, soil hydrological characteristics, intensity and duration of rain, type of crops and seepage from the adjoining areas. As an example, the average discharge rates from the drains installed in a 10 ha area of sandy loam saline soil at 1.75 m depth with spacing of 25, 50 and 75 m is given in Table 3.

Table 3. Mean observed seasonal cumulative drain discharge (mm) at Sampla (Haryana) experimental station

Season	Drain spacing (m)		
	25	50	75
Monsoon (July to September)	730	198	150
Daily average (mm/day)	8.1	2.2	1.7
Winter (October to February)	512	158	141
Daily average (mm/day)	3.7	1.1	0.9

Drainage Water Analysis

To evaluate reuse potential, standard water sampling techniques and analysis should be used to determine the quality of drainage water. The most important water quality parameters are EC, SAR and boron concentration. The water should also be analyzed for the presence of toxic elements.

Crop Substitution

Most agricultural crops differ significantly in their tolerance to concentration of soluble salts in the root zone. It is desirable to choose crops/varieties that can produce satisfactory yields under conditions resulting from saline drainage water irrigation. The difference between the tolerance of the least and the most sensitive crop crops may be 8-10 fold. The wide range of tolerance allows for greater use of marginal waters. The extent the tolerance limits for the low quality waters are raised, it will permit greater use of such waters, thereby reducing the need for leaching and drainage. Crops, which are semi-tolerant to tolerant, as well as those with low water requirement, should be grown. For an example mustard is a salt tolerant crop and it requires one or two irrigation after seeding. Experiments at Sampla indicated that high salinity drainage water can be used for post-plant irrigation for mustard without any substantial loss in yield. The grain yield was more when it was irrigated with 8 dS/m salinity water than with canal water (Table 4). The added salts at this level had a slight boosting effect on yield.

Table 4. Effect of drainage water salinity on relative (%) yields of mustard

EC_{iw} (dS/m)	1st year	2 year	3 year	Mean
0.5	100	100	100	100
8	100.7	120.1	116.7	112.5
15	94.1	90.4	88.0	

Pre-sowing Irrigation

The period of germination and seedling emergence is the most critical stage in most crops. Failure at this stage leads to poor crop stand and a considerable decrease in yields. By applying good quality water for pre-sowing irrigation, it is possible to reduce the risk of poor stand during the germination stage. The relative yield of wheat with pre-sowing irrigation with fresh water followed by saline water throughout compared with yield where no pre-sowing irrigation with fresh water was made were always higher when equal amount of salt was applied (Table 5).

Table 5. Comparative effect of pre-sowing with canal irrigation and blended saline water on wheat yield (%)

EC_{iw} of blended water, dS/m	All irrigations with blended water	Only post-plant irrigation with blended water
0.5 (Canal water)	100.0	100.0
3.0	90.0	- - -
6.0	80.4	95.8
9.0	72.5	90.3
12.0	72.5	83.7
18.8	- - -	78.0

Irrigation Practices

The method of irrigation with saline waters should create and maintain favorable salt and water regime in the root zone such that water is made readily available to plants for their growth with out any adverse effect on yield. The surface irrigation including the border strip, check basin and furrows are the oldest and most commonly practiced methods in most parts of the country. The properly designed and operated surface irrigation methods can maintain the salt balance and minimize the salinity hazard. To meet these twin objectives, proper land levelling is necessary to apply lesser water per irrigation and to ensure an even distribution of irrigation water. Shallow depths of irrigation water at frequent intervals would be beneficial for the crop growth. Apart from these, the following suggestions may be helpful:

- In areas with rainfall more than 400 mm and having monsoon type of climate, no extra leaching is usually required and the conventional irrigation practices may be followed. However, in areas of sub-normal rainfall, a heavy pre-sowing irrigation with good quality water should be applied so that the accumulated salts during the preceding *rabi* season are pushed beyond the root zone.

- In arid areas, some 15-20 per cent extra water, in each irrigation should be applied compared to a case of good quality water.

- In low rainfall areas (average rainfall < 400 mm) if the good quality water is not available, it is advisable to keep the fields fallow during *kharif* season. During *rabi*, only tolerant and semi-tolerant crops should be grown.

Nutrient Management

Under saline water irrigation conditions, balanced use of essential nutrients is very important for optimum production. Apart from the recommended dose of fertilizers, the following points should also be considered:

- Soils irrigated with chloride rich waters respond to higher phosphate application, because the chloride ions reduce availability of soil phosphorus to plants. The phosphorus requirement of crops is, therefore, enhanced and nearly 50 per cent more

  phosphorus than the recommended dose under normal conditions should be applied, provided the soil tests low in available phosphorus.
- For sulphate rich waters, no additional phosphorus fertilization is required and the dose recommended under normal conditions may be applied.
- For other nutrients such as nitrogen, potassium and zinc, the recommended doses based on soil tests values should be applied.
- Use organic materials such as FYM for higher yields. The FYM not only has its nutritive value, but also plays an important role in improving soil physical properties, which further influences leaching of salts.

Adequate Subsurface Drainage

Use of saline drainage water adds salts to the soil. If no leaching takes place, salts may gradually accumulate in the root zone over the years. Adequate subsurface drainage is essential to facilitate the leaching of accumulated salts from the root zone during the monsoon period. The results indicated that under subsurface drainage system the critical limits of saline irrigation water for different degrees of yield reduction in crops will be higher than those prescribed in the literature.

Alternate Area/Area Switching

For sustainable use of saline drainage water in the project area for irrigation, area can be divided in different sectors. Depending upon the availability of drainage water, different sectors should be selected for irrigation with drainage water/canal water. Irrigate the selected sector with saline drainage water for 3-4 years and than switch to next sector. This practice will prevent the salt accumulation in the lower layers. If the volume of drainage water is surplus in the project area, its use in the adjoining area should be considered. If the elevation at which the water is available is higher than the place where it is needed, cost of lifting will make the reuse unfeasible.

Conclusions

The available options in arid and semi-arid regions for the management of low quality drainage water are discussed. The important conclusions are presented below:

- Supplies of fresh water, which is an essential ingredient for the sustainable crop production, are just not enough to meet the irrigation requirements.
- Reuse of saline drainage water for irrigation of salt tolerant crops is a viable option to minimize the disposal needs. Studies conducted indicated that saline drainage water of varying salinity levels can be successfully utilized for irrigation of winter crops either directly or in conjunction with canal water by blending or by cyclic use without any serious soil degradation. The extent of salt leaching and crop establishment will depend on the total amount of monsoon rains and adequate subsurface drainage.
- In arid and semi-arid regions there are situations where good quality water is available for irrigation but not in adequate quantities. Under such conditions the use of drainage water would not only permit the expansion of irrigated agriculture but would also reduce drainage disposal needs and associated environmental problems.
- The disposal of unusable saline drainage water by an out fall drain towards the sea should be seen as the last interstate water management option to solve excess water problem. The idea may gain momentum when large- scale drainage projects are commissioned in northwestern states of India.

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Application of Plastics in Water Management

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Introduction

Plastics are typical polymer of high molecular weight, and may contain other substances to improve performance or reduce costs. Polymers are the materials made of long strings of carbon and other elements. Polymers are synthetic and natural macromolecules composed of smaller units called monomers that are bonded together. Examples of natural polymers include proteins, polysaccharides and nucleic acids. Synthetic polymers have been developed for durability and resistance to all forms of degradation. These characteristics and others, such as rigidity, permeability and transparency can be controlled by changing the polymer synthesis, molecular weight and by the use of specific additives. The resulting plastic's versatility allows them to be used in a very wide range of applications including water management.

The major synthetic polymers used in water management are polyvinyl chloride (PVC), polypropylene (PP), polyethylene (PE) and nylon. The majority of recycled plastic products are made from PP and PE. India produced about 03 million tonnes of plastics in 2001 and its usage in India is growing quite rapidly and is likely to touch the annual consumption level of about 8 million tonnes by 2006-07. In 2001, per capita plastic consumption in India was about 2.7 kg and that of world was 19 kg (Table 1). The changing scenario of globalization in India will enhance the plastic consumption. The long-term option for India is exploitation of cellulose from biogases, cotton lintel and non-edible starches from spoiled grains along with biodegradable plasticizers.

Table 1. Per capita consumption of plastics in India and that of the world in 2001

Plastics related parameters	India	World
Per capita consumption, kg	2.7	19.0
Recycling of plastics, %	60.0	20.0
Solid wastes, %	0.5	7.0

Source: Ali, Nawab (2005)

Water Management

Water is an absolute necessity and it is lifeline. It is already a scarce commodity in many parts of the world. Proper management of water in agriculture has a vital role in the overall use of water at local, national and global levels. Agriculture is the major user of fresh water, accounting for more than 70% of the total water withdrawals. It has been estimated that 40,000 km^3 can reliably be used by human population on planet earth. The amount of water on planet earth is about 1,400 million km^3 which can neither be increased nor decreased. Most of it, 95.7 % is salt water, a further 1.76% is locked away in perma-frost, ice-caps and glaciers. Merely all of the remainder is stored underground, leaving only 136,000 km^3, less than 0.4% of the world's fresh water in rivers, lakes, reservoirs, the soil, swamps, and the atmosphere and in the living organisms.

Table 2. Losses of irrigation water in unlined canal distribution system

Particular	*% of supplies at canal head*		
	Seepage	*Evaporation*	*Total*
Main canals and branches	13.6	3.4	17.0
Distributaries (10% of supply at distributaries)	6.4	1.6	8.0
Field water courses (27% of supply at outlet head)	16.0	4.0	20.0
Losses from field during application (30% of supply reaching the head)	13.2	3.3	16.5
Total	**49.2**	**12.3**	**61.5**

Water management assumes paramount importance to reduce the wastage of water to increase the water use efficiency and ensure equitable distribution. In India, the surface water potential is about 180 million ha m and the ground water resource is about 44 million ha m. With annual precipitation of about 400 million ha m, the average annual natural flow is about 188 million ha m. The annual requirement of fresh water is estimated at 105 million ha m by the year 2025 AD which is nearly equal to the ultimate water resource's level of the country. Out of this, 77 million ha m has been considered for irrigation purpose. On the basis of the available water resources, the total irrigation water potential from surface and ground water resources is estimated to be 139.9 m ha. Although India has the largest irrigated area in the world but its water use efficiency has not been more than 40 per cent. In any irrigation project the total losses in the canal distribution system and field has not been less than 50% of the head discharge. The losses of irrigation water in unlined canal distributaries system in north India are given in Table 2 (Anonymous, 1982). The main component of water losses in an irrigation system are (a) water losses in storage 10-20%; (b) Water losses in conveyance system 25-40%; (c) Water losses in operation 10-30%; and (d) water losses in application 45-70%. In view of these heavy losses; it is necessary to find out where and how improvement can be made which result in more efficient use of irrigation water.

Use of plastic as lining material for canal, ponds and field channels, plastics pipe for conveyance system and modern irrigation system like drip are found to be very effective in minimizing the water wastage in an agricultural system. It has been seen that adoption of plastics in form of different object such as plastic film, plastic pipe and irrigation equipment can be saved substantial water from wastage (Table 3).

Table 3. application of plastics in water management

Application of plastics	Description
Lining of canal, ponds and field channels	Reduces seepage losses. 75% of water carried in an unlined canal network is lost in transit as seepage and evaporation. 10-15% water can be saved using plastic lining of water courses/channels.
Plastic pipes for water conveyance	Water losses (30-35%) in open channel can be eliminated using plastic pipes and if laid underground, it would save 5-10% aerable lands resulting in higher production. Use of plastic pipes in suction and delivery in argicultural pump sets results into 20-25% energy saving as compared to use of steel pipes. Therefore, the cost of lifting water for irrigation using plastic pipe is lower.
Irrigation equipments	Drip irrigation system permits better utilization of irrigation water. In general, 20% of the irrigation water is typically lost between reservoirs and irrigation field/area, 15% of what remains is lost in distribution and 25% of even that is wasted in the field. Thus, overall, gives an efficiency of about 40%. The wastage can be reduced by using drip irrigation system.
Mulching	Covering of soil with plastic film saves up to 25% water by retaining soil moisture

Plastic Film as Lining Material

The use of plastic films (also known as agri-film) as lining material has offered tremendous scope which provides an impervious lining thus prevent water losses due to percolation. The performance of these films as lining material has been found very satisfactory. These linings using Poly vinyl chloride (PVC) and Low Density Polyethylene (LDPE) film have been tried experimentally. Out of all the types tested so far, LDPE film appears to be the best whereas, PVC lining has several limitations. It cannot be manufactured in wide width and, further, the stability of this film is hampered by the migration of plasticizers, which are essential for extruding flexible PVC film. In India, where plastic materials are always sold on weight basis, PVC film becomes too expensive compared to LDPE film. Due to its higher specific gravity, PVC film gives 40% less film for a given weight compared to LDPE film. LDPE film lining which had been tried on an experimental basis for the past several years is now being extensively used.

Lining of Farm Pond with Plastics

Water storage structures i.e tanks, ponds or reservoirs are located in a variety of soil types, which exhibit a wide range of seepage characteristics. The seepage losses in some soil types are as higher as 11 cubic meters per sec per million square meter area. Because of seepage, the water level of the reservoirs and tanks depletes rapidly. Seepage losses do not only mean loss of useful water but also leads to other problems such as breach in the embankments, water logging and increased salinity in the adjacent areas. With appropriate lining of reservoir and ponds, the seepage loss could be minimized. Plastics film has brought a new hope in reduction of lining cost appreciably and at the same time offering a very effective water barrier material. Side slope in range of 2:1 to 3:1 must be maintained depending upon the type of soil while excavating the pond. Lying of 600 gauge (150 micron) thick film with 45 cm soil cover would be most economical and efficient mode of lining the farm pond. Plastic film lining is easy to install, requiring a minimum of equipments and skilled labour. Plastic film is placed on a prepared sub-grade and can be covered with soil or bricks or cement concrete of suitable thickness as the case may be (Anonymous, 1985). Agri-film lining has the advantage of being able to be placed in relatively cold or wet weather.

Plastic film is available in thickness ranging from 100 microns (0.01 mm or 400 gauge) to 250 microns (0.25 mm or 1000 gauge) and width ranging from 4 meters to 12 meters. The relationship between thickness of Plastic film and its weight and area to be covered is presented in Table 4. As the thickness of the film increases, the area cover per unit weight decreases.

Methods of Reservoir Lining with Plastics

When the excavation of the pond is complete, the beds as well as sides of the pond have to be leveled and prepared for laying the film. Any rocks, large stones or other projections, which might damage the film, should be removed from the beds and sides of the excavated pond. The unevenness of the surface is to be removed either by cutting or filling up. It is important that the bed as well as sloping sides of the pond are well compacted. In case of ponds where soil removed from excavation has been used for preparing the embankments, the side slops should be particularly well consolidated. The success of any pond lining depends on the careful installation and joining of the Agri-film. It has been observed that in windy conditions, laying of the film becomes difficult. It is therefore, advisable to choose conditions as free of wind as possible.

Table 4. Relationship between thickness and area of plastic film

Thickness			Area coverage per (m^2/kg of film)	Weight/m^2 of Plastic film (kg)
Microns	mm	gauge		
100	0.100	400	10.74	0.093
125	0.125	500	8.59	0.116
150	0.150	600	7.16	0.139
175	0.175	700	6.14	0.163
200	0.200	800	5.37	0.186
225	0.225	900	4.77	0.209

After being layed, the plastic film should be covered with a suitable material. The protective cover plays an important role in the longevity of Plastic film lining. The cover material should be such that it is free draining, erosion resistant and stable on the side slope. In case of soil cover, the inclusion of rocks, boulders, vegetable matter, large roots, and other objectionable foreign matter should not be permitted. Proper placement of the cover material is important to avoid possible puncturing, tearing, or stressing Plastic film. In placement of cover material, care should be taken that the lining is not displaced or injured. In addition, it is also recommended that the side slope be covered first.

Do's and Don'ts for Plastic Film Lining

- Do keep the Plastic film rolls in original packing prior to actual use or laying of film.
- Don't leave unpacked Plastic film rolls exposed to sun over prolonged periods or preferably store them indoors.
- Don't rough-handle or drag Plastic film rolls, as the film may get damaged in the process.
- Don't let workers walk on the Plastic film while the lining operation is in progress to avoid puncturing of the film. In case this is unavoidable, they should walk barefoot.
- Don't slide the cover material like bricks etc., on Plastic film to avoid damage and displacement of flexible membrane lining.
- Don't use hooks for lifting Plastic film rolls.
- Don't use re-processed LDPE film in place of Plastic film as the quality of re-processed LDPE film cannot be guaranteed which may lead to premature failure of the film.

Drip Irrigation

Drip irrigation is an advance method of irrigation based on the fundamental concept of irrigating root zone rather than the entire land, which resulted in higher water use efficiency and enhanced crop yield. Drip irrigation systems can be categorized as either line source or point source irrigation systems; however, each of these categories has variations within themselves.

Drip irrigation is used extensively in many water scarce countries like Israel, Arabian states, Mexico, etc. In India, its development is slow as compared to other developing countries. Though, experiments and farm trials have been going on in India from 1970 onwards. But the growth of micro irrigation has really gained momentum in recent years. From a mere 1,500 ha in 1985, the area under drip irrigation has grown to 0.4 million ha in 2004 (Table 5). These developments have taken place mainly in areas of acute water scarcity states of Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu and Gujarat.

Drip irrigation optimizes the use of irrigation water. It can also apply nutrients with irrigation water. Drip irrigation can save about 50% of water and may also provide benefits as i) saves fertilizers up to 50 % ii) make saline water usable for irrigation iii) makes undulating land cultivable iv) shortens gestation period of crop growth v) prevents soil erosion vi) reduces labour cost on weeding vii) increases yield by 30-40% depending upon the crop. Drip irrigation has had a remarkable successful track record in India. Indian farmers have obtained high yield in tomato, grapes, banana, guava, pomegranate, kinnow, lemon, okra, cabbage, cauliflower, potato, onion and capsicum. The results of different studies carried out in India to asses the response of various crops to drip system in comparison to traditional irrigation is summarized in Table 6.

Mulching

Mulching is a practice of covering the soil surface around the plant to make conditions more conducive for plant growth through in-situ moisture conservation, weed control, better CO_2 exchange for root system and soil structure maintenance. Use of dry leaves, straw, hay etc. as a mulching material has been prevalent for ages. However, the introduction of plastic film as mulch increases the efficiency in terms of conserving moisture and controlling weeds and consequently increases yield. LDPE and LLDPE plastic films are commonly used for mulching. LLDPE black plastic mulch films are more popular due to opacity, which check the weed growth under the film.

Table 5. Area covered under drip irrigation in India

State	Area (ha)	State	Area (ha)
Andhra Pradesh	39,500	Orissa	3,000
Assam	200	Punjab	2,000
Gujarat	10,000	Rajasthan	35,000
Haryana	3,000	Tamil Nadu	42,500
Kamataka	50,000	Uttar Pradesh	2,500
Kerala	7,500	West Bengal	200
Madhya Pradesh	3,800	Others	2,000
Maharashtra	2,00,000		
			Total = 4,02,000

Table 6. Performance of different crop under drip and traditional irrigation

Crop	WUE (q/ha/cm)		Advantage of drip irrigation (%)	
	Surface	Drip	Saving of water	Increase in yield
Ash gourd	1.3	1.6	12	11.1
Beet	0.07	0.5	79.1	56.1
Bottle gourd	4.5	7.5	12	47.0
Bitter gourd	0.42	1.3	56.6	34.4
Brinjal	3.11	7.6	53.3	14.3
Broccoli	2	3.25	14.3	39.3
Capsicum	1.77	9.90	30.0	68.0
Cauliflower	2.1	4.5	33.3	40.0
Okra	1.87	13.2	84.0	13.0
Onion	2.04	6.42	47.7	64.2
Potato	2.9	10.6	54.2	69.2
Tomato	1.28	3.12	44.6	35.0
Banana	2.41	6.72	42.0	61.1
Grapes	5.0	11.6	47.2	23.1
Kinnow	3.1	5.7	21.7	44.1
Pomegranate	1.62	4.2	23.8	97.1
Lemon	0.65	1.54	23.9	80.0
Papaya	0.6	3.20	68	77.0

Source: Samra J.S. (2005)

Natural mulches such as leaves, straw, sawdust, peat moss and compost have been used for centuries to control weeds and conserve moisture in the soil. It is only in the last fifty years that synthetic materials have altered the methods and benefits of mulching. Their potential for mulching was established through early research projects with polyethylene, foil, and paper. Paper mulches attracted a good deal of attention in the early 1920's. They were not adapted for commercial production because of their short life, as well as the cost of material and labour, which was not mechanized (Hopen and Oebker, 1976). In the late 1950's and early 1960's, research was carried out for improved formulations of paper-including combinations of paper and polyethylene, foils and waxes-stimulated for their effective use as mulching materials. Petroleum and resin mulches for arid climates were developed at the same time. Of these mulches, only those made of polyethylene are still used today in the agricultural industry. The preferred colours are clear and black, although a wide variety of shades and colors are used for specific reasons in the production of food crops. Currently, red, blue, yellow, gray and orange are being investigated and are used in different parts of the world. Each colour has distinct optical characteristics and appears to affect plant growth and development (Decoteau *et al*, 1989; Orwlek and Murphy, 1993). Mulches with a silver surface colour have shown to repel certain sucking type insects, which are often vectors of various viruses (Lamont *et al*, 1990). Significant advances in the use of mulches occurred during the early 1960's with mechanization, the invention of mulch applicators, and transplanters, which would plant directly through the mulch. Today, millions of hectares are planted with the use of plastic mulching. In the People's Republic of China alone, about 2.9 million hectares area was under plastic mulching in 1989, a phenomenal increase over the 44 hectares in 1979 (Jensenn and Malter, 1994). In India, extensive experiments have proved the enormous advantages like saving in water, increase in yield and weed control with of the use of plastic mulch (Table 7).

Plastic mulching has been poorly developed in many developing countries, although some recent work has demonstrated that mulching of soils with transparent and black polyethylene films increases growth of many crops such as tomato, capsicum, mango, papaya, banana, strawberry. For vegetable crops, the effect of transparent mulch, floating row covers, and oil sprays on insect populations, virus disease, and cantaloup yield have been evaluated by Orozco *et at.* (1994). Similarly, clear plastic mulches increased fruit number and yield of cucumber in comparison with black, white, and un mulched soil (Farias-Larios *et al.,* 1994a).

Table 7. Benefits of plastic mulching in different crops under trail in Indian conditions

Crops	Increase in yield (%)	Water saving (%)	Weed control (%)
Groundnut	46	26	30
Sunflower	10	28	74
Mustered	98	-	41
Sesame	135	-	62
Cotton	22	40	-
Banana	10	53	90
Tomato	56	29	91
Grapes	54	78	-

Disposal of plastic mulch posses a serious problem and is a debatable issue for environmentalists. It is well recognized that biodegradable or environmentally degradable plastic could offer a solution to the disposal problem associated with plastic mulch. Environmentally degradable materials are those that undergo significant structural modifications, mainly reduction in molecular weights, when placed in suitable environments (Table 8). Blending synthetic polymers with natural materials does not make the product biodegradable. It only renders the product to easily disintegrate. Residues of synthetic polymers could persist in environment indefinitely. A material derived from nature is not necessarily biodegradable for example, the natural rubber. Chemical transformation of natural resources often makes the materials non-biodegradable. For example, cellulose is biodegradable but not cellulose acetate. Biological breakdown of plastics releases CO_2 and CH_4. Both are heat-trapping green house gases. There is now an international effort to reduce these emissions- Kyoto Protocol. Production of biodegradable polymers needs more burning of fossil fuel to generate energy leading to increased emission of greenhouse gases.

Table 8. Environmentally degradable polymers materials

Type of degradation	A brief description
Biodegradable	Materials that by action of microorganisms gets quantitatively converted either to CO_2 and H_2O or CH_4 and H_2O under aerobic or anaerobic conditions.
Hydrolytically degradable	Materials that undergo degradation by hydrolytic process
Photodegradable	Materials that undergo degradation by combined action of light and oxygen
Oxidatively degradable	Materials that undergo an oxidation degradable process.

Improving Canal Water Productivity Through Plastic Intervention- A Case Study

In general, traditional methods of irrigation (flooding) are employed to irrigate the crop in canal command, which results in heavy conveyance and water application losses, and cause water logging, salinity and loss of nutrients through leaching. Besides this, due to some unavoidable reason, canal water supply is not regular through out the year. For example, in summer, canal is usually closed for 2-3 weeks for cleaning and repair or due to shortage of water at heads etc. Further, the authorities distribute water among the farmers and the turn for canal water supply hardly comes once in a week. Hence, irregular water supply often poses water stress to crop and results into low yield and water productivity in canal irrigated areas. Drip irrigation in conjunction with secondary reservoir may be an alternate for successful fruit crop production in canal command by providing ensured irrigation with limited available water (Kumar *et al* 2008). This study was conducted with the aim to assist orchardist in making investment decisions by estimating the expected water saving and yield increase through plasticulture. Fruit crops such as pomegranate, guava and kinnow were grown with drip irrigation.

Secondary reservoir was prerequisite for using drip system in canal command. Secondary reservoir was fed with a part of irregular canal water supply to provide ensured water source for operating drip system. A dug–out secondary reservoir (pond) was constructed at the research site and lined with LDPE film (agrifilm) to eliminate any possibility of seepage (Fig 1). Since, farmers get their turn once in a week, therefore, for safety purposes; capacity of reservoir was estimated for two weeks of crop water demand. Accordingly, reservoir was constructed for using drip system. Results of the study are discussed under following subheads

(a) (b)

Fig. 1. View of plastic lined pond for using drip system (a) plastic film being used for lining (b) Plastic lined pond being used for drip irrigation

Water Applied and Water Use Efficiency

Irrigation to fruit crop was provided at 100% of evapotranspiration under drip irrigation. A significant saving of irrigation water is evidence of drip system influence in canal command (Table 9). Drip system used about 46, 24 and 42 per cent less canal water in irrigating pomegranate, guava and kinnow, respectively as compared to the farmer's practice of irrigating entire field. The saved water can be used to cultivate some more orchards of these fruits by using drip system if land is not constraint. In general, in canal irrigated areas, water is limited resources rather than land.

Table 9. Response of different fruit crop to drip and conventional irrigation

Particular	Drip irrigation			Surface irrigation		
	Pomegranate	Guava	Kinnow	Pomegranate	Guava	Kinnow
Water applied (mm)	40.70	45.90	50.80	59.60	56.90	72.00
Yield (t/ha)	21.60	21.60	40.40	17.39	12.90	34.50
Water use efficiency (kg/m^3)	5.32	4.78	7.95	2.92	2.27	4.79

Table 9 also reveals that irrigation water use efficiency (IWUE) value was less during initial fruiting year due to lower yield level in both the irrigation systems. However, drip irrigated crops performance was comparatively better and recorded higher IWUE. This was due to the fact that drip system in conjunction with service reservoir managed crop water demand more efficiently which resulted into better growth and higher yield (Mandal *et al*, 2006). Higher yield with smaller amount of irrigation water used resulted into greater IWUE values for drip system as compared to conventional irrigation practices. Irrigation water use efficiency of drip irrigated pomegranate, guava and kinnow was recorded to be 7.24, 4.81 and 11.10 kg/m^3, respectively while 3.67, 2.79 and 6.74 kg/m^3 under conventional practices. The higher IWUE favoures the use of drip system in canal irrigated command where water is always limiting factor for crop diversification.

Yield Response

Early fruiting of 3.31 t/ha as winter crop was recorded for drip irrigated guava. It was probably due to the fact that less plant stress and efficient and reliable nutrient distribution in drip irrigation resulted into better crop growth and early yield (Martin *et al*, 1994; Asrey *et al.*, 2007). The impact of drip system was more visible in pomegranate crop. Fruit cracking due to fluctuation of soil water potential is a severe problem in dry areas. Drip system reduced the fruit cracking (about 15-20%) by frequent watering which otherwise was not fit for marketing in existing practices. Higher yield may also be attributed to uniform development of fruit and higher average fruit weight under drip system (Table 9). The yield of kinnow was also higher in drip system. It was due to the fact that drip system provided adequate water to mitigate water stress during peak summer which led to normal bearing and fruit retention. Kinnow plant is very sensitive to water stress during flowering which falls during very hot summer. In conventional system, plant experienced water stress due to irregular canal supply which effects yield.

Conclusions

Introduction of drip irrigation system in conjunction with plastic lined service reservoir in canal command saved about 40% water as compared to existing practices and registered uniformly higher yield for pomegranate, guava and kinnow. Fruit production per unit volume of water applied was found almost double in drip system as compared to conventional system.

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Salt Water Dynamics under Drip with Saline Irrigation

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Introduction

The shrinking fresh water resources have motivated many researchers to investigate and evaluate the use of poor quality saline water using improved irrigation techniques such as drip irrigation. The drip irrigation has some proven advantages over other irrigation methods like conservation of water through reduced evaporation, deep percolation and runoff losses. As such, drip irrigation helps to achieve high irrigation efficiencies. Since in this system, periods of matric stress are minimal, the system has given high production and productivity in most field trials. It is mainly due to the ability of this technique to result in no or minimal matric stress that blunts the adverse effect of osmotic stress. In spite of this researchers have engaged themselves to minimize the adverse effect of osmotic stress in drip irrigation. The additional advantage of this technique emerges from the fact that when either land or water or both resources are of poor quality, the system has functioned well with minimum adverse impact on crop production (Pandey *et al*., 2008).

In the process of saline water application through a point source of drip, salts get accumulated in the root zone adversely impacting the crop production as well as causing concern to the sustainable productivity. The knowledge of wetted soil volume and its extent has remained of great interest. Since the accumulation of the salts is towards the outer wetted zone, the knowledge of the actual shape and size below the point source of drip irrigation remained a concern to researchers who have studied or modelled the flow around a point source (Ben-Asher *et al*., 1978; Brandt *et al*., 1971; Bresler *et al*., 1971; Provenzano, 2007; Raats, 1971; Warrick, 1974; Warrick, 1985; Wooding, 1968 and Zur, 1996).

These modellers have approximated the shape of the wetted volume as a rectangular or square column (Keller and Bliesner, 1990), a hemisphere (Ben-Asher *et al*., 1986 and Jaiswal *et al*., 2001), a cylinder (Amoozegar-Fard *et al*., 1984 and Schwartzman and Zur, 1986) and a truncated ellipsoid (Zur, 1996). These assumptions have led to equations, which are either too simplistic or somewhat complex. In this article, worldwide studies on the moisture front and the solute dynamics under the point source of drip irrigation have been critically reviewed and compared. Simultaneously, the impact of the drip with saline irrigation on yield or the related attributes has also been related through the review of the work done in Indian conditions.

Soil Moisture Around Point Source - Effect of Discharge, Applied Volume and Frequency of Irrigation

Water movement under the point source of drip irrigation is very complex, as it is applied through emitter the water spreads in all the directions, above the soil surface, entry into the soil as well as its movement within the soil. Therefore, the resulting water infiltration process is three dimensional with respect to three space co-ordinates. Many researchers in India and abroad have tried to evaluate and expressed the movement of water and moisture distribution over time and space.

Drip irrigation systems consist of small emitters, either buried or placed on the soil surface, which discharge water at a controlled rate. Water infiltration takes place in the region directly around the emitter, which is small compared with the total soil volume of the irrigated field. As a result, three-dimensional transient infiltration occurs. This differs from more traditional techniques of flood or sprinkler irrigation, where water infiltrates through most or all of the soil surface area, and water infiltration can usually be adequately simulated by one-dimensional vertical movement (Brandt *et al*. 1971; Bresler, 1977). As the frequency of irrigation increases, the infiltration period becomes a more important part of the irrigation cycle. The hydraulic properties are critical because they control the infiltration phase (Rawlins 1973; Bresler, 1978). Irrigation management under high-frequency water applications involves controlling the quantity of water passing through the root zone by regulating the drip discharge rate according to the soil hydraulic properties (Hanson *et al*. 1996). Goldberg *et al*. (1976) developed emitter discharge and wetted diameter as an empirical power relationship. Schwartzman and Zur (1986) described the relationships between the emitter discharge, total wetted volume, width and depth of wetted front and saturated hydraulic conductivity of the soil with a set of empirical formulae. Zozueta *et al.* (1995) had derived a relation for wetted diameter with emitter discharge and the basic infiltration rate, root depth and dimensionless constant.

Mathematical Modelling for Moisture Distribution

Several procedures and approaches have been adopted to mathematically explain the flow situation in the soil beneath the drip source. Richards' equation, which combines Darcy's law with conservation of mass, is usually used to describe the three-dimensional infiltration and subsequent redistribution of water in the soil (Molz, 1981; Coelho and Or, 1996; and Clothier and Green, 1997). The major difficulty to solve the Richards equation is due to non-linear dependency of the hydraulic conductivity (K) on the unknown water content (θ).

Several researchers in India have published empirical relationships for spatial distribution of soil moisture. One of the foremost of these were conducted by Kaul (1979), who studied the hydraulics of soil moisture front under drip irrigation source. He reported that the soil moisture in the wetted zone, resulting from the point source of water application, manifested itself by a rapid increase in the soil moisture content in the soil layer close to the point of water application. Later, Rema Devi (1983) evaluated the soil moisture distribution as a function of elapsed time at different rates of water application and reported that the vertical and the horizontal moisture fronts could be represented by exponential and second order polynomial equations respectively.

Nehra *et al*. (1991) and Singh *et al*. (2001) studied the movement of moisture front advance from a surface point drip source and established the empirical relationships between the emitter discharge, time of application and the vertical or the horizontal distance of the advance front. Jaiswal and Lal (2001) fitted several mathematical models for the wetted front advance under line source of drip. They found that Quadratic, Hoerl, Weibull, Vapour pressure, Power fit, Exponential association, Sinusoidal, Heat-capacity, Modified-geometric and Modified-exponential models were best fitted for wetted width and time.

The steady state multidimensional infiltration described by the Richards equation without a plant uptake, for the moisture distribution around a buried point source in an infinite medium is usually obtained by using a boundary condition (Philip, 1968; and Or, 1995). Similarly, analytical solutions for matrix flux potential distribution around a surface and buried point sources have been given using the exponential integral (Philip, 1971; Raats, 1971; and Revol *et al*., 1996). Other multi-dimensional analytical solutions to Richards equation have been provided by Gilley and Alfred (1974),Warrick *et al*. (1979) and Warrick *et al*. (1980). Coelho and Or (1997) compared the theoretical and experimental distributions of soil matric potentials for surface and subsurface point sources. They used two analytical solutions of Philip (1968) and Raats (1971). Nehra *et al*. (1991) conducted field experimentation with surface point source and verified that the Warrick (1974) model based on linearized transient flow for two or three dimension can be used to predict the moisture profile. Zazueta *et al*. (1995) proposed a simple equation to estimate soil–water movement from a drip irrigation point source.

Numerical procedures like finite elements (Taghavi *et al*., 1984) or finite difference (Lafolie *et al*., 1989) have generally been adopted to mathematically explain the flow situation in the soil beneath the drip source. The solutions for surface and buried sources largely depend upon the geometry of the flow domain (infinite medium for buried vs. semi-infinite for the surface source). Consequently, for a given emitter discharge, different wetting patterns from surface and buried sources have been reported (Raats, 1971; Mmolava and Or, 2000, b). The surface source solution does not consider the development of a small pond on the soil surface during infiltration (Revol *et al*., 1996). The soil water distribution due to the distribution of matric head around either a surface or buried point could be obtained via soil water retention models of van Genuchten (1980) or Russo (1988). Several one-dimensional numerical solutions to Richards equation have been provided over years (Nimah and Hanks, 1973; Feddes *et al*., 1974; Jung and Taylor, 1984 and Ragab *et al*., 1990). Similarly multi-dimensional numerical solutions to Richards equation have also been provided by Clausnitzer and Hopmans (1994).

The water flow equations that describe the physical model are non-linear. When no plants are present, numerical solutions have been developed by Brandt *et al*. (1971), Ababou (1981), Taghavi *et al*. (1984), Lafolie *et al*. (1989), Elmaloglou and Grigorakis (1997). In contrast to the relatively large number of the models developed to describe infiltration from a point source in bare soil, a few studies focused on drip irrigation with respect to water uptake by the plant roots system (Warrick *et al*., 1979; Oron, 1981; Jury *et al*., 1991; Wu *et al*., 1999; and Elmaloglou and Malamos, 2005). Šimůnek *et al*. (1994) developed a general purpose and user friendly two dimensional numerical model (known as SWME 2D, or more recently as Hydrus 2D, Šimůnek *et al*. (2006)). It is based on a finite elements scheme and incorporates a graphical user interface for data entry (of soil properties, atmospheric conditions, emitter discharge, boundary conditions etc.), and provides visualized simulation results.

Elmaloglou and Malamos (2006) applied and verified the results of cylindrical flow model for the moisture movement in the root-zone under a point source of drip irrigation on two soils. The results showed a good statistical agreement between observed and modelled values.

Models Base on Simplified Geometry and Volume Balance

In absence of detailed information on soil hydraulic properties, boundary conditions, potential distributions etc. which are essentially required for both numerical and analytical predictions, several models based on volume balance and flow geometry have been developed using simple mathematics.

A hemi-spherical model was suggested by Ben-Asher *et al*. (1986) for prediction of the wetting pattern by a surface point source. They gave the relationship between time dependent effective radius of hemispherical wetted soil volume and the amount of water applied.

Schwartzman and Zur (1986), proposed a semi-empirical model to predict the wetting pattern and developed a method for determining emitter spacing and geometry of the wetted soil volume below an emitter.

They related the key parameters affecting the water distribution, such as emitter discharge, saturated hydraulic conductivity, total water in the wetted volume, and wetting geometry (maximum wetting width and the depth). Healy and Warrick (1988) used numerical solutions of a dimensionless form of Richards equation for flow from a point source to estimate the empirical coefficient of generalized equations for the shape of the wetted soil volume. Their analysis is simplified by assumptions such as homogeneous soils, absence of evapotranspiration, uniform initial moisture content and non-hysteretic moisture content-pressure head relation. They presented an extensive table for the coefficients that cover most soil types and emitter discharges. Angelakis *et al*. (1993) compared various methods for predicting wetting front including a finite element solution based on Warrick's analytical linearized flow. They found that most solutions provide better predictions of wetting front positions for clay loam soils than for sandy soils.

Zur (1996) gave a design methodology on the basis of truncated ellipsoidal shape for the wetting front volume and the assumptions of Schwartzman and Zur (1986) model for the selection of operating time and emitter discharge and spacing. Saxena and Gupta (2008) proposed a simplified geometry based design procedure for saline water irrigation, which considered the wetting volume below a surface drip as a combination of cylinder and below which a semi-ellipsoid. Their model used the assumptions of Schwartzman and Zur (1986) and predicted the salt concentration in the outer fractional volume where the salt concentration can be maintained at the concentration of the irrigation water by increasing its wetted volume. The formulae for the wetted volume and the salt concentration are as following.

$$V = \frac{\pi a w^2}{6}\left(1 + \frac{3h}{2a}\right) \tag{1}$$

$$C_l = \frac{C_o + C_i(N\, M_c\, MAD - l)}{(1 - l)} \tag{2}$$

Where,

a = Semi-major axis or vertical polar radius of the semi-ellipsoid or depth of ellipsoidal tip from the end of cylinder [L],
h = Depth to which the cylindrical column is assumed to occur [L],
V = Total wetted soil volume [L^3],
w = maximum width of the wetted soil volume (The diameter of the wetted cylinder, and in case of semi-ellipsoid it is the minor axis or equatorial diameter of the wetted soil volume, which in the homogeneous soils would be similar in X and Y directions, and twice of both semi-equitorial diameters) [L].
I = Irrigation interval [T],
M_c = Moisture holding capacity [L^3/ L^3], and
MAD = Management allowed deficit (fraction).
N = Total number of irrigations to be given in the season (Numbers)
C_0= Initial salt concentration in the root zone [ML^{-3}]
C_i = salt concentration in irrigation water, [ML^{-3}]
C_l = Average seasonal salt concentration in the outer fraction (l) of wetted volume (e.g. g/l) [$M L^{-3}$].

Modelling Salt Dynamics under Drip Irrigation

All irrigation waters contain some amount of dissolved salts, which determine its quality, and when the evapotranspiration takes place, water gets lost while the salts remain in the soil. The salt accumulation in the root zone can be aggravated if no off-season leaching occurs either by precipitation or irrigation sufficient for leaching. Since the amount, concentration and the distribution of solute determine the crop performance and yield, a thorough understanding of salt movement and its distribution within the wetted volume is of great importance. Alternatively, low quality water sources with drip irrigation have been recommended for agriculture in scarce fresh water situations (Oster, 1994).

Kumar and Sivanappan (1983) developed iso-salinity curves for the root zone with plain bore well water and four treatments of saline water application with different electrical conductivities (2.5, 5.0, 7.5 and 10 dS m^{-1}) in a field experiment.

Solute Transport in Drip Irrigation

Solute transport in the wetted soil volume is often described by the convection dispersion equation (CDE) that takes into account the three main mechanisms of solute transport, namely convection, diffusion and dispersion. In convective transport, solutes are carried by mass flow of water. Diffusive transport occurs as solutes diffuse from locations of higher solute concentration to lower concentrations. Because the soil has different sizes and shapes of pores, differences in pore velocities cause solutes to be transported at different rates to different locations. This leads to mixing of incoming solutes with resident concentrations and this phenomenon is referred to as hydrodynamic dispersion. These types of solute transport and their combinations have led to several formulations of models for predicting solute transport. Solute transport modelling approaches vary in their assumptions, complexity, as well as their data requirement, and acquisition. According to Jury (1984), field scale solute transport can generally be categorized into deterministic and stochastic models. Deterministic models use continuity equations with parameters having values at every point in space and having a fixed logical relation to each other. On the other hand, stochastic models use parameters that are assumed to vary randomly and may be characterized in terms of a probability distribution (Jury, 1984). A multi-dimensional convection-dispersion equation for reactive solute in an anisotropic media is given as (van Genuchten and Alves, 1982)

$$\theta \frac{\partial \theta}{\partial t} = \theta \nabla (D \nabla C) - q \nabla C - \rho \frac{\partial S}{\partial t} - Q \quad (3)$$

Where, C is the solute concentration (kg m^{-3}), ρ is the soil bulk density (kg m^{-3}), D is the solute dispersion coefficient (m^2 s^{-1}), Q is a sink or source for irreversible solute interaction (g m^{-3} s^{-1}), t is time (s), q is the Darcy soil water flux (m s^{-1}), ∇ is the spatial gradient operator, S is the amount of solute adsorbed to the soil matrix (kg kg^{-1} of soil).

The above CDE equation has been solved under different solute transport scenarios and assumptions (Bresler, 1975; Leij *et al*., 1991; Van Genuchten and Alves, 1982). For non-reactive solute transport in the absence of sources or sinks for the solute in the soil, the last two terms from the above equations are removed. A two-dimensional form of this equation has been solved numerically by Bresler (1975) and Tim and Mostaghimi (1989) to describe the transient phosphorous movement and distribution in the vadose zone. Numerical solutions for one-dimensional CDE have been provided (Moldrup *et al*., 1989; Shao *et al*., 1998).

Similarly, analytical solutions have been provided for CDE by several others (van Genuchten and Alves, 1982; Leij and Dane, 1990; and Leij *et al*., 1991). Despite the simplifying assumptions in their development, analytical models have remained easier and simpler to handle than numerical models. But they are usually preferred over numerical models because they require fewer parameters both to describe and analyze the problems; there is direct relationship between input and output parameters; and analytical models offer predictive capabilities whereas numerical models often apply only to the particular simulated case. These relationships can allow sensitivity analysis of the input and output analytical model parameters (Mmolava and Or, 2000, b). According to Leij *et al*. (1991), analytical solutions can also become handy for extrapolating transport parameters over large distances and times when numerical models become less applicable.

Cote *et al*. (2003) used two dimensional solute transport model HYDRUS-2D to analyze and simulate soil wetting and solute transport in subsurface drip irrigation under various irrigation and fertigation strategies. They demonstrated that fertigation in the beginning of the irrigation cycle might reduce the nitrate leaching under specific conditions. Gardenas *et al*. (2005) investigated the nitrate movement using model HYDRUS-2D for citrus, grape, tomato and strawberry fields. Ajdary *et al*. (2007) applied two dimensional solute transport model HYDRUS-2D to simulate water and nitrogen distribution and leaching for sandy clay loam, sandy loam, loam, silt clay loam, and silt soils. They used three dimensional axi-symmetrical form of polar coordinate advection-dispersion form of modified Richards equation by Simunek *et al*. (1999) for single non reactive ion and uptake.

Root Distribution, Water Uptake and Solutes' Movement under Drip Irrigation

Plant uptake of water and solutes is perhaps the most difficult to quantify as far as root zone solute and soil water dynamics are concerned. Most, if not all, of the uptake models that exist, contain parameters for uptake that have to be adjusted for a specific crop and for the specific conditions under which it is growing. Spatial distribution of plant roots is an integral part of water extraction functions or models. Root systems can be expressed in several ways, such as root percentage distribution, root density distribution and root length density (RLD) distribution. Phene *et al*. (1991) explained that it is especially important in drip irrigation to define these root parameters, since it is widely believed that drip irrigation may limit the wetted soil volume and, therefore, the extent of root development. But root distributions have been found to depend mostly on the availability of the water, type of irrigation system, crops and soils (Kamara *et al*., 1991; Phene *et al*., 1991; and Zhang *et al*., 1996).

Although root distribution is a highly dynamic process, Ehlers *et al.* (1991) assumed steady state conditions for their development of a model linking root density and water uptake. If soils are frequently irrigated, especially from the surface, they will remain relatively wet there and most of the root water uptake will then take place in the upper soil layers (Klepper, 1991). Alaerts *et al.* (1985) compared the performance of some macroscopic root uptake models. In most cases the important difference between these various models is the way in which the root water uptake term was derived or as Cardon and Letey (1992) put it, the uniqueness of each model depends on its formulation.

High transpiration rates can cause large flux of nutrients towards the root, and rapid accumulation of nutrients at the soil–root interface may lead to high and detrimental nutrient concentrations around the root zone. If these nutrients are excluded by the root, then the osmotic potential close to the root surface can become an exponential function of water uptake, and this could reduce water uptake if the salt concentration in the soil solution is so high as to lower the soil water potential close to the root surface (Hamza and Alymore, 1992).

Zhang *et al*. (1993) developed one and two dimensional models for describing spatial distributions of peanut roots. They used RLD under different water treatments to model the root distribution. Working under the assumption that root length density is an indicator of root water activity, they formulated both linear and exponential forms of root length density for one and two-dimensional cases.

Although the macroscopic approach is more convenient to model root water uptake, it does not help to increase the understanding of water uptake by plant root, as the microscopic approach does (Aura, 1996). For the microscopic approach a single root is considered as a cylinder that is taken as a line source of uniform thickness and infinite length, having uniform water absorbing properties (Radcliffe *et al*., 1986; and Aura, 1996). The flow to the root is usually assumed radial (Clothier and Green, 1997) and gravity is ignored.

Chandra and Rai (1996) have mentioned that many studies suggest that root water uptake is related to the root density and that root water uptake varies nonlinearly with depth in the soil profile.

Coelho and Or (1999) have characterized a two-dimensional root distribution for drip irrigated corn plants. They fitted Gaussian distribution parametric models they had earlier developed (Coelho and Or, 1996) to the corn RLD to produce two-dimensional root distributions that they compared to root water uptake (RWU) patterns. It has however noticed that root water and solute uptake models based on RLD are destine to fail when there is large disparity between the RLD and actual root uptake of water and solutes (Clothier *et al*., 1990; Coelho and Or, 1999).

Hanson *et al*. (2006) analysed four micro-irrigation systems in five fertigation strategies for various soil types and using HYDRUS-2D model to study the distribution of soil nitrogen, phosphorous, potassium and nitrate leaching. They used Feddes model for root water uptake while Vrugt model was used for the distribution of the roots. The spatial distribution of urea and nitrates for surface, subsurface and drip tapes were discussed.

Solute and Plant Interaction under Drip Irrigation

The area under drip is likely to increase dramatically in the time to come yet the experiences of drip irrigation under salt affected environment are limited. Although in many countries particularly in Israel,

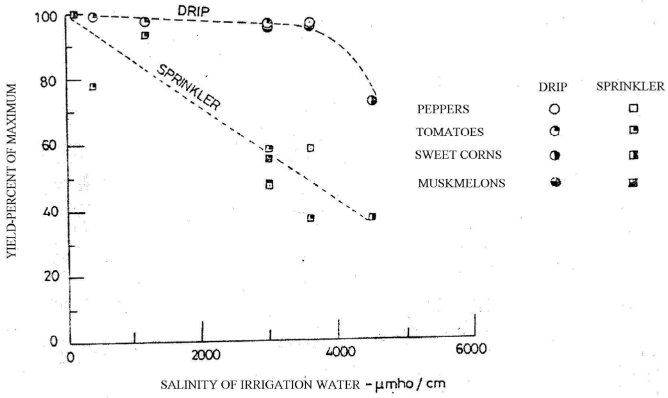

Fig. 1. Variation in yield with saline water in drip and sprinkler irrigation (Source: Godberg and Shmueli, 1970)

saline/sodic waters are extensively and intensively used with drip irrigation so much so that it has become a normal practice. If one has to look for the experimental evidences, one has to go back to more than 25-30 years before since currently research organizations do not indulge in such experimentation to prove the benefits of drip irrigation. As an example, good information on the relative merits of drip and sprinkler systems was made available way back in 1970 (Fig. 1). The data clearly reveal the superiority of drip over the sprinkler method at all salinity levels for all the crops (Fig. 1).

Under the Indian conditions, Agrawal and Khanna (1983) reported the results of an experimental trial conducted at CCS HAU, Hisar, for growing radish crop with saline tube well water (EC = 6.5 dS m^{-1}) and good quality canal water (EC = 0.25 dS m^{-1}). The results revealed the utility of drip irrigation in two ways. The yield was higher with drip being maximum in subsurface than surface drip (Table 1). The yield reduction was much less in case of saline water in drip as compared to surface irrigation. However, it may be mentioned that benefits of subsurface drip are not always forthcoming and the usefulness has to be investigated considering the soil, crop, salinity of the soil and water etc.

Table 1. Water use efficiency under different methods of irrigation with saline and good quality water

Method of Irrigation	Good quality water (EC= 0.25 dS m^{-1})		Saline water (EC= 6.5 dS m^{-1})	
	Yield (t ha^{-1})	WUE (kg ha^{-1} cm^{-1})	Yield (t ha^{-1})	WUE (kg ha^{-1} cm^{-1})
Subsurface drip	2.68	3000	2.36	2600
Surface drip	1.75	1900	1.57	1800
Surface irrigation at 35 mm CPE	1.64	1400	0.99	900
Surface irrigation at 60 mm CPE	1.39	1200	0.67	600

Field experiments were also conducted at CCS HAU farm for tomato, cauliflower, cabbage, brinjal, watermelon, grapes, cotton, and sugarcane under deep water table conditions (> 5m) and shallow water table conditions (<1.5m) in sandy loam soils to study the comparative performance of drip irrigation with saline tube well water (EC=6.5 dS m^{-1}) and good quality canal water (EC = 0.28 dS m^{-1}) for different irrigation schedules based on ratio of the depth of irrigation to the potential evapotranspiration (IW/PET) varying from 0.3 to 1.0. Drip irrigation performed better under deep water table conditions but the performance of drip irrigation under shallow water table conditions was mixed (Singh and Kumar, 1989, Singh *et al*., 1990 and Singh and Kumar, 1994).

Jain and Pareek (1989) observed that salt accumulation was minimal in drip irrigation when saline waters of EC ranging from 2.7 to 9.0 were used to irrigate date palm trees. Similar results were reported by Singh *et al*. (1990) when sodic waters containing RSC 2.1, 8.45 and 12.45 meq l^{-1} were applied to grow the kinnow (*Citrus reticulata*) plantation. Drip irrigation system was also found more effective in the establishment of fruit garden on salt affected soils (Dwivedi *et al*., 1990) whereas Pampattiwar *et al*. (1993) reported higher water use efficiency with drip method of irrigation over the conventional method.

Kumar and Sivanappan (1983) concluded that drip irrigation gave higher crop yield than any other irrigation method when irrigating with saline water. They developed iso-soil salinity curves for the root-zone at different durations from the day of application of 5 levels of saline water (EC 0.85, 2.5, 5.0, 7.5, and 10.0 dS m^{-1}) in equal amount by micro-tube, nozzle and orifice type emitters. They prescribed that saline water having an EC of 7.5 dS m^{-1} is safe for growing crop with the drip irrigation.

Jain (1984) reported that drip lines installed at 90 and 150 cm distance in paired rows of tomato and cotton increased the yields almost 3 times over the conventional flood irrigation method and attained 30-50 per cent economy in water use. He also reported that salt concentration in root zone under drip was minimum at the drip points. Compared to the drip points, salt concentration was twice at 10-15 cm distance and thrice at 30-60 cm. Similarly moisture content at drip points was 20 and 40 per cent higher respectively as compared to those at 30 and 60 cm distance. The major drawback of irrigation with drippers is the high salt concentration that develops at the wetting front. Accumulated salt cause difficulties in the planting of subsequent crops because effective leaching of salts require flooding. Another problem reported is the clogging of drippers due to precipitation of salts.

Subba Rao *et al.* (1987) observed up to 50 per cent decrease in yield of tomato when EC of irrigation water exceeded 6 dS m^{-1}. Singh and Kumar (1988) studied the comparative performance of drip and subsurface irrigation systems on tomato at different EC and IW/PET ratios. Results reported in Table 2 explain the effect of irrigation scheduling on yield and salt build-up. Apparently, a low IW/PET ratio for irrigation scheduling seems to be preferable to get high yields, save water and to minimize salt build-up.

Table 2. Yield, irrigation depth, water use efficiency and soil EC for tomato

Year	IW/PET	Yield (t ha^{-1})	Irrigation depth (cm)	WUE (kg ha^{-1} cm^{-1})	EC (dS m^{-1})
	0.7	5.47	40.4	135	2.03
1986	0.5	15.14	29.4	515	0.82
	0.3	14.22	21.2	610	0.70
	0.7	13.06	38.1	343	0.83
1987	0.5	12.23	30.0	397	0.32
	0.3	7.83	23.5	333	0.55

Irrigating tomato and brinjal crops through drip using canal water, and waters of 4 and 8 dS m^{-1} at three IW/CPE levels (0.75, 1.00 and 1.25) at different irrigation intervals of 2, 3 and 4 days gave better yield at higher IW/CPE ratios (CSSRI, 2000). It was also observed that when total amount of water application remained constant, 13 and 33 per cent higher yield was observed at irrigation intervals of 3 and 4 days in comparison to the interval of 2 days. In another study on tomato under drip, the yield decreased from 38.7 to

29.8 t ha^{-1} as salinity of irrigation water increased from 0.21 to 5 dS m^{-1}, which was about 24 per cent less over the normal water application (Kadam and Patel, 2001).

Abd El Warth (2005) compared the performance of surface and subsurface drip irrigation system with saline irrigation water. Field experiments were carried out at some farms in El-Gebeel, south Sinai, Egypt. Tomato plants (*Lycopersicon esculentum* cv. G.S.) were transplanted and irrigated with irrigation water of four salinity levels 1.90, 3.98, 6.20 and 10.00 dS m^{-1}. Fresh water was used as control (0.88 dS m^{-1}). Results obtained indicated that the rate of salt accumulation in the first layer (0-20 cm) was relatively higher in soil irrigated using subsurface drip system than that under surface drip irrigation system. Moreover, the second layer had relatively low value of salt accumulation under subsurface drip irrigation system compared with surface drip irrigation. Tomato yield decreased in the successive seasons under salt stress, but under subsurface drip irrigation the decrease in yield was lower than that under surface drip irrigation. Water use efficiency significantly decreased with increasing irrigation water salinity. Water use efficiency was higher in subsurface drip system compared to surface drip.

Ma *et al.* (2005) determined the effects of drip rate, saline water irrigation amount and water quality on water and salt movement. The results indicated that the power function fitted well to the advances of horizontal wet front and ponding water area with time under the conditions of sufficient water supply. It was also observed that smaller drip rate conformed to less salt content along the soil depth, and larger drip rate resulted to a more indistinct tendency of salt content to increase with distance. It was also observed that irrigation water volume was a key factor to control salt accumulation when irrigating with saline water. Insufficient irrigation cannot guarantee enough leaching of salts in soil with small infiltration volume. Besides, the increase in the salt content of irrigated water will increase the salt content of the surface soil.

Malash *et al*. (2008) evaluated drip and furrow irrigation systems using saline drainage water (electrical conductivity of 4.2–4.8 dS m^{-1}) in blending and cyclic mode of application for tomato. Their results indicated that the growth parameters, yield and the water use efficiency remained higher in drip than in furrow irrigated tomato, but with increasing salinity these parameters gave a decreased trend among all the cases. In both drip and furrow, the soil moisture one day after irrigation was higher at the top 20 cm layer and at the location of the irrigation water source; it was minimum in the root zone (20–40 cm layer), but showed a gradual increase at 40–60 and 60–90 cm and was stable at 90–120 cm depth. Soil water content decreased gradually as the distance from the irrigation water source increased. Soil salinity at the irrigation source was lower at a depth of 15 cm (surface layer) than that at 30 and 60 cm, and was minimal in deeper layers (i.e. 90 cm). Salinity increased as the distance from the irrigation source increased particularly in the surface layer. The results indicated that the salinity followed the water front. They recommended the use of drip irrigation as the fruit yield per unit of water used was on an average one-third times higher than furrow irrigation. The use of blended fresh water with low to medium saline water led to only a slight reduction in yield when compared to cyclic treatment.

Drip Irrigation Studies at CSSRI, Karnal/AICRP Centers

Studies on drip irrigation have been conducted at CSSRI, Karnal since its inception. Three levels of RSC 0.6, 4 and 8 meq l^{-1} (at a fixed value of EC of 3 dS m^{-1}) were given through drip irrigation in kinnow orchards at 3 l hr^{-1} at an irrigation interval of 3 days. The distribution of moisture, chlorides, SAR and the nutrient status were monitored in the root zone (CSSRI, 1986). Since rainfall during monsoon season leached down the salts, no build-up of salts was observed over the years.

A study conducted on sugarcane at Trichurapalli centre of AICRP on Salt Affected Soils and Use of Saline Water in Agriculture revealed that irrigation scheduling under drip with alkali waters (pH 8.8, EC 2.2 dS m^{-1}, RSC 12.9 meq l^{-1} and SAR 18.2) at 60 per cent of pan evaporation (PE) gave higher water use efficiency than 80 and 100 per cent of PE and farmers' practice (surface irrigation), under both the sub-treatments of no gypsum or 50 per cent application of gypsum requirement (Table 3) (CSSRI, 2000).

Table 3. Effect of irrigation schedules on growth and yield of sugarcane under drip irrigation

Main treatments of irrigation at percentage of PE	Yield (t ha^{-1})		Water applied		Water use efficiency (t ha^{-1} cm^{-1})	
	50 per cent of gypsum requirement	No gypsum application	Depth (cm)	Reduction in water applied (%)	50 per cent of gypsum requirement	No gypsum application
100	99.3	95.6	44.8	7.14	2.21	2.13
80	107.4	98.5	33.8	42.01	3.18	2.91
60	96.6	91.1	23.0	108.69	4.20	3.96
Farmers' practice	99.5	93.8	48.0	-	2.07	1.95

Saxena and Gupta (2006) evaluated the growth of litchi (*Litchi cheninsis* Sonn.) under drip irrigation in a varying sodic environment (pH value ranging from 7.34 –10.01). At an over all water application uniformity of 0.75, linear decline was observed in plant height and percent increase in height with increase in pH. In the soil having pH up to 8.1 the annual growth in plant height was recorded above 50 per cent, whereas it was less than 5 per cent in the plants grown in pH more than 9.0.

Subsurface drip gave 1.5 times more yield of okra crop over surface drip using poor quality domestic sewage water, while yield increase in the case of cabbage was not observed (Pandey *et al.*, 2008). While comparing the surface and subsurface drip for irrigation with saline water, favourable and unfavourable results have been reported calling for more researches on this issue.

Singh *et al.* (2000) compared the plant performance and the soil salinity before and after three years of application of 0.4, 4.0, 8.0 and 12.0 dS m^{-1} saline water through drip and basin irrigation in sapota crop at Khanpur farm, CSSRI-RRS, Anand, Gujarat. The plant performance and the soil salinity after the experiment showed that drip irrigation had performed better for growth of plant and less salinity build- up was observed compared to the basin methods in all the treatments.

Table 4. Interaction effect between EC and IW/CPE ratio on fruit yield (t/ha) of tomato and chilli in drip and surface irrigation

IW/CPE ratio	EC_{iw} levels (dS/m)			Mean	EC_{iw} levels (dS/m)			Mean
	Control	4	8		Control	4	8	
	Drip Irrigation				Surface Irrigation			
Tomato	2003-2004							
0.75	26.47	21.74	18.66	22.29	26.45	22.48	17.31	22.08
1.00	28.63	23.46	17.07	23.05	26.39	22.54	16.95	21.96
1.25	28.52	23.72	16.98	23.07	27.79	21.99	15.00	21.61
Mean	27.87	22.97	17.57		26.87	22.34	16.42	
	2004-2005							
0.75	53.02	37.95	27.51	39.49	50.03	40.83	25.05	38.64
1.00	53.58	37.78	26.31	39.22	44.64	33.43	24.6	34.22
1.25	50.59	37.88	25.78	38.08	44.44	32.93	22.55	33.31
Mean	52.40	37.87	26.53		46.37	35.73	24.07	
Chilli	2004							
0.75	1.71	0.14		0.62	2.40	0.08		0.83
1.00	2.05	0.50		1.02	2.74	0.24		0.99
1.25	2.44	0.70		1.05	2.76	0.41		1.06
Mean	2.07	0.45			2.63	0.24		
	2005							
0.75	4.80	3.25	0.10	2.72	4.92	2.85		2.59
1.00	5.01	2.76	0.10	2.62	5.11	1.74		2.28
1.25	5.45	2.88	0.10	2.81	5.01	1.62		2.21
Mean	5.09	2.96	0.10		5.01	4.32		

An experiment was conducted at AICRP, Agra to assess the tolerance of tomato-chilli rotation with treatment combinations of saline irrigation water (Canal, EC_{iw} 4 and 8 dS/m) and irrigation schedule (IW/CPE ratio 0.75, 1.00 and 1.25) (CSSRI, 2007). Irrigation interval for drip irrigation was 4 days and depth of water application in each irrigation was 4 cm. The fruit yield of tomato decreased significantly with increasing EC_{iw} in both drip and surface irrigation system. With EC_{iw} 4 and 8 (dS/m), the tomato fruit yield reduced by 18 and 37 in 2003-04 and 28 and 49 percent in 2004-05 in drip irrigation and 17 and 39 and 23 and 48 percent in surface irrigation system respectively (Table 4). Since the yield in surface and drip methods of irrigation did not vary much, it could be inferred that drip irrigation method could not play a significant role in case of tomato at these salinity levels. Although data are not available to confirm the observation, irrigation scheduling being same in the two methods, advantage of drip irrigation to facilitate frequent application of water was not utilized in the present set-up. However, equivalent yield of tomato could be obtained with 25-30 percent less water in drip than with surface method. Amongst the IW/CPE ratios 0.75 to 1.00 ratio could be used. After the harvest of winter tomato, chilli was transplanted during summer season. The saline irrigation affected chilli more in 2003 compared to 2004. The yield with EC_{iw} 4 (dS/m) declined by 78 percent in 2004 and 42 percent in 2005 over BAW. At higher EC_{iw} 8 dS/m crop failed completely in both the years. Overall, growing of the chilli crop is not advisable with saline water during summer season.

The fruit yield of chilli in 2005-06 (Winter season) significantly decreased with increasing EC_{iw} levels in both drip and surface irrigation system (Table 5). The EC_{iw} 4 and 8 dS/m reduced the fruit yield by 36 and 40 percent in drip irrigation and 40 and 54 percent in surface irrigation system, respectively. The IW/CPE ratio treatments were found non-significant.

Table 5. Effect of EC and IW/CPE ratio on yield (t/ha) of chilli in drip and surface irrigation

IW/CPE ratio	EC_{iw} levels (dS/m)			Mean	EC_{iw} levels (dS/m)			Mean
	Control	4	8		Control	4	8	
	Drip Irrigation				Surface Irrigation			
0.75	15.40	9.82	9.43	11.55	10.24	6.38	5.60	7.41
1.00	15.60	9.87	9.26	11.58	10.34	6.36	4.34	7.01
1.25	14.74	9.52	8.64	10.97	10.30	5.63	4.28	6.74
Average	15.21	9.74	9.10		10.30	6.13	4.74	
CD 5% Salinity		6.8				10.7		
IW/CPE ratio		NS				NS		
EC x IW/CPE		NS				NS		

Concluding Remarks

Drip irrigation technology under the saline environment could be quite suitable and useful, it ensures increased crop yield, higher fertilizer and water use efficiencies, reduced water and energy consumption and weed problems, as studies have reported its use for several horticultural and vegetable crops, particularly which are widely spaced.

Modelling for the accurate prediction of the salt water movement in the wetting volume can save water, fertigation and chemigation seepage without much extra nutrient loss to the plant under salt stress condition. A methodology that yet needed to be evolved using such wide ranged available models for more accurate design of drip in saline environment for sustainable crop production. It can be made possible by increasing the wetted volume which can result in a low salt concentration (up to same concentration of saline water for irrigation) around the roots, while transporting and accumulating the extra incoming salts away to the outskirts of the wetting volume, and therefore inside wetting volume would be suitable for crop.

Development of a sound data bases on crops with different soil and water quality however, still needs upgradation. But in the absence of detailed information, its popularity and adoption is lacking and needs to be increased through awareness and training to the users.

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Modeling Sustainable Conjunctive Use of Sodic Groundwater and Fresh Water

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Introduction

In semi-arid and arid parts of north and northwestern India, use of poor quality groundwaters for irrigation in wheat-based crop rotations is a common practice. The shortage of water in these areas is so acute that there seems no other way except harnessing the available poor quality groundwaters. The use of poor quality waters in India ranges from 32-84 percent of total groundwater development (Minhas and Gupta, 1992). The state of Haryana has saucer shape topography with depression of inland basin between Indus and Ganges basin. In between fresh groundwater area of northeast and saline groundwater area of southwest, there are patches of sodic groundwaters. The state receives canal water from Western Jamuna Canal (WJC) and Bhakra canal system. Due to intensive agriculture besides limited canal water supply, use of groundwater is common. The use sodic and saline waters for irrigation in poor quality groundwater areas enhance the soil salinisation and sodification. In the poor quality water areas, the extent of saline, sodic and saline-sodic waters are approximately 20, 37 and 43 percent, respectively (Yadav and Kumar, 1995). Poor quality sodic water zones occur in Uttar Pradesh, Haryana, Punjab and Rajastan. Sodic water occupies 25 and 21 percent in State of Punjab and Haryana, respectively. The All India Coordinated Research Project (AICRP) on Saline Water, Central Soil Salinity Research Institute (CSSRI), Karnal, Haryana Agricultural University (HAU), Hisar and Punjab Agricultural University (PAU), Ludhiana jointly developed and recommended guidelines for use of saline and sodic waters for crop production under Indian monsoon type of climate (Gupta *et al.*, 1994).

Solute transport in the soil as a result of sodic water irrigation is reactive transport and it is controlled by cation exchange capacity and hydraulic conductivity of the soil. A linear relationship exists between cation exchange capacity and clay percentage while the hydraulic conductivity has an exponential relationship with clay percentage. Both properties vary spatially and an ESP (Exchangeable Sodium Percentage) development in the topsoil layer as result of sodic water irrigation is not influenced by spatial variability of these soil properties. However, irrigation water quality and its temporal variability can influence ESP development (Kaledhonkar *et al.* 2001, 2006; Kaledhonkar and Keshari 2006a, 2006b). Temporal variability in irrigation water quality might occur due to alternate use of sodic and canal water or due to occurrence of rain event. Though ESP is not influenced by spatial variability in soil properties, adsorption of sodium ions is directly proportional to cation exchange capacity of the soil. Thus, soil with higher cation exchange capacity may have higher sodium ions at soil exchange complex compared to soil with lower cation exchange capacity at the same ESP value (Kaledhonkar, 2003). Soils having different cation exchange capacity values might show different desorption behaviour on application of canal water or on occurrence of rain event. There is need to understand these behaviours for making/ improving guidelines on sodic water irrigation. The joint guidelines (Gupta *et al.*, 1994) for use of saline and sodic waters for *kharif* fallow/ *rabi* crop rotation provided limits of SAR and RSC of irrigation water, considering soil textural group and annual rainfall amount of the region. In this research existing guidelines for use of sodic waters were further investigated through UNSATCHEM modeling. Improved guidelines were verified with published and field data. Sustainability of rice- wheat rotation under conjunctive water use of sodic groundwater and canal water, in Assandh and Nissang blocks of Karnal district, was assessed with help of the improved guidelines.

Understanding the Soil Variability

Data on the soil properties such as textual class, soil moisture retention characteristic, cation exchange capacity, saturated hydraulic conductivity, bulk density, etc. from different places in the commands of the Bhakra Canal system and Western Jamuna Canal system in Haryana were collected from Sood (1969) and Sharma (1972). The sandy loam is dominant textural class in the area. Therefore, data relating to sandy loam class from 27 samples were pooled together irrespective of location, and used in further analysis. The data of cation exchange capacity (CEC) expressed in $mmol_c/kg$ followed lognormal distribution with mean ($\mu_{ln(CEC)}$)and standard deviation ($\sigma_{ln(CEC)}$) as 4.25 and 0.28, respectively. Data of saturated hydraulic conductivity (Ks) in cm/day also followed lognormal distribution with mean ($\mu_{ln(Ks)}$) and standard deviation ($\sigma_{ln(Ks)}$) as 4.02 and 0.52, respectively. The statistical properties of CEC and Ks were used to prepare three soils with combinations of CEC and Ks as mentioned in Table 1. The three soils, considered for analysis, represented the possible variability in sandy loam textural class within the region.

In irrigation water quality guidelines, Gupta *et al.* (1994) defined moderately coarse group of soils as soils with 10-20% clay. Sandy loam textural class mainly belongs to this group. Safe limits for RSC and SAR of irrigation water for moderately coarse soils are 5-7 and <15, respectively. These limits pertain to *kharif* fallow/*rabi* crop rotation when annual rainfall is 350-550 mm. These guidelines are of general type. It would be interesting to study how the irrigation water quality safe limits vary with variability in soil properties within a textural class and variability in rainfall amount.

Table 1. Properties of different sandy loam soils

Sr. No.	Soil	CEC (mmol$_c$/kg)		Ks (cm/day)	
1	A	$\mu_{ln(CEC)}+\sigma_{ln(CEC)}$	93.18	$\mu_{ln(Ks)}+\sigma_{ln(Ks)}$	33.37
2	B	$\mu_{ln(CEC)}$	70.11	$\mu_{ln(Ks)}$	55.91
3	C	$\mu_{ln(CEC)}-\sigma_{ln(CEC)}$	52.74	$\mu_{ln(Ks)}-\sigma_{ln(Ks)}$	93.18

UNSATCHEM Modeling to Improve Guidelines

The one-dimensional variably saturated flow and multi-component transport model; UNSATCHEM (Simunek *et al.*, 1996), was employed for simulations to find the safe water quality limits, for soils in Table 1, considering variability in rainfall/ canal amount and consequent variability in sodic groundwater use for irrigation. The model required soil hydraulic properties in terms of soil water retention and hydraulic conductivity parameters (Van Genuchten, 1980). Though variability in CEC and Ks was considered by selecting three soils as given in Table 1, variability of soil water retention parameters such as volumetric saturated water content (θ_s), residual water content (θ_r), α and η was ignored. The average values of these parameters for sandy loam soil class were determined by analyzing an array of (h,θ_{mean}) by the RETC model (Van Genuchten *et al.*, 1991). The θ_{mean} represents the geometric mean of θ values determined from n individual pF curves by applying following equation.

$$\theta_{mean} = \exp\{(\sum_{i=1,n} \ln \theta) / n\}$$

The geometrically averaged soil water retention parameters θ_s, θ_r, α and η were equal to 0.43, 0.0, 0.033 and 1.31, respectively. The bulk density and Gapon selectivity coefficient were assumed as 1.5 g/cc and 0.35 $mol_c^{-0.5}/l^{-0.5}$, respectively.

The model was calibrated and validated by Kaledhonkar *et al.* (2001) for sodic water use experiment on summer moong crop conducted by Dhaliwal (1992). It was also calibrated and validated by Kaledhonkar and Keshari (2003, 2006b) for saline water use experiment on wheat crop conducted by Naresh *et al.* (1993). The calibrated and validated UNSATCHEM model was used for further simulations. The simulations were planned considering sodic water guidelines (Gupta *et al.*, 1994), which suggested upper limit of SAR as 15 $(mmol_c/l)^{0.5}$ and range of RSC as 5.0-7.5 mmol$_c$/l, for irrigation water use in fallow *kharif* and *rabi* crop rotation on moderately coarse soils with 10-20% clay. These water quality limits were applicable for *kharif* fallow/ *rabi* crop rotation when annual rainfall remained 350-550 mm. As *kharif* fallow/ *rabi* crop rotation required one year, simulation period was taken as one year, starting from pre-sowing of wheat crop to end of monsoon season, for all simulations. As per guidelines, *kharif* season was kept fallow to promote desodification process and wheat crop was assumed during *rabi* season. For each soil given in Table 1, three simulations were done with three levels of rainfall amount i.e., 350, 450 and 550 mm, respectively. Thus total 27 simulations were done. Daily potential soil evaporation and irrigation by sodic water were considered as input at soil surface during simulation. It meant that irrigation and little rainfall during wheat and much of rain during kharif (i.e. remainder of year. Pre-sowing irrigation and four post-sowing irrigations, for wheat crop, were applied by sodic water. Total irrigation amount was 38 cm. The rainfall during wheat period was assumed as 7 cm. The rainfall events and their amounts, during remaining part of the year, were adjusted to have annual rainfall amounts equal to 350, 450 and 550 mm as required for different simulations. The weather data of Hisar meteorological station in south- western region of Haryana were selected considering its annual rainfall of 420 mm, which was in the range of rainfall selected for simulations. The class A pan evaporation for Hisar station was 2150 mm for period from November 1985 to October 1986. The sowing and harvesting dates of wheat crop were assumed as 10th November 1985 to 20th April 1986. The daily pan data were analyzed to determine reference evapotranspiration during wheat period using CROPWAT model (Smith *et al.*, 1999) and soil evaporation for remaining period (Feddes *et al.*, 1974; Singh, 1983). The average annual class A pan evaporation for Hisar station was 2136 mm and variability in class A pan evaporation data was ignored during simulations. The period November 1985- October 1986 was randomly selected. It was ensured that rainfall of a particular year (i.e. 390 cm) was within the decided range of rainfall (i.e. 350- 550 mm). Penman Monteith method was used to estimate reference evapotranspiration as suggested by Tyagi *et al.* (2000). Evapotranspiration requirement for different growth stages of wheat crop was determined by using crop coefficients such as 0.35, 0.44, 0.84, 1.11, 1.07 and 0.59, respectively (Smith *et al.*, 1999).

Initial concentrations of dissolved Ca^{++}, Mg^{++}, Na^+ K^+, HCO_3^-, SO_4^{--}, and Cl^- were taken as 3.15, 1.55, 1.2, 0.1, 1.6, 2.9 and 1.5 mmol$_c$/l, respectively for all three soils. The corresponding initial adsorbed concentrations of Ca^{++}, Mg^{++}, Na^+ and K^+ were determined as 0.66, 0.32, 0.0025 and 0.0124 times the CEC for all soils. These ratios were determined from the field data of Dhaliwal (1992) that were used in calibration and validation of the UNSATCHEM model. Initially soils were assumed as non-sodic. The Gapon selectivity coefficient was assumed as 0.35 $mol_c^{-0.5}/l^{-0.5}$ for all soils (Poonia *et al.*, 1990). Free drainage was assumed at lower boundary. The CO_2 concentration (cm^3 cm^{-3}) was assumed to increase linearly from 0.00033 at the soil surface to 0.0006 at 30 cm depth. It reduced to 0.0004 (at 32 cm) and remained constant up to 50 cm. Below, a constant concentration of 0.0002 cm^3 cm^{-3} was assumed considering some trapped air in sub layers. The assumption related to CO_2 concentration was based on the presence of the organic matter in the soil due to root activity. A time invariant CO_2 concentration was prescribed depth wise during the simulations.

The quality parameters such as RSC and SAR of sodic irrigation waters during simulations were selected according to irrigation water quality guidelines of Gupta *et al.* (1994). These parameters were worked out by adjusting the concentrations of different ions. As per guidelines, range of RSC of sodic water should be between 5 to 7 $mmol_c/l$ for moderately coarse soil. Therefore an average value of 6 was selected as suitable (safe). During the simulation, SAR value of sodic irrigation water was considered as suitable (safe) under *rabi* wheat- *kharif* fallow crop rotation provided average ESP for 0-30 cm soil layer at the end of simulation period (i.e. at the end of monsoon) remained less than 3. The same value of SAR is referred as threshold SAR for sodic irrigation water. It was assumed that sodification would take place due to sodic water application during wheat crop, while rainfall during monsoon season (fallow period) would help in desodification. The ESP value of 3 is sufficient enough to assume the soil as non-sodic. Hira *et al.* (1980) reported that wheat root growth was unaffected and also wheat yields were not affected significantly when ESP did not exceed 30.5. Wheat plants were reported to tolerate this degree of sodium saturation without yield reduction (Pearson, 1960). The ESP value of 3 (10% of threshold ESP value) was much lesser than threshold value 30.5.

Thus, keeping RSC of sodic water at 6, the threshold value of SAR was determined for each soil (in Table 1) through different repetitive simulations. Temporal changes in 0-30 cm ESP values on application of sodic water having RSC =6 $mmol_c/l$ and SAR=10 $mmolc^{0.5}/l^{0.5}$ for soil A under wheat-fallow crop rotation are shown in Fig. 1. It was appropriate to select 0-30 cm depth as maximum ESP on application of sodic water was observed in topsoil layers (Kaledhonkar, 2003). Also yield and fibre quality of cotton cultivars under sustained sodic water irrigation under semi-arid condition were predicted on the basis of ESP development in topsoil layers by Choudhary *et al.* (2001). The ESP increased during wheat crop period with use of sodic water for pre-sowing irrigation as well as for four post-sowing irrigation on 2nd, 32nd, 61st, 76th and 112th day, respectively. The sowing and harvesting of wheat crop was done on 10th and 161st day. The rainfall events before and after harvest, with total rainfall amount of 35 cm, reduced the ESP. The average ESP (0-30 cm) at the end of monsoon season (simulation period) was 5.33, which was higher than 3. Temporal changes in ESP as result of sodic waters of different SAR such as 7, 6, and 5 $mmolc^{0.5}/l^{0.5}$ but RSC as 6 $mmol_c/l$ are shown in Fig. 1.

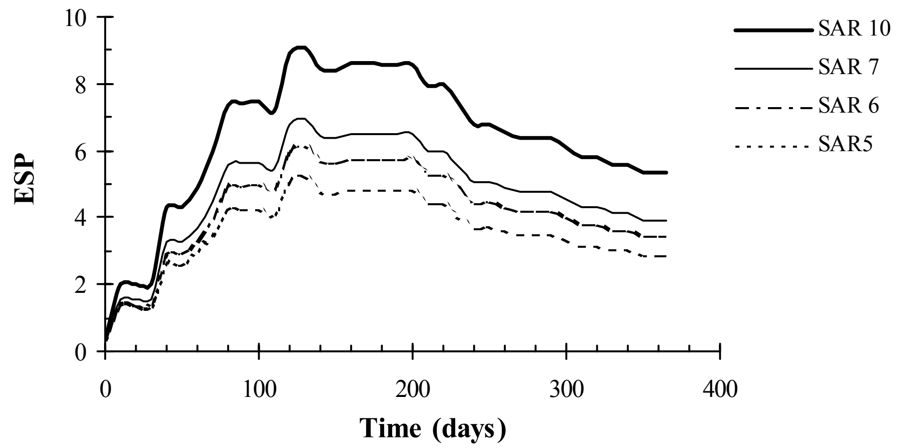
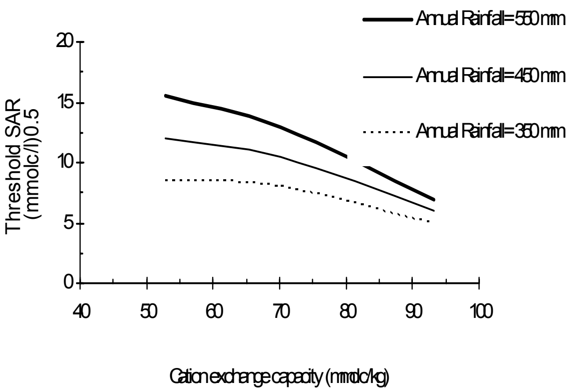


Fig. 1. Temporal changes in ESP (0-30 cm) for wheat-fallow crop rotation

The average ESP (0-30 cm) values at end of monsoon season for these waters were 3.93, 3.45 and 2.87, respectively. In case of sodic water with RSC=6 $mmol_c/l$ and SAR=5 $mmolc^{0.5}/l^{0.5}$, the average ESP (0-30 cm) at end of monsoon was less than 3. Therefore, it was considered as safe sodic water for soil A under wheat- fallow crop rotation and SAR 5 was treated as threshold SAR for soil A. Similarly threshold SAR values (at RSC=6) for soil A for 45 cm and 55 cm annual rainfall amounts were 6 and 7 $mmolc^{0.5}/l^{0.5}$, respectively. The threshold SAR values of sodic waters having constant RSC=6 $mmol_c/l$ were 6, 10.5 and 12 $mmolc^{0.5}/l^{0.5}$ for soil B and 7, 13 and 15.5 $mmolc^{0.5}/l^{0.5}$ for soil C at annual rainfall amounts of 35, 45 and 55cm, respectively. The threshold SAR and cation exchange capacity values are plotted in Fig. 2.



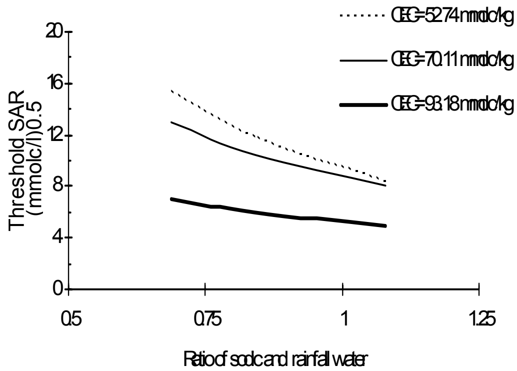


Fig. 2. Threshold SAR of sodic water with RSC=6 for wheat-fallow crop rotation

Fig. 3. Safe SAR of sodic water with RSC=6 for different annual rainfall amounts

Effects of cation exchange capacity and rainfall amounts on sodification were analyzed further to develop set of curves/ equations to determine threshold limits of sodic water quality parameters on the basis of soil properties and proportion of sodic and fresh water. At constant annual rainfall, threshold SAR value decreased with increase in cation exchange capacity. However, it increased with increase in rainfall amount at constant cation exchange capacity. The Fig. 2 also suggested that sodic waters of higher SAR could be used for soils with low cation exchange capacity values and the effect of rainfall would be more significant for such soils. As soils with low cation exchange capacity adsorbed less Na^+ ions at same ESP, desodification might be much quicker in case of such soils. The threshold SAR values, and ratios of sodic and rainfall water at constant cation exchange capacity are plotted in Fig. 3. The ratios were determined from the applied amounts of sodic waters during wheat crop and rainfall amounts during wheat and fallow period. The threshold SAR value of sodic water decreased with increase in ratio of sodic and rainfall water (or reduction of fresh water availability). The equation y=mx+c was fitted to three lines in Fig. 3 and results are given in Table 2.

Table 2. Equations for determining the safe SAR values

Soil	CEC (mmol$_c$/kg)	Equation	Regression coefficient
A	93.18	Y = (-5.010*X)+10.354	0.99
B	70.11	Y = (-12.525*X)+21.386	0.99
C	52.74	Y = (-17.535*X)+ 27.24	0.99

Y means safe SAR; X means ratio of sodic and rainfall water (fresh water)

The threshold SAR values for soil A, B and C could be determined by simply putting the ratio of sodic water and rainfall amount in the equations in Table 2. The amount of sodic water required in any crop rotation could be approximately estimated from evapotranspiration requirements of different crops and availability of fresh water. Available canal water might be added to rainfall amount to get total amount of fresh water available for desodification. These equations clearly indicated that threshold SAR of sodic water should be reduced with increase in amount of sodic water to make its use safe. Water quality guidelines by Gupta *et al.* (1994) gave general hints for use of sodic water. However, equations developed in this study provided the threshold SAR at constant RSC of 6 on the basis of cation exchange capacity and ratio of sodic and fresh water, which could be determined on the basis of proposed crop rotation. These curves/ equations are very easy to use and require easily available information. As cation exchange capacity has linear relationship with clay percentage, it can be approximately estimated from clay percentage alone. For the sandy loam soils, having cation exchange capacity values other than those mentioned in Fig.3, parallel lines might be drawn to existing lines by interpolation. Though the analysis was done wheat–fallow crop rotation, it can be easily applied to any other crop rotation. Similar type of analysis could be carried for other textural classes to find threshold SAR value based on soil properties.

Verification Improved Guidelines

Verification of curves in Fig.3 was done with help of published field data (Sharma and Mondal, 1981). The average CEC value for soils under consideration was taken as 8.5 mmol$_c$/100g approximately. The ratio of sodic water amount to fresh (canal and rainwater) water amount, in case of rice-wheat crop rotation, was worked out as 1 (Table 3).

Using ratio of sodic and fresh water utilization alongwith average cation exchange capacity value of 85 meq/kg, threshold SAR value was estimated as 6.56. The threshold SAR for CEC of 93 meq/kg, considering ratio of sodic and fresh water as 1, was 5.34 while it was 8.86 for 70.11 meq/kg with same ratio. Threshold SAR for CEC of 85 meq/kg, with ratio of 1, was estimated as 6.56 $(mmol_c/l)^{0.5}$ by interpolation. It indicated that there would be reduction in yield, if SAR of groundwater exceeded this threshold value. This assumption was verified with farmers' views about crop performance for 24 cases reported by Sharma and

Mondal (1981). The details of groundwater quality, soil EC_e, Soil ESP, prediction about crop performance and farmers' reactions are given in Table 4. It was found that predictions made with the help of curves were very much satisfactory.

Table 3. Estimation of ratio of sodic water and canal water

Details	Depth of water, cm
Paddy water requirement	120
Wheat water requirement	40
Annual water requirement	160
Rainfall amount	60
Canal water	20
Total fresh water used	80
Sodic groundwater used	80
Ratio of sodic water and fresh water	1.00
Threshold SAR as per curve	6.56

Table 4. Verification of guidelines with published data of Sharma and Mondal (1981)

Sr. No.	Ground Water EC dS/cm	SAR	RSC	Threshold SAR	Soil Ece	ESP	Safe or not	Yield reduction Prediction	Farmers' reaction about yield
1	2.62	23.5	10.8	6.56	10.8	64.1	No	Severe Yield Reduction	Very poor
2	2.19	16.4	10.6	6.56	4.5	42	No	Severe Yield Reduction	Very poor
3	2.62	20.5	9.5	6.56	15.0	81	No	Severe Yield Reduction	Very poor
4	1.83	14.4	8.0	6.56	14.8	67.2	No	Severe Yield Reduction	Very poor
5	1.71	11.5	7.0	6.56	6.8	41.2	No	Slight yield reduction	Fair
6	1.52	14.1	7.3	6.56	7.0	53.8	No	Severe Yield Reduction	Poor
7	1.34	10.5	7.2	6.56	8.2	57.2	No	Slight yield reduction	Poor (wheat) Rice (Fair)
8	0.98	6.7	6.0	6.56	3.7	19.6	Yes	No Yield Reduction (Normal Yield)	Good
9	1.83	8.9	4.3	6.56	2.4	18.9	No	Slight yield reduction	Good
10	0.57	2.8	2.8	6.56	1.4	6.2	Yes	No Yield Reduction (Normal Yield)	Good
11	2.61	17.6	5.7	6.56	18.4	67.2	No	Severe Yield Reduction	Very poor
12	3.54	18.7	4.7	6.56	8.3	56.5	No	Severe Yield Reduction	Poor
13	2.14	18.3	4.9	6.56	6.5	50.6	No	Severe Yield Reduction	Poor (wheat)/ Rice (Fair)
14	2.15	15.7	6.1	6.56	13.5	73.7	No	Severe Yield Reduction	Very poor
15	2.07	17.5	9.0	6.56	11.3	73.3	No	Severe Yield Reduction	Very poor
16	1.22	6.5	5.1	6.56	2.9	25.4	Yes	No Yield Reduction (Normal Yield)	good
17	1.28	9.9	5.0	6.56	4.1	35.4	No	Slight yield reduction	Fair wheat) Good Rice)
18	1.18	7.5	5.6	6.56	3.1	19	Yes	No Yield Reduction (Normal Yield)	Good
19	0.85	8	6.3	6.56	1.6	21	No	Slight yield reduction	Good
20	1.10	6.5	6.4	6.56	2.1	23.5	Yes	No Yield Reduction (Normal Yield)	Good
21	1.10	6.5	6.0	6.56	1.7	15.3	Yes	No Yield Reduction (Normal Yield)	Good
22	1.15	12.5	8.6	6.56	4.1	35.9	No	Severe Yield Reduction	Fair wheat) Good (Rice)
23	2.68	20.9	8.0	6.56	5.8	59.5	No	Severe Yield Reduction	Poor wheat)/ Rice (Fair)
24	0.73	2.5	2.8	6.56	1.0	7.3	Yes	No Yield Reduction	Good

Sustainability of Rice-Wheat Rotation in Sodic Water Blocks

The curves were further used to assess the sustainability of rice-wheat rotation in villages of Assandh and Nissang blocks of Karnal district. Groundwater samples from irrigation tubewells from different villages of these two blocks, ranging from 3 to 14 tubewells per village depending on the area of village, were randomly collected. Soil samples were also collected and analyzed for cation exchange capacity (Singh, 2005). The water samples were analyzed for SAR and RSC and ranges for both quality parameters were determined. The minimum and maximum values for SAR and RSC were determined. As RSC was constant at 6 during the simulations, hence more importance was given to SAR data. There were variations in RSC values also and RSC values were not always close to 6. Minimum values of RSC ranged from 0 to 2.7 with average of 0.45 while maximum values ranged from 0 to 18.10 with average of 5.76. Minimum values of SAR ranged from 0.26 to 9.64 with average of 2.58 while maximum values ranged from 1.4 to 19.86 with average of 8.18. On the basis of ratio of sodic and fresh water (canal and rain water) utilization for rice-wheat crop rotation and average soil cation exchange capacity, a threshold SAR value of groundwater was estimated for each village. Yield reduction was expected, if SAR of the groundwater was greater than its threshold value. With this assumption, a village was considered as safe under prevalent conjunctive water use of sodic and fresh water, if minimum and maximum values of groundwater SAR range were below threshold value. If minimum value was below the threshold but maximum value was higher than threshold, the village was considered under marginal category. The village was treated as unsafe provided both minimum and maximum values of SAR range were higher than threshold value. With these assumptions, safe, marginal and unsafe villages were explored and maps indicating those villages were prepared for Assandh and Nissang blocks of Karnal district.

Analysis to assess the sustainability of rice-wheat rotation in villages of Assandh and Nissang blocks of Karnal district revealed that both blocks had areas under safe and marginal zone villages. The areas under marginal zone villages were considerable. The Assandh block had few villages under unsafe category, but there was no village under this category in Nissang block. The change of crop rotation is required in unsafe category villages in Assandh block for sustainability of crop production while villages under marginal zone need cautious approach. It means that farmers in unsafe and marginal zones must change the rice-wheat crop rotation to reduce the use of sodic water. There is need to find a substitute to rice crop, which may require less water.

Conclusions

Existing irrigation water quality guidelines for use of sodic waters are for kharif fallow and rabi crop rotation and are of general type. The guidelines were further investigated through UNSATCHEM modeling to prepare set of curves for sandy loam class, which could be used to determine threshold SAR value (at constant RSC of 6 meq/l) of sodic water considering soil properties and, ratio of sodic and fresh water utilization in crop production. The curves could be used to assess the sustainability of conjunctive water use policy in sodic groundwater areas or to prepare conjunctive water use plan of sodic and fresh water (canal and rainwater) under any crop rotation. The use of amendments can be minimized by sodic water irrigation planning by this approach. Similar type of curves could be easily developed for other textural classes. The improved guidelines are more flexible and it would be possible to consider individual soil and exact amounts sodic and fresh water being utilized in the crop production and quality parameters of irrigation waters. Also it would be possible to work out threshold SAR of groundwater respective of conjunctive water use mode. Therefore, these guidelines could be effectively used for better planning of conjunctive water use of sodic and canal (fresh) water.

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Subsurface Drainage for Waterlogged Saline Lands

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Introduction

Land drainage is the removal of excess surface and/or subsurface water from the land including the removal of soluble salts to enhance crop growth (ICID, 1979). World Bank in a report in 2004 defined drainage as land and water management through the process of removing excess surface water and managing shallow water tables by retaining and removing water to achieve an optimal mix of economic and social benefits while safeguarding key economical functions. Clearly in the later definition drainage has been made a part of overall land and water management. Moreover, removal of subsurface water has been changed to management either by retaining or removing the water. This shift would have greater implication in managing water logged salt affected soils.

The main objective of agricultural drainage is to improve the profitability of farming. But all lands suffering from excess water may not need drainage if the quantities are small or if the periods of occurrence are of short durations or if the excess water occurs during a non-critical season and unlikely to affect the crop productivity. It is only when large quantities prevail for prolonged durations at critical periods and removal of excess water by artificial means becomes necessary. Moreover, most lands have some natural drainage, which assists in the removal of certain amount of excess water/salt, and any artificial drainage should be designed to strengthen the natural drainage.

Categories of Waterlogged Areas

- Rainfall induced water logging caused due to excessive precipitation, mostly a problem of humid and in some cases sub-humid areas. In monsoon climatic conditions excess rainfall could occur even in semiarid regions to cause short-term water logging situations
- Flood prone areas causing water inundation
- Irrigation induced waterlogged areas, due to losses from irrigation network and excess irrigation water application
- Coastal water logging due to tidal ingress of water

One or more of these areas might have the problem of soil salinity in addition to the problem of water logging. Rise in water table due to irrigation induced water logging is often accompanied by soil salinity. In fact, under such situation, soil salinization is inevitable with the rise in water table so much so that the problems are aptly described as twins. A subsurface drainage system helps to solve both water logging and soil salinization although in arid and semi-arid irrigated lands, salinity might be more critical to crop productivity than water logging.

Planning Drainage Systems

There are number of land drainage techniques by which water table at the land surface or below it could be controlled. These are surface drainage, interceptor drainage, horizontal subsurface drainage, tube well drainage and bio-drainage. A number of other names may also be encountered such as mole drainage and bio-interceptor drainage but these techniques are mostly a variation of the main subsurface drainage systems named before. Usually, no single kind of drainage system would solve the problem and as such two or more of the drainage systems could be integrated to arrive at the optimum most economical solution to the problem. To decide, which combination of drainage systems would apply to the local conditions, several steps are to be taken up. One of the first steps is to decide on the various drainage criteria as follows:

- Agricultural drainage criterion
- Technical drainage criterion
- Environmental drainage criterion, and
- Economic drainage criterion

Agricultural Drainage Criteria

It specifies the highest permissible levels of the water table, on or in the soil, so that water logging does not reduce the agricultural benefits.

Technical Drainage Criteria

It aims to minimize the costs of installing and operating the system while maintaining the agricultural criteria.

Environmental Drainage Criteria

This criterion is used to ensure that environmental damage is minimized.

Economic Drainage Criteria

The purpose is to minimize the cost and to maximize the net benefit.

The Preparation of Plan

Drainage planning involves the preparation of a plan for the solution of a drainage problem. The plan will generally consist of a number of measures to be taken and/or works to be constructed. In some cases the best solution to a drainage problem may well be a change in crop rotation, land use or farm practices and/or making the agricultural use of the land, which may be less susceptible to excess water. In most cases, however, the core of a drainage plan remains to construct some new drainage works suited to soil, climate, irrigation and geo-hydrological conditions and cropping pattern as the problem generally gets attention, when it is unmanageable by preventive methods. One should proceed as follows in deciding a drainage plan (Smedema and Rycroft, 1988; Louis Berger Int./WAPCOS, 1988).

1. **Identification stage**: The problem is identified mostly on the basis of available information with hardly any analysis or appraisal.

2. **Reconnaissance/ Pre-feasibility stage**: Information collected through reconnaissance type field investigations, preliminary diagnosis of the drainage problem, rough outline of possible solutions, delineation of the project area and its sub-divisions and evidence that the proposed project is promising and desirable.

3. **Feasibility stage**: Information collected through semi-detailed type of field investigations (mapping scale 1:10,000/50,000), presentation of the proposed plan in sufficient detail to demonstrate technical soundness and to enable cost estimation within ~10% accuracy. At this stage, information on hydraulic conductivity, drainable porosity, infiltration characteristics, soil salinity, depth of impermeable layer, aquifer parameters, groundwater fluctuation and quality, fresh water supplies, surface drainage network and the availability of outlets etc. is collected, which is a prerequisite for planning the drainage of waterlogged saline soils. In addition, knowledge on the drainage requirement of different crops and criterion for the drainage design is also required.

4. **Final stage**: Analysis of information collected through detailed investigations, elaboration of all plans to the extent that they can work as working documents. These include detailed plan and design, construction drawings and specifications.

Application of Subsurface Drainage to Indian Conditions

Subsurface technology has been widely used in India by many organizations to reclaim waterlogged and/or waterlogged saline lands. Locally adaptable solutions have also been developed such as open well drainage in Haryana, chimney drains in Maharashtra and skimming well technology in Punjab (Table 1). Besides, bio-drainage has also been tested at many locations in few states. However, its performance has varied from place to place due to varied reasons. As such, this kind of drainage has emerged as a potential technology to prevent water logging to develop rather than as a reclamation strategy. Following are some of the important case studies completed recently in various states.

Case Studies

CSSRI Project at Sampla, Haryana

In 1979, 10 ha area was taken on lease from village Panchyat, Sampla and the first trial with deep open drains and pipe drainage was implemented in 1980. Success of this trial encouraged the institute to put take more area on lease and put an additional area of about 10 ha under pipe drainage to develop drainage guidelines and a reclamation package for waterlogged saline lands besides demonstrating strategies for the use of saline drainage effluent. The project was monitored for about 15 years and later handed over to village

Panchayat. The area lies in the Western Jamuna Canal (WJC) command. At about the same time the

Table 1. Drainage technologies tested in different states of India

State	Drainage strategies tested
Andhra Pradesh	Shallow pipe drains, deep open drains (Gravity/pumped outlets)
Assam	Pipe drains, open drains for tea gardens
Gujarat	Shallow pipe and deep open drains, vertical drainage+
Haryana	Deep/shallow pipe drains*, deep open drains^, open well drainage, bio-drainage (Pumped outlets, evaporation ponds)
Karnataka	Shallow pipe drains, bio-interceptor drains (gravity outlets)
Kerala	Shallow pipe drains for acid sulphate soils
Madhya Pradesh	Shallow pipe drains, mole drains
Punjab	Shallow pipe drains, vertical drainage, skimming well drainage, bio-drainage
Rajasthan	Shallow pipe drainage, open well drainage+, Open interceptor drains, Deep open seepage drains (Pumped outlets, evaporation tanks)
Uttar Pradesh	Pipe and bio-interceptor drains
Uttrakhand	Shallow pipe drainage for *terai* region

*deep pipe drains > 2 m depth; shallow pipe drains < 2 m depth; ^ open drains deeper than 0.9 m; + Results were not encouraging; Text in brackets indicate technologies for drainage effluent disposal

Government of The Netherlands extended support which continued till the end of the project. Major accomplishments of the project are:

a) An area of about 80 ha was put under subsurface drainage at the site including farmers' fields in a nearby Ismalia village. Later on, with support from the Haryana Land Reclamation Corporation and Department of Agriculture, a number of pilot projects were installed in the state covering WJC and Bhakra Canal Command (BCC). In association with Water and Land Management Institute, Anand, four pilot projects were installed in the Mahi Canal Command in Gujarat.

b) A complete package to reclaim waterlogged saline soils has been developed. It consists of on-farm land management (Dyking, land leveling and surface drainage), subsurface drainage to control water table, selection of crops and cropping pattern and additional 25 % application of nitrogen.

c) A complete package to reuse saline drainage effluents was made available resolving to some extent the fear of environmental problems due to land drainage. It was observed that 25 % of the drainage effluent could be disposed off in natural/artificial drainage system during the monsoon season while the remaining 75 % could be used in conjunction with fresh canal water in the reclaimed lands during the winter season.

d) Literature on investigations, design and construction of subsurface drainage was brought out including manuals for the Ministry of Water Resources and Ministry of Rural Development. These organizations support subsurface drainage activities in different states.

e) A large number of training programmes were arranged to sensitize the policy makers, planners, scientists/field officer and farmers. In association with the Govt. of The Netherlands and Govt. of Haryana, the HOPP project was flagged off culminating in the set-up of HOPP as a regular organization within the Department of Agriculture to undertake land drainage activities in the states.

Design Criteria

Following design criteria for the state of Haryana has been finalized:

Drain depth	Shallow drains (< 2.0 m) preferably around 1.5 m for pumped outlets
Drainage coefficient	1.5-2.5 mm/day
Drain spacing	75 m drain spacing for medium texture soils of Sampla, later modified in HOPP as 60-67 m to be on killa lines
Pipes	PVC corrugated pipes
Envelope requirement	Geosynthetic envelop with O_{90} >300 on laterals

Impacts

The results revealed that completely barren lands could be reclaimed right in the first year. Optimum yields are obtained in 2-3 years following land drainage. Spectacular productivity increase was obtained in the case of pearl millet, sorghum, cotton, wheat and mustard. For example, the wheat yield increased from nil to about 4.0 t/ha, which is the normal yield of wheat in the district. The cropping intensity increased from nil to

200 %. Even after handing over the project to village *Panchayat*, the land is being auctioned by the *Panchayat* to earn revenue. The most important impact of the project has been that it sensitized the people about the social acceptability and economic feasibility of land drainage projects.

Haryana Operational Pilot Project (HOPP), Haryana

Haryana Operational Pilot Project is a large scale applied implementation/research project to reclaim waterlogged salt affected soils in the state of Haryana in the WJC and BCC. Initially it was supported by the Government of The Netherlands but currently being operated by the Department of Agriculture (Harayana) and is a continuing project with support from the Center and State Governments. Major accomplishments of the project are:

a) An area of about 5000 ha has been put under subsurface drainage at Gohana, Kalayat, Beri, Dadri, Rori, Daraba Kalan and Dhanana. The implementation at few of these is in progress

b) HOPP has three drain laying machines and all of them are in operation

c) The project is a comprehensive project as it undertakes identification of the problem areas, prepares projects for funding, designs and implements the project in the identified area

d) A gravity-cum-pumped drainage outlet has been designed and evaluated (Fig. 1)

e) In view of the high water table, floating of collectors was observed. As such, the problem was overcome by putting perforated collectors

f) The funding pattern adopted in the project is 60:30:10 by the central: state: beneficiaries (farmers). No crop compensation is paid to the farmers for damage of crops during the installation and it is also considered as their contribution towards the project

g) Central Soil Salinity Research Institute, Karnal undertakes monitoring and evaluation studies in the projects

Fig.1. Gravity-cum-pumped outlet developed and implemented in HOPP

Design criteria

Based on the CSSRI guidelines, following design criteria has been finalized:

Drain Depth	Lateral 1.5 m (average)
Drainage Coefficient	1.5 mm/day
Drain spacing	60-67 m ton killa lines
Pipes	PVC corrugated pipes as per ASTM/DIN standards
Envelope requirement	Geosynthetic envelop with O_{90} >300 on laterals
	Nylon sock of 60 mesh on perforated collectors

Impacts

The CSSRI monitoring studies have revealed that SSD provides effective water table control, reclaims saline lands within 2-3 years with an increase in land productivity of rice and wheat crops and increases cropping intensity. There is a great potential to replicate this set-up in other states, which are threatened by the problems of water logging and soil salinity. HOPP could provide consultancy to the states both on the set-up as well as by undertaking land drainage projects.

Rajasthan Agricultural Drainage Research Project (RAJAD), Rajasthan

RAJAD was a large scale applied research project on the use of horizontal subsurface drainage (SSD) and associated water management techniques to control soil salinity and water logging problems in irrigated agricultural lands in Chambal Command in Rajasthan. It was supported by Canadian International Development Agency (CIDA). The project was initiated in 1991 and continued up to 2000. Particulars of the project area are:

a) An area of 60,000 ha was surveyed using total station for topography, EM38 for soil salinity, soil sampling laboratory analysis for physical and chemical properties and in-situ saturated hydraulic conductivity on 8 ha grid.

b) About 25,000 ha was identified as waterlogged saline area.

c) 15,000 ha were put under SSD including test plots of 1,400 ha (Table 2).

d) Computer aided design and drawing (CADD) was initiated under Indian conditions.

Design criteria

Based on test plot results from 1400 ha, the following design criteria was developed and adopted:

Drain depth	1.2 m
Drainage coefficient	1.5 mm/day for laterals and 3 mm/day for collectors to allow for additional seepage control from canals and surface drains
Drain spacing	35–60 m to provide satisfactory salinity and water table control
Envelope requirement	Not required if soil profile clay % is >40 Required if clay % < 30 or clay content is between 30 to 40 % with soil sodicity, SAR >8

Table 2. SSD Installations in RAJAD Project

Project	Area installed (ha)	Installation equipment	Year
1. Small test plots	410	Excavator/Backhoe	1991-93
2 Large test plots	1010	Integrated trenchless plow	1993-94
3 Pre CON/1 (Training phase)	700	Trenchless plow (Bull dozer with plow attachment)	1995-96
4.CON/1	10,671	Mastenbroek Trencher, V-Plow and Wolf Plow	1996-99
5.Areas with patchy salinity	2,134	Excavator/Backhoe	1997-99
Total	**14925**		**1991-99**

Source: Ram (2008)

Impacts

The RAJAD research and monitoring studies showed that SSD provides a number of significant benefits to the farmers in CCA (Table 3).

Table 3. Benefits of SSD in RAJAD project

Impact	Improvement
Soil reclamation (reduce EC_e to <4 dS/m)	
i. EC_e 4-8 dS/m	2-3 years
ii. EC_e 8-16 dS/m	3-4 years
iii. EC_e >16 dS/m	>4 years
Water table control	20-40 cm draw down in 3-4 days
Soil trafficability	Reduced time to access land by 8-10 days
Crop yield	Soybean- 55% increase Wheat- 50% increase
Crop intensity	Increase from 170% to 190%

Indo-Dutch Network Project (IDNP), India

To extend the technology developed at Sampla to other irrigation commands and to develop drainage guidelines for different agro-climatic conditions, the IDNP was conceived and became operational in the year 1995 and continued till 2002. The project covered the states of Andhra Pradesh (Nagarjuna and Krishana Western Delta commands), Haryana (WJC and BCC), Gujarat (Ukai Kakrapar command), Karnataka (Upper Krishana and Tungabhadra canal commands), Rajasthan (Indira Gandhi *Nahar Pariyojana*). The project also included researches in associated water management techniques to minimize drainage effluent and/or to prevent development of soil salinity and water logging problems in irrigated agricultural lands. The major accomplishments are:

a) A methodology to assess water logging and soil salinity was finalized.
b) Five pilot drainage projects were designed, installed and monitored. Besides six drainage projects were monitored in Tungabhadra, Western Jamuna and Bhakra canal commands.
c) Modelling studies were conducted to assess the design and performance of the drainage systems using SALTMOD and SWAP. Later WASIM was also tested and used for the Sampla site and its performance was found to be good.
d) Data were used to develop drainage guidelines based on climate, outflow conditions and soil texture.
e) The drainage activities could be expanded in the Andhra Pradesh through the AP Water Management Project, an offshoot of the IDNP being handled by ANGRAU, Hyderabad.

Design Criteria

Based on test plot results, the following design criteria guidelines were developed:

Table 4. Guidelines on drain depth

Outlet conditions	Depth of the drains	Optimum depth (m)
Gravity	0.9-1.2	1.1
Pumped	1.2-1.8	1.5

Table 5. Guidelines on drainage coefficient for subsurface drainage

Climatic Conditions	Range (mm day^{-1})	Optimum value (mm)
Arid	1-2	1
Semi-arid	1-3	2
Sub-humid	2-5	3

Table 6. Guidelines on lateral drain spacing

Soil texture	Spacing of drains (m)
Light textured	100-150
Medium textured	50-100
Heavy textured including vertisols	30-50

Impacts

The Indo-Dutch Network Project established that SSD has the potential of application in wide ranging agro-climatic and soils conditions. It also established that investments on drainage research have paid dividends. A large contingent of Indian scientists and field officers were trained under various training programmes and today this trained manpower is capable to undertake land drainage activities both on small and large scales. Private investments and entrepreneurship is coming forward to undertake land drainage activities.

Water Resources Department/Rex Polyextrusion/CSSRI Project Sangli, India

Most of the drainage projects so far were implemented in irrigation commands. However, large areas in Maharashtra have turned waterlogged saline in non-commanded lift irrigation schemes operated by the farmers mainly because of the mismanagement of irrigation water in the sugarcane crop. Water Resources Department, Maharashtra and Rex Polyextrusion Ltd., Sangli joined hands to provide relief to these farmers by implementing subsurface drainage. Later CSSRI also joined hands to provide technical guidance in implementing the drainage projects.

Three pilot drainage projects are at different stages of completion: first one covering an area of about 1100 ha has already been completed while in the second project implementation is in progress. The third project is in Karanataka. The design stage is almost complete. More than 1500 ha area has already been covered at the two sites. The drainage system included design and construction of main drain to transport the effluent to a suitable outfall.

The funding of the project is in the ratio of 60:20:20 by the Centre: state: beneficiaries. The banks have come forward to fund the 20% share of the beneficiaries in a cooperative mode. The bank returns a portion of loan interest (1.5% of total) to the farmers' society for operation and maintenance of the system or to meet other expenditures of the society.

Impacts

The performance of the system has shown promising results in case of sugarcane and turmeric crops. As a result farmers are coming forward at individual level also and are willing to pay 100% of the cost of land drainage. Besides, large scale installations, Rex Poly Extrusion is installing on average 100 acre of SSD system on farmers fields with 100% contribution by farmers. The farmers in the Ukai Kakrapar Command in the state of Gujarat are also showing similar enthusiasm.

Who Should Pay for Subsurface Drainage?

The cost of subsurface drainage is enormous i.e. around Rs. 40,000 per ha in alluvial plains of Haryana and Punjab; and around Rs. 60,000 in heavy soils of Maharashtra, Karnataka and Gujarat. It is beyond the reach of most farmers, particularly who are facing waterlogging and salinity problems in their fields. The current approach of financing the subsurface drainage projects by the government on project-to-project basis seems inadequate, ineffective and unsustainable to tackle the large-scale extent of the problem. Loud/ general thinking that all or a major part of the cost of subsurface drainage should be born by the farmers also does not seem reasonable. Just to illustrate: firstly the problem has been created by factors beyond the control of the farmers. In most cases he has no say in layout of the development activities that hinder natural drainage. The leakage and seepage from the irrigation distribution network is also not within his control. Secondly, drainage would not only benefit the farmers or a village alone but would have major benefits to local people, environment, public health, water resources, water supply, irrigation and industries. In fact the government would be the major beneficiary as investments on health services and infrastructure maintenance would go down steeply with large-scale implementation of land drainage. Finally, reclaimed lands contribute to food security of the nation and generate self-employment. Therefore, all the agencies involved should invest on drainage. The current ratio of financing 60:20:20 or 60:30:10 by Centre: State: Beneficiary depending upon the states involved seems reasonable. But as said before, the project to project financing is slowing the pace of land reclamation programme in most states. The states should be asked to prepare their Drainage Master Plans (in fact most of them have already done so) identifying the areas requiring various kinds of drainage treatments. Lump sum funds could be released to the states to tackle the problem of water logging and soil salinity. States should also be allowed to spent funds from various centrally sponsored schemes as most of drainage projects are likely to generate employment or meet some of the critical component of the scheme. The idea should be to tackle the problem in a time bound manner of say 5 or at the most in 10 years. At the current rate of reclamation, it may not happen in near future and escalation of cost would further slow down the reclamation programmes.

Concluding Remarks

No firm data are available to show whether the area affected by the problems of water logging and soil salinity is increasing or decreasing or has almost stabilized. The specific information from southwest Punjab and Tungabhadra command in Karnataka has shown some increasing trends in the affected areas. As such, water logging and soil salinity would continue to attract the attention of the nation. All the more so because poor and marginal farmers are the worst affected with these problems. Unlike large farmers who might have some unaffected land to make their livelihood, the poor and marginal farmers often end up loosing their whole parcel of land due to water logging and soil salinization. Moreover, a fierce competition for land is developing between various sectors of economy and therefore food needs of the nation are to be met from degraded land and water resources. All ammunition in our arms should be geared to land reclamation programmes to provide household food security, social security and to bridge the gap between the poor and the rich in the rural setting. Subsurface drainage is one such ammunition in our arms that should be effectively used to combat the problem of water logging and soil salinity and achieve the productivity targets of irrigated lands.

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Drainage Salinity Simulation Model (Drainsal)

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Introduction

Soil salinity is a long-term problem often associated with irrigated agriculture in the arid and semi-arid regions. The productivity potential of these lands can be sustained for a long time if adequate drainage is provided and proper leaching techniques are employed to maintain a favourable salt content in the root zone. The disposal of saline drainage water can be a matter of serious environmental concern and of high cost. Predicting consequences of irrigation management and salinity control measures under different drainage designs can best be achieved through simulation models.

A two dimensional finite element model (DRAINSAL) of solute transport in tile drained soil-aquifer system has been developed and tested in the field (Kamra *et al.*, 1991a, b). The flow domain consisting of unsaturated part above the watertable and saturated zone between two lateral subsurface drains is shown in Fig. 1. The water movement through the partially saturated soil and to drains in the saturated zone has been assumed to be in steady state. The numerical solution is exact in time and explicit expressions are obtained for concentration field at any future time without computing concentration at intermediate times. The model provides long-term predictions of the desalinization of a tile-drained soil, and of the associated changes in the quality of the groundwater and the drain effluent. DRAINSAL is a DOS based model and can be linked to graphical package like SURFER for plotting 2 dimensional graphs of salt transport between two drains. A number of comprehensive more window based 1 and 2 dimensional models of water and solute transport in soil having features to study the effect of subsurface drainage and much stronger user interface and graphical features have come in the market. Of these HYDRUS- 1D (Simunek, 1998) and HYDRUS 2D (Simunek, 2006), with regular periodic updates, are the most robust and popular models for simulating 1,2 and 3 dimensional water, heat and multiple solutes in variably saturated media. These software are extremely complex and need proper training and technical expertise. DRAINSAL is also complex but is better equipped to study specifically the effect of subsurface drainage parameters on salt dynamics in soils and long term prediction of drainage water salinity.

The basic features of DRAINSAL, its calibration and field validation and computer program are briefly discussed in this lecture. Instructions are given for data input preparation and example input files of the main program.

Model Formulation

The movement of water and dissolved solutes to parallel drains in a tile-drained soil-aquifer system has been schematically shown in Fig. 1. The space co-ordinate X is positive towards right, whereas Y is positive downward. Infiltrating rain and irrigation water is assumed to flow vertically downward through the partially saturated soil. After reaching the water table, water and dissolved salts move two-dimensionally towards the parallel drains.

Consider the governing equation of two dimensional solute transport in unsaturated-saturated porous media (Kamra *et al.* 1991a)

$$\theta R_f \frac{\delta C}{\delta t} = \frac{\delta}{\delta X}\left(\theta D_{xx}\frac{\delta C}{\delta X} + \theta D_{xy}\frac{\delta C}{\delta Y}\right) + \frac{\delta}{\delta Y}\left(\theta D_{yx}\frac{\delta C}{\delta X} + \theta D_{yy}\frac{\delta C}{\delta Y}\right)$$
$$-\left[\frac{\delta}{\delta X}(q_x C) + \frac{\delta}{\delta Y}(q_y C)\right] + \phi(X, Y, t) \qquad (1)$$

in which C is the dissolved solute concentration (M/L^3), R_f is the retardation factor, θ is the volumetric water content (equal to porosity in the saturated zone) (L^3/L^3); D_{xx}, D_{xy}, D_{yx}, D_{yy} are the components of dispersion coefficient tensor (L^2/T), q_x and q_y are the Darcian specific discharge components, (L/T), and ϕ (X, Y, t) is a source or sink term, being positive for sources and negative for sinks (M/L^3 T), X and Y are space coordinates (L), and t is time (T). The retardation factor R_f in (1) accounts for linear equilibrium interactions between the solute and the porous medium and is given by $R_f = 1 + \varepsilon K_\alpha/\theta$ where ε is the bulk density of porous medium (M/L^3) and K_α is a solute distribution coefficient (L^3/M). The dispersion coefficients for a two-dimensional isotropic porous medium were adopted from Scheidegger (1961) which relate D_{xx}, D_{xy}, D_{yx} and D_{yy} to q_x, q_y, θ, q, α_L and α_T where α_L and α_T are the longitudinal and transverse dispersivities (L), respectively and q is the magnitude of specific discharge vector (L/T).

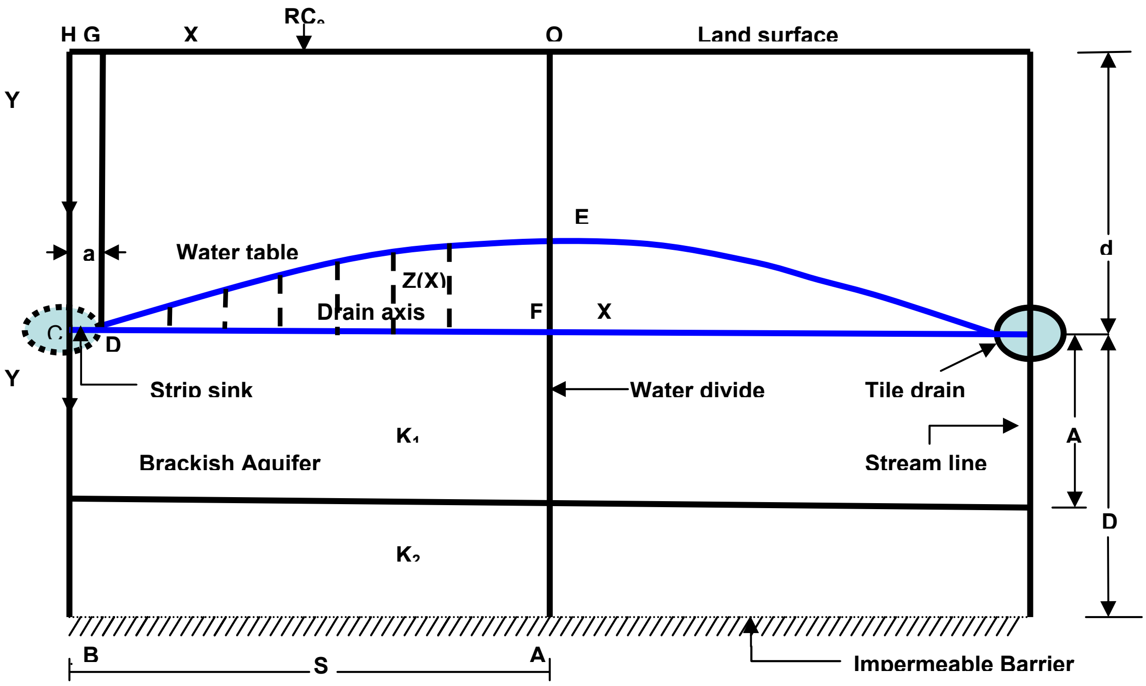

Fig.1. Flow domain for solute transport in a tile- drained soil aquifer system

Steady State Water Movement

Beese and Wierenga (1980) and Destouni (1991) have shown that transport models based on steady state water flow can produce concentration distributions that are comparable to those obtained with transient flow models, but with considerably less input data requirements that the transient models. The steady state formulations can be particularly useful for making long-term predictions by ignoring the often highly dynamic but short-term oscillations in water content and solute concentration near the soil surface. Accordingly steady state water flow models were used in this study for both the unsaturated and saturated zones.

Unsaturated Zone

The velocity field for the unsaturated part of the flow domain was obtained by considering the water flow to be vertical (q_x = zero) and taking q_y equal to the net upward or downward steady state flux. The net water flux during a period was obtained from the water balance of the area and a reliable estimate of the groundwater contribution to evaporation. The Darcy law equation was numerically integrated to compute pressure heads (and consequently moisture contents provided the water retention and hydraulic properties of soil are known) at required heights from water table during steady upward or downward water flow. The functional forms of unsaturated hydraulic properties used in this study were those of Van Genuchten (1978).

Saturated Zone

Kirkham (1958) and Toksoz and Kirkham (1971) analytically solved the Laplace equation for the watertable height, Z, above the drain axis, and the hydraulic head distribution in the flow domain ABCDFA below the drain axis (Fig. 1) for a homogeneous and a two-layered aquifer respectively. Both analyses consider the flow of water in the arch-shaped saturated region above the drain axis to be vertically downward. The drain tube in each case was replaced by a strip sink of zero thickness and width ‘a’ in the X direction. The specific discharge components, q_x and q_y, were computed for the region ($0 \le X \le S$, $0 \le Y \le D$) with the help of Darcy’s law (Kamra, 1991a). Solutions are applicable to other half of the domain between the two drains because of symmetry.

Initial Conditions

The measured solute concentration in the flow domain before the beginning of the simulation period is taken as the initial condition:

$$C(X, Y, 0) = C_o(X, Y) \text{ at } t = 0$$

Boundary Conditions

The solute flux is prescribed on a Cauchy boundary, the normal gradient of concentration on a Neumann boundary, while concentrations are prescribed on Dirichlet boundary nodes. A Cauchy boundary condition is applied to a boundary through which solute enters the region. The Neumann boundary conditions are imposed on flow-through boundaries with outflow from the region, and on impervious boundaries. The land surface GO (Fig. 1) acts as a Cauchy boundary during the infiltration phase and the segments BA (bottom basis layer), OA (water divide), and BC and DG (streamlines) are treated as impervious boundaries. The tile surface CD and land surface GO during evaporation are outflow boundaries, while there are no Dirichlet boundaries in the present study.

Finite Element Solution

The Galerkin finite element method was used to simulate solute transport in tile-drained soils. The procedure involves discretization of the flow domain into finite elements and using approximate basis functions to interpolate concentration within each element. Quadrilateral elements and linear basis functions were employed in this model to approximate equation (1) with a vector-matrix differential equation which was solved by eigenvalue- eigenvector method of Euler (Kamra *et al.*, 1991a).

Model Calibration and Field Validation

The model was validated against field results of a sub-surface tile drainage experiment of Central Soil Salinity Research Institute, Karnal ((India), conducted on its Saline Soil Research Farm at Sampla (District Rohtak) in the State of Haryana. Sub-surface drainage system, consisting of thrice replicated three drain spacings of 25, 50 and 75 m and average drain depth of 1.80 m, was installed at Sampla in the summer of 1984 in a 10 ha saline area. The soil salinity (EC, electrical conductivity of the saturation extract) of the surface 15 cm soil in the area ranged from 20 to 100 dS/m. The salinity was about 30 dS/m in the 15-30 cm layer and 20 dS/m below 30 cm. Dissolved salts were mainly calcium, magnesium and sodium chlorides. Before installation of the drains, the watertable in the area typically fluctuated between a depth of 1.5 m (during early summer) and the soil surface (during the rainy season). Salinity of the groundwater near the watertable varied from 10-40 dS/m. The soil in the region is sandy loam alluvium having hydraulic conductivity of 1.0 m/day upto 1.75 m depth, followed by a loamy sand zone of 3 m/day hydraulic conductivity. This porous zone extends to a fine textured layer of low permeability at 3-4 m which was treated as the impermeable boundary (Rao *et al.*, 1986). The values of selected hydraulic and drainage system parameters, including steady annual water fluxes, are listed in Table 1.

The observed seasonal drain discharge rates, after correcting for estimated lateral seepage and upward water fluxes from watertable during summer in individual plots, were combined to compute annual water fluxes which were highly variable for different drain spacing plots. Numerical results corresponding to different values of longitudinal dispersivity, α_T, was assumed to be always one tenth of α_L. The model was then applied to make 10 year predictions on salt distribution in soil, groundwater and drainage effluent. Further details on the calibration, field validation, long-term predictions and sensitivity analysis of a number of model parameters can be found elsewhere (Kamra *et al.*, 1991b).

Table 1: Values of Selected Soil Hydraulic and Drainage System Parameters

Parameter	Value(s)
Drain Spacing, 2S	25, 50, 75 m
Drain Depth, d	1.8 m
Depth of impervious layer below drain axis, D	1.2, 2.0, 5.0 m
Saturated hydraulic conductivity of aquifer, K	3.0 m/day
Soil water retention parameters (van Genuchten, 1978)	
K	1.0 m/day
θ	0.4486
θ	0.1004
α	0.0088 1/cm
n	1.6715
M	0.4017
Soil bulk density, ε	1.5 g/cm^3
Distribution coefficient, K_α (cm^3/g)	0.0
Longitudinal dispersivity, α_L	0.8 m
Transverse dispersivity, α_T	0.08 m
Annual steady water flux for 25, 50 and 75 m drain spacing	1.0, 0.7, 0.4 mm/day

The model was calibrated with observed data of two years and 10 years predictions on salt distribution in soil, groundwater and drainage effluent were made. The steady state downward water flux during monsoon and winter due to rains and irrigation was computed from record of cumulative drain discharge during this period, substracting the estimated seepage from outside areas and averaging for the season in the form of steady state water fluxes for these periods. For long-term predictions, the water balance of the area was worked out on annual basis to compute steady state water flux.

Predicted results on salinity in soil profile matched favourably with observed ones except in the surface 20 cm layer. The differences in the surface layers exist due to assumption of steady water movement during a time interval in which short-term and highly dynamic oscillations of solute concentration near soil surface get ignored. These differences can be minimized by taking a smaller time interval for computing the steady state water flux. Predicted results on long-term improvement in salinity of groundwater and drainage effluent did not match with observed field values because salt load of seepage water from surrounding areas was not considered in the model. After validating the model for conditions at the Sampla field site, it was applied to analyse the sensitivity of a number of model parameters on salt distribution in soil and groundwater as well as salt load of drain effluent. While the model results related to the effect of drain spacing-drain depth, initial groundwater salinity and aquifer layering on salt dynamics in tile-drained soil-aquifer system are presented in Kamra *et al.* (1991b), detailed analysis on the effect of drain depth (Kamra *et al.*, 1991), of adsorption (Kamra *et al.*, 1994) and of the depth of impervious layer and quality of irrigation water (Kamra *et al.,* 1995) demonstrate that the proposed model is appropriately designed to study the sensitivity of salt distributions in a tile-drained soil to practices commonly considered in irrigation and drainage management.

Computer Program

To work on DRAINSAL, it is strongly recommended to clarify and understand the mathematical formulation and conceptualization of different subsystems of the model from Kamra *et al.*, 1991a. The general flow chart (Fig. 2) illustrates the sequence of computations performed through the FORTRAN 77 computer program of the proposed **DRAIN**AGE **SAL**INITY SIMULATION MODEL (DRAINSAL).

The inputs to the program consist of information on finite element discretization of the flow domain, types of boundary conditions, drainage, recharge and aquifer parameters, volumetric moisture distribution in the unsaturated zone, porosity, soil water retention θ(h) data, initial soil and groundwater salinity and distribution coefficients in the unsaturated and saturated zones (if linear adsorption is to be considered). This data (except moisture distribution in unsaturated domain) is either available from field observations or historical records or can be estimated from field studies. Longitudinal and transverse dispersivities for the specific problem area, decided from comparison of observed and results predicted for arbitrarily values of dispersivities during the calibration and validation phases of simulation, also form part of input parameters.

Subprograms

Input of volumetric water contents in the unsaturated portion of the flow domain is possible only after independent execution of three subprograms. Subprogram 'WTHITE' determines the steady state watertable profile between two drains (using eqs. 5 and 8 of Kamra *et al.*, 1991a for homogeneous and two-layered aquifers, respectively). Subprogram 'RISE' is employed to estimate volumetric water contents at different nodes of finite element discretization (at different heights from watertable in the unsaturated flow domain) corresponding to a steady state water flux. A positive q indicates upward flow, and a negative q downward flow. The empirical constants (α, n, θ, θ) of functional forms of soil hydraulic properties as per van Genutchen (1978) model (given by eqs. 2-4 of Kamra *et al.*, 1991a) from input to the subprogram 'RISE'. These are obtained by fitting the data of moisture retention, θ(h) and saturated hydraulic conductivity in the third subprogram 'RETC' which employs the method of least squares to estimate the constants.

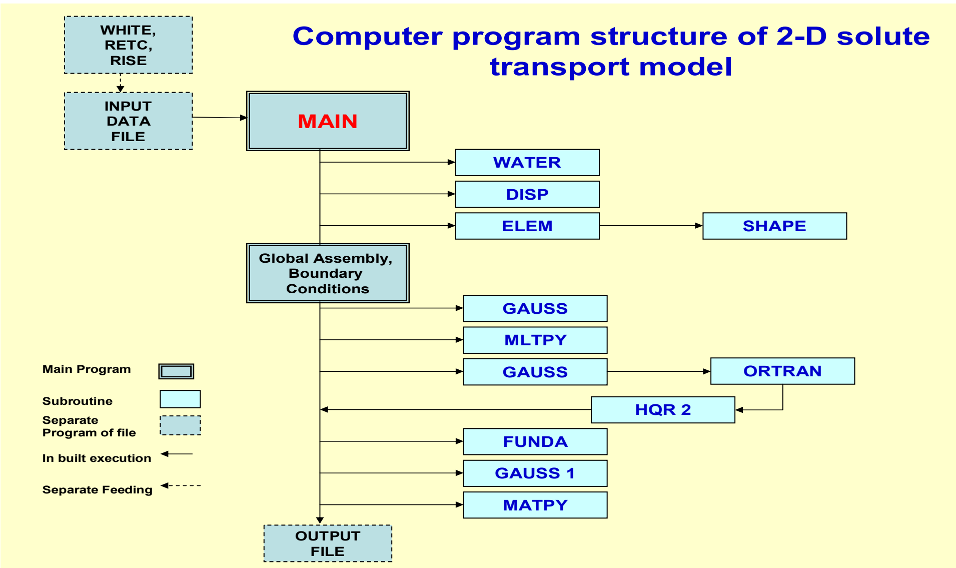

Fig. 2. Computer program structure of 2-dimensional solute transport model 'DRAINSAL'

Main Program

The main program controls the entire sequence of operations. Application of boundary conditions, assembly of (4 x 4) elemental matrices of each element into global matrices of size (NN x NN) and multiplication of a matrix by a column vector at various stages is also performed in the main program itself.

Subroutine WATER determines q_x and q_y, the specific discharge components in X and Y directions, at all nodes of flow domain. In the unsaturated zone, q_x is taken as zero and q_y at all nodes is taken equal to net recharge rate. In the saturated zone, q_x and q_y are determined by using eqs. 6-7 (of Kamra *et al.*, 1991a) for homogeneous aquifers and eqs. 9 through 16 (of Kamra *et al.*, 1991a) for 2-layered aquifers. The subroutine ADSORB determines the retardation factor while the subroutine DISP (using eq. 18 through 22 of Kamra *et al.*, 1991a) determines dispersion coefficients at the Gauss integration points of each element. The subroutine ELEM evaluates (4 x 4) size elemental coefficient matrices [AM] and [DM] of each element by numerical integration over the area of each element. To facilitate integration, Cartesian co-ordinate (X, Y) are transformed into local co-ordinates. For each discretization coefficient matrices are generated only once. The subroutine 'ELEM' calls another subroutine 'SHAPE' which computes basis functions and their derivatives in local co-ordinates for iso-parametric linear quadrilateral elements. EISPACK Computer Package (Smith *et al.*, 1976) was employed to compute all eigenvalues and eigenvectors of a real general matrix while subroutine FUNDA computes the fundamental matrix solution at any time t which leads to computation of matrix exponential and final solute concentration at each node of flow domain.

The two subroutines GAUSS and GAUSSI, essentially same, are used to obtain inverse of a matrix by GAUSS Elimination method. Similarly both subroutines MLTPY and MATPY are used for multiplication of two square matrices.

Running DRAINSAL Model

DSSM.EXE, (DSSM: a short for Drainage Salinity Simulation Model), is an executable file for which four data files MAIN.DAT, NODES.DAT, ELEMENT.CHR and ELEMENT.DAT provide the input. Three files MAIN.FOR, NUMERIC.FOR and WATER.FOR are compiled and combined (linked) to get DSSM.EXE. MAIN.FOR is a file that contains the read statements and small comments useful for defining different variables and for construction of input data files. Running the program from DSSM.EXE results a file DSSM.RLT that contains results on salinity distribution at different nodes of the discretization at required times. It also results in a number of files corresponding to required number of times which individually are direct inputs to any graphical package for presenting two-dimensional salinity contours. For example, if the time of start (TS in MAIN.DAT) is given as 91 (a two digit number to indicate the day, month, season or year as the starting time), then files named DR91A1.DAT, DR91B1.DAT, DR91C1.DAT, …, containing predicted results at times time 1, time 2, time 3, … after the start of simulation are resulted. Appendix A1 presents the instructions for setting up input data files MAIN.DAT, NODES.DAT, ELEMENT.CHR and ELEMENT.DAT, while the format of actual input data files for the example simulation discussed are presented in Appendix A2.

Menu Driven DRAINSAL

The model can also be run through menu driven interfaces through a batch file named DRAINSAL.BAT. The menu becomes operational by just typing DRAINSAL after entering the relevant directory. The interfaces facilitate easy access to input data files MAIN.DAT, NODES.DAT, ELEMENT.CHR and ELEMENT.DAT which can be edited directly through NORTON EDITOR (NE). Run command in the user-friendly interfaces directly executes DSSM.EXE command. After completion of the simulation, the results are stored in DSSM.RLT file and in files needed for graphical results. Output command in the main menu directly takes us to the graphical package to process different output files. The present version obtains the salinity contours through 'SURFER'. It is mandatory on the part of the user to be familiar with SURFER and NORTON EDITOR to use menu driven version. Alternately, DRAINSAL.BAT file can be easily modified to use menu driven facility with other editing or graphical packages.

The present DSSM.EXE works for a discretization having maximum 103 nodes. Users of this package may initially confine to the discretization of Fig. 3 and adjust X and Y dimensions to suit different drain spacing, drain depth and depth of impervious layer configurations. Further, node numbers 8, 9, 10 must be reserved for tile drain (strip sink).

Example Simulation

Appendix A2 lists the input data files MAIN.DAT, NODES.DAT, ELEMENT.CHR and ELEMENT.DAT of DRAINSAL (as per instructions of setting up these files in Appendix A1) for the example that requires simulation of solute transport in a 50 m drain spacing plot with drains installed at 1.8 m depth and with D = 2.0 m. The discretization for the above drainage configuration, having 103 nodes and 82 finite elements is presented in Fig. 3. The example simulation is carried out for Sampla subsurface drainage experimental fields of CSSRI, Karnal. The soil in the region is sany loam with hydraulic conductivity of 1.0 m/day upto 1.8 m depth. Below 1.8 m, there is a homogeneous loamy sand of hydraulic conductivity (K) of 3.0 m/day extending to 3-4 m depth to a relatively low K layer which can be taken as the impermeable boundary. The initial groundwater salinity of 24 dS/m was assumed to be constant in the saturated zone. The initial soil salinity upto the drain level along all vertical profiles of Fig. 3 has been assumed to be uniformly same as the observed salinity profiles during June, 1983.

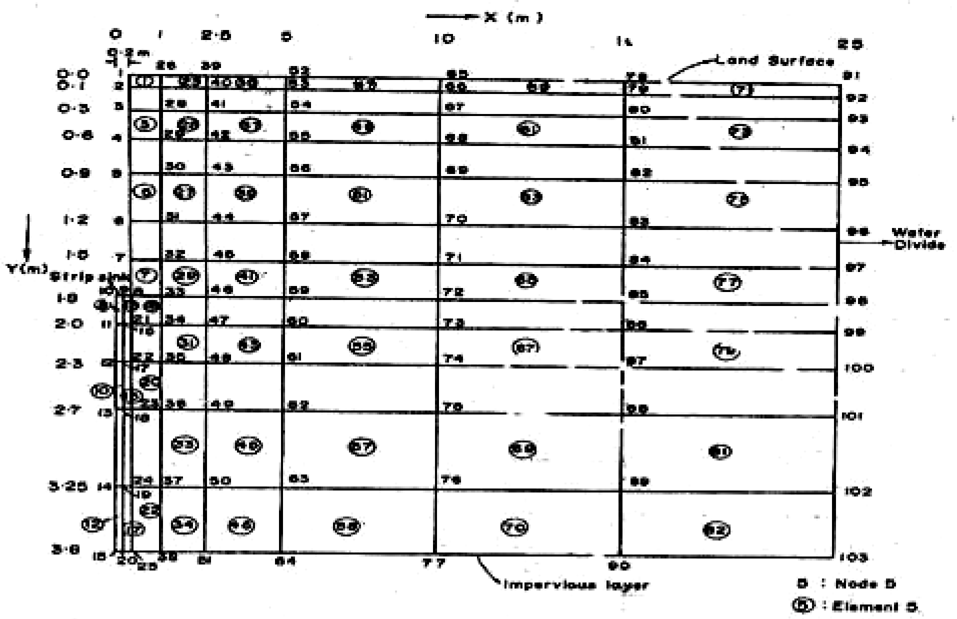

Fig. 3. Finite element discretization of the tile-drained soil-aquifer system during steady downward water flow (2S = 50 m, d = 1.8 m, D = 2.0 m), NN = 103; NE = 82

An average annual downward flux of water of 0.7 mm/day or 0.0007 m/day was worked out from the water balance of the area. It is proposed to predict the effect of applying 5 dS/m water at the above rate on the desalinization of soil and on the changes in the salinity of ground water and drain water.

The subprogram WTHITE was employed to determine the steady state water table profile corresponding to annual water flux of 0.0007 m/day. The representative $\theta(h)$ data for soils of Sampla field, collected from field observations (upto about 1 bar tension) and supplemented by laboratory data from pressure plate apparatus is summarized in Table 2 below. This was used as input data in RETC subprogram which estimated the empirical constants of van Genuchten's hydraulic functions listed in Table 2. . Incorporating these constants in RISE subprogram for a water flux of 0.0007 m/day resulted in data sets of Z(h) or $Z(\theta)$. The volumetric water contents at different nodes of discretization (i.e. at different values of Z from steady state watertable profile) were interpolated from these data sets. The interpolated water contents have been used in the input file NODES.DAT.

Table 2. Soil moisture retention data of Sampla (K_m = 1 m/day)

Pressure head (-cm)	0	50	100	330	500	1000	2500	5000	10000
θ (cm^3/cm^3)	0.45	0.428	0.368	0.278	0.201	0.189	0.146	0.132	0.114

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APPENDIX A1. Set- up of the input data files of DRAINSAL

File: MAIN.DAT

```
-----------------------------------------------------------------
Line   ----------------- variable -------------    Format
-----------------------------------------------------------------
 1    NN    NB    NDB    TS              3(I5),3X,1A2
 2    S     RECH  R1     COND1   COND1     5(F10.5)
 3    D     A     DDRAIN SLITW   SEEPF     5(F10.5)
 4    ISEEP                      I5
 5    NTIM                       I5
 6    T(1)                       F10.2
 7    T(2)                       F10.2
      .                          .
      .                          .
6+NTIM  T(NTIM)                      F10.2
-----------------------------------------------------------------
```

FILE: NODES.DAT

```
-----------------------------------------------------------------
Line  -------------------- variable -----------    Format
-----------------------------------------------------------------
 1    1   XL(1,1) XL(2,1) AL(1)  AT(1)   (2X,I3,2X,2(F5.2,
        BD(1)  DC(1)  P(1)   CO(1)   2X),2(F3.2,2X),
                              F8.3,2X,F4.2,2X,
                              F6.3,2X,F6.3)
 2    2   XL(1,2) XL(2,2) AL(2)  AT(2)   (2X,I3,2X,2(F5.2,
        BD(2)  DC(2)  P(2)   CO(2)   2X),2(F3.2,2X),
                              F8.3,2X,F4.2,2X,
                              F6.3,2X,F6.3)
 .    .         .               -- do --
 .    .         .               -- dO --
NN   NN   XL(1,NN) XL(2,NN) AL(NN)  AT(NN1)  -- dO--
       BD(NN)  DC(NN)  P(NN)   CO(NN)
-----------------------------------------------------------------
```

File: ELEM.CHR

```
-----------------------------------------------------------------
Line  -------------------- variable -----------    Format
-----------------------------------------------------------------
 1    1   NODE(1,1)      NODE(1,2)     2X,I3,2X,4(I3,4X)
        NODE(1,3)      NODE(1,4)

 2    2   NODE(2,1)      NODE(2,2)     2X,I3,2X,4(I3,4X)
        NODE(2,3)      NODE(2,4)
 .    .    .        .         -- do --

NE   NE   NODE(NE,1)      NODE(NE,2)       -- do --
        NODE(NE,3)      NODE(NE,4)
-----------------------------------------------------------------
```

File: ELEMENT.CHR

```
------------------------------------------------------------------
Line  --------------------- variable -----------      Format
------------------------------------------------------------------
 1    1   ICON(1)   NC1(1)    NC2(1)      2X,I3,2X,3(I5,
         FLUX(1)   CIN(1)                2X),F9.5,2X,
                                    F9.5

 2    2   ICON(2)   NC1(2)    NC2(2)      2X,I3,2X,3(I5,
         FLUX(2)   CIN(2)                2X),F9.5,2X,
                                    F9.5
 .    .    .        .       .            .
 .    .    .        .       .            .

 NE    NE   ICON(NE)   NC1(NE)    NC2(NE)    2X,I3,2X,3(I5,
         FLUX(NE)   CIN(NE)              2X),F9.5,2X,
                                    F9.5
------------------------------------------------------------------
```

APPENDIX A2. Input data files of DRAINSAL for example simulation

File: MAIN.DAT

```
------------------------------------------------------------------
  103   82    0   83
0025.00000    .00070    .05000   3.00000   3.00000
0002.00000   1.40000   1.80000    .20000    .00000
   2
   3
   365.00
   730.00
  1825.00

------------------------------------------------------------------
```

File: NODES.DAT

```
------------------------------------------------------------------
   1   .20    .00  .80  .08     1.500   .00    .341  82.000
   2   .20    .10  .80  .08     1.500   .00    .344  50.700
   3   .20    .30  .80  .08     1.500   .00    .352  19.400
   4   .20    .60  .80  .08     1.500   .00    .365  15.800
   5   .20   0.90  .80  .08     1.500   .00    .380  16.800
   6   .20   1.20  .80  .08     1.500   .00    .400  15.500
   7   .20   1.50  .80  .08     1.500   .00    .435  16.700
   8   .20   1.80  .80  .08     1.500   .00    .449  28.000
   9   .10   1.80  .80  .08     1.500   .00    .449  28.000
  10   .00   1.80  .80  .08     1.500   .00    .449  28.000
  --   --    --   --   --    ---    --    ---   ---
  --   --    --   --   --    ---    --    ---   ---
 101  25.00   2.70  .80  .08     1.500   .00    .449  24.000
 102  25.00   3.25  .80  .08     1.500   .00    .449  24.000
 103  25.00   3.80  .80  .08     1.500   .00    .449  24.000
------------------------------------------------------------------
```

File: ELEMENT.CHR

```
------------------------------------------------------------------
   1   2    27    26     1
   2   3    28    27     2
   3   4    29    28     3
   4   5    30    29     4
   5   6    31    30     5
   6   7    32    31     6
   -   -     -     -     -
   -   -     -     -     -
  78  86    99    98    85
  79  87   100    99    86
  80  88   101   100    87
  81  89   102   101    88
  82  90   103   102    89
------------------------------------------------------------------
```

File: ELEMENT.DAT

```
------------------------------------------------------------------
   1    1    26     1    .00070   05.00000
   2    1     2     3   .00000    .00000
   3    1     3     4   .00000    .00000
   4    1     4     5   .00000    .00000
   5    1     5     6   .00000    .00000
   6    1     6     7   .00000    .00000
   -    -     -     -     ---      ---
   -    -     -     -     ---      ---
  80    1   101   100    .00000    .00000
  81    1   102   101    .00000    .00000
  82    1    90   103   .00000    .00000
```

Subsurface Drainage for Vertisols

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Introduction

The black soils, commonly known as black cotton soils belong to vertisol group and cover about 63.54 million ha area in Maharashtra, Andhra Pradesh, Karnataka, Gujarat, Western Madhya Pradesh and some parts of Tamil Nadu. These soils are more suitable for dry land farming as the soils have highest number of micro pores and can store the soil water for longer duration, which can be used by agricultural crops during the drought periods. Black soils are more prone to drainage problems because of low hydraulic conductivity and drainable porosity. Hence it is essential to provide proper drainage facility, if irrigation is to be provided to black soils. With efforts of the central and state governments, dams were constructed to store surface / river water to provide irrigation to agricultural crops. These irrigation networks/ projects proved as boon to the agriculture initially. However, irrigation facility proved as a curse in some pockets of the commands of irrigation schemes as well as lift irrigation schemes. The sugarcane yields on the affected soils got adversely affected and yield level reduced from more than 200 Mg ha^{-1} during the initial stages of the introduction of irrigation to 30-40 Mg ha^{-1}. This has been caused as result of water logging and soil salinity due to improper utilization of irrigation water and the seepage losses from conveyance and distribution networks. The groundwater quality in black cotton areas generally remains poor and hence conjunctive water use of surface and groundwater also remains very poor. It results in rise of watertable in many commands in vertisols if natural drainage is not proper. Such situations are really detrimental to crop growth and land becomes totally barren. The sub drainage system to reclaim the affected soils has been experimented at many places in black soil areas and large-scale drainage projects are coming up in different states. The overview of subsurface drainage in vertisols is presented in this lecture.

Causes of Salinity

Several reasons responsible for conversion of productive land into unproductive one and consequent economic losses are listed below:

- Low annual rainfall and high annual evaporation in semi-arid and arid regions promote upward salt movement in irrigated areas
- Heavy and deep soils are having low permeability with impended drainage system
- Seepage from the irrigated areas located at higher elevation results in rise of watertable and soil salinity over the years in low lying areas
- Indiscriminate use of irrigation water in lift irrigation scheme commands for crops such as sugarcane on heavy clay soils results in increase in water table in absence of efficient drainage system
- Poor maintenance of natural drainage system as result of clogging and silting problem and damage to natural drainage system due to human interference/ encroachments and development activities such as roads, highways, railways, big buildings, etc.
- Seepage and leakages of irrigation canals cause water logging in low-lying lands
- Poor maintenance of irrigation networks and improper irrigation methods promote the rise of water table and ultimately lead to development of saline lands
- Improper crop rotations/ lack of conjunctive water use policies for groundwater and surface water also contribute to development of salinity

Characteristics of salt affected soils

Saline Soils

- Saline soils form white crust of salts on surface layer in summer
- Soil structure is good with adequate drainage ability
- There is no crop growth, when salt concentration is higher
- Testing of soil saturation paste extract shows electrical conductivity higher than 4.0 dSm^{-1}
- pH is less than 8.5 due to presence of salt of sulphates and chlorides
- Exchangeable sodium percentage is always less than 15

Sodic Soils

These soils are also known as *Chopan* soils.

- There is deposition of ash like salt layer on soil surface in summer
- When dry, sodic soils form deep cracks
- In wet condition the soils become very sticky and very plastic
- Rain water is stagnated on surface layer
- There is no crop growth on such soils, the bushes of Prosopis is seen in some patches
- Electrical conductivity is less than 4 dSm^{-1}
- pH is always higher than 8.5 due to higher proportion of salts of carbonates and bicarbonates
- Exchangeable sodium percentage is higher than 15 per cent, which causes destruction of soil structure due to dispersion

Though saline sodic soil is not treated a separate category as such. There exist soils, which are having high salinity and ESP both. If such soils are leached out with provision of drainage system, presence of sodicity might be noticed. Under such situations, incorporation of crop residues, application of Farm Yard Manure (FYM), pressmud and other organic materials can help in reduction of sodicity. In the worst case, where soil structure gets adversely affected due to sodicity, application of gypsum is necessary. These soils show following characteristics under field conditions.

- The soils show the characteristics of saline as well as sodic soils and there is formation of white crust of salts on surface soils in summer
- Plant growth is affected
- The soil structure starts deteriorating
- Soil pH is less than 8.5; ESP is greater than 15; EC of saturation paste extract is higher than 4.0 dSm^{-1}
- If salts are higher, these soils behave like saline soils and if exchangeable sodium is higher, they behave like sodic soils (Generally these soils start behaving like sodic after leaching of salts by subsurface drainage system)

Historical Perspective

Manjari Drainage Scheme

As per documentary evidences, subsurface drainage has been experimented in India for the last 130 years or so. The first-ever subsurface drainage experiment to reclaim salt affected land was conducted by Mr. Robertson in 1873 (Gupta, 2002 and Gupta, 2003). Similarly, Manjari drainage scheme in Maharashtra state is located in Khadakwasala irrigation project near Pune, in the command of distributory No. 5 and 6 of old Mutha right bank canal. Irrigation in this area commenced in 1880. The land adjacent to the nala was seen damaged due to waterlogging in 1920. Some portion of damaged land was also affected by salt. The scheme comprised of two main drains with 16 underground closed lateral drains, comprising earthen pipes loosely shunted in sockets and filled with filter material in periphery. The drainage scheme was successful and almost all damaged area was reclaimed during the period of 5 years. Out of 194 ha of damaged area in 1931, 68 ha area was improved in 1932, 108 ha in 1933, 135 ha in 1934 and 140 ha in 1935.

Drainage Experiment at Rahuri

The drainage scheme for 30 ha was designed for reclamation of waterlogged black cotton soil in D-block of Mahatma Phule Agricultural University Rahuri 1981. The main causes of waterlogging were seepage from Mula right bank canal, excess irrigation on the upper part of field and percolation tank on the upper boundary of the field. The natural drainage of the area was blocked due to canal in vicinity. The subsurface drainage system was provided after detailed drainage investigations. The pH and soil salinity decreased after provision of drainage. The sunflower crop successfully after one year and wheat crop was grown after second year.

Though there were some success stories in past indicating identification of drainage problem and competence to tackle it, major achievements could be accomplished during the last thirty years when a subsurface drainage based reclamation package was developed and implemented to cover about 40000 ha of waterlogged saline lands in the country.

Experiences with Subsurface Drainage in Vertisols

Subsurface Drainage Activities in Rajasthan

RAJAD (Rajasthan Agricultural Drainage Research Project) was a large scale applied research project on the use of horizontal subsurface drainage (SSD) and associated water management techniques to control soil salinity and water logging problems in irrigated agricultural lands in Chambal Command in Rajasthan. Canadian International Development Agency (CIDA) supported it. The project was initiated in 1991 and continued up to 2000. Particulars of the project area are:

e) An area of 60,000 ha was surveyed using total station for topography, EM38 for soil salinity, soil sampling laboratory analysis for physical and chemical properties and in-situ saturated hydraulic conductivity on 8 ha grid.

f) About 25,000 ha area was identified as waterlogged saline area.

g) Computer Aided Design and Drawing (CADD) activity was initiated under Indian conditions.

Design Criteria

Based on test plot results from 1400 ha, the following design criteria was developed and adopted for RAJAD project.

• Drain depth	1.2 m
• Drainage coefficient	1.5 mm/day for laterals and 3 mm/day for collectors to allow for additional seepage control from canals and surface drains
• Drain spacing	35–60 m to provide satisfactory salinity and water table control
• Envelope requirement	Not required if soil profile clay percentage is >40 Required if clay percentage < 30 or clay content is between 30 to 40 % with soil sodicity, SAR >8

The RAJAD implemented integrated surface and subsurface drainage with improved water and agricultural management to control soil salinity and waterlogging in irrigation commands. The subsurface drainage system was installed on total area of 14925 ha using 3.04 million metre of locally produced corrugated and perforated PVC pipes from 1991-1999. The financial analysis of RAJAD project has showed the cost-benefit ratio from 1.28 to 2.87, with payback period of 4.5 to 6.9 years and an internal rate of return of 18-35% (RAJAD, 2001).

Subsurface Drainage Activities in Gujarat

- Considering the severity and extent of water logging and secondary salinization problems in *Ukai Kakrapar* Command (UKC), Soil and Water Management Research Unit, Navsari Agricultural University (formerly Gujarat Agricultural University), Navsari conducted studies on subsurface drainage in 56 ha block at the farmers' fields situated in the jurisdiction of Chalthan Sugar Factory, Chalthan during 1984-85 to 1991-92. After installation of subsurface drainage, paddy and sugarcane yields were higher as compared to pre drainage yields. The pH and EC values also showed a decreasing trend with the progress of time after drainage.
- Similarly, WALMI, Anand (middle Gujarat) also conducted pilot scale demonstrations of subsurface drainage technology in Mahi Right Bank Canal Command during 1990-91. The soils were extremely saline and water logged and the area was almost lying barren. After installation of subsurface drainage, paddy crop was grown and yield level of 2 to 3 t/ha was achieved.
- Subsequently, for testing and demonstrating the drainage need on larger scale for controlling waterlogging and soil salinity, a collaborative project (Indo-Dutch Network Project) with ILRI, the Netherlands was approved by ICAR, Government of India with Navsari as one of the network centers and CSSRI, Karnal as the coordinating center. Under this project, two pilot areas were selected in UKC. The important characteristics of both the pilot areas are given in Table 1. The distinct difference between both the pilot area was cropping intensity i.e. in Segwa it was 116 percent and only 48 percent in Sisodara. This was mainly because of severity of waterlogging and salinity problems were more in Sisodara than in Segwa. The cropping intensity of 48 per cent in Sisodara suggests presence of barren land in pilot area.

After completion of pre project survey and analysis of drainage related parameters of soil, drainage design details were worked out and system installation work was initiated during 1998. The system details are presented in the Table 2.

Table 1. Important characteristics of pilot area

Sl. No.	Particulars	Pilot area	
		Segwa	Sisodra
1.	Taluka/district	Kamrej/Surat	Ankleshwar/Bharuch
2.	Climate	Sub humid	Semi arid
3.	Branch/minor	Surat branch/ Segwa minor	Kosamba branch/Pandvai minor
4.	Size of pilot area (ha)	188	169
5.	Cropping intensity (%)	116	48
6.	Major crops	Sugarcane, paddy	Sugarcane, paddy
7.	Major constraints	Water logging and initiation of salinization	Extreme water logging and high salinity/sodicity
8.	Source of irrigation water (ha)		
	- Canal	76	76
	- Well alone	37	--
	- Drain	4	--
	- Conjunctive use	26	--

Table 2. Information about drainage system installed

Particulars	Segwa				Sisodara	
	Singular pipe drains (m)	Area (ha)	Composite pipe drains (m)	Area (ha)	Open drains (m)	Area (ha)
Drain depth/ spacing	0.9/30	4.2	1.2/30	2.6	0.8/30	2.0
	0.9/45	5.6	1.2/45	5.7	0.8/60	14.0
	0.9/60	5.4	1.2/60	4.6		
Installation method	M	--	M + E	--	M	--
Envelop	None	--	Some	--	--	--
Amendment	None	--	Some	--	--	--
Total area (ha)		15.2		12.9		16.0

M = Manual, M + E = Manual + Excavator

At Segwa pilot site, singular and composite closed subsurface drainage (CSSD) systems were installed at 30, 45 and 60 m spacing with and without amendment and envelope. In all, 28.1 ha area was brought under CSSD in phased manner. While at Sisodara, only open subsurface drainage (OSSD) was laid out in 16 ha area with 30 and 60 m drain spacing. Both these pilot areas were monitored rigorously for soil; drain water, ground water level and crop yield parameters.

After installation of CSSD in Segwa pilot area, salinity and sodicity parameters of the soil were monitored periodically. The soluble salt content in soil (0-90 cm) under CSSD declined from initial value of about 4.0 dS/m in 1998 to 1.0 dS/m in 2002. Similarly sodicity was also tended to decline after installation of CSSD system at Segwa. Also there was increase in sugarcane yields with time by 35 percent as yield increased from 78-104 to 105-140 t/ha.

Subsurface Drainage Activities in Maharashtra

Agricultural Research Station, Kasabe Digraj under Mahatma Phule Krishi Vidyapeeth, Rahuri (Ahmednagar) in Maharashtra is conducting research work on reclamation of salt soils, since its inception in 1987. The scientists of the station designed the subsurface drainage with perforated corrugated PVC pipes for reclaiming waterlogged black Karl soils on 0.4 ha area of the research farm in 1989-90. The objective was to reclaim the saline sodic black soils by adding amendments and providing sub surface drainage. Drainage investigations were carried out to know salinity status of soil, water table and its fluctuations, drainage porosity and depth of impervious layer. The surface drainage was provided by laying out 90 m collector drain and three lateral pairs at distance of 30 m in herringbone fashion. The results revealed that within span of 7 years the EC and ESP decreased from 10.35 dS/m and 19.57 to 0.97 dS/m and 1.28, respectively; with better performance of rice (32.45 q/ha), wheat (27.52 q/ha), sugarcane (94.75 m/ha), soyabean (10.0 q/ha) and sunflower (7.0 q/ha).

The surface drainage system was also installed in the area of 8.81 ha in challis biga farm (survey no. 155) of Agricultural Research Station, Kasabe Digraj. The soil in this area is clayey in nature and saline. It is of saline to saline sodic and waterlogged type. The pH fluctuation was in the range of 8.13 to 8.52. The electric conductivity was found in the range of 2.22 to 17.82 dS/m. The exchangeable sodium percentage was recorded in the range of 7.04 to 17.50. The hydraulic conductivity was found in the range of 0.0236 to 0.0579 m/day. The water table fluctuation was recorded in the range of 0.265 to 1.85 m from the surface in different seasons. The field is partly covered with dense *Prosopis* growth. Perforated corrugated PVC pipes of 80 mm diameter was used for collector drain. The average depth of collector and lateral drains was 1.32 m. The spacing between two laterals was 25 m. Coarse sand filter and synthetic filter were used as filter envelope. The drainage inspection chambers were installed on collector drain. The drainage effluent was taken out by gravity and expenditure on pumping is minimized. The installation of drainage system could help to bring these barren soils under cultivation. The cost of providing the subsurface drainage system including cost of material and installation was Rs. 56,000/ha. A good crop of soyabean DS, 228 (Phule Kalyani) was grown in *kharif* 2003 and production of 10 q/ha was harvested. In December 2003 sugarcane variety co-94012 was planted on 4.0 ha. The cotton on 0.4 ha, beet 0.4 ha, wheat 0.2 ha and onion 0.2 ha were planted on partly reclaimed field. During one year the EC and ESP both were lowered down by 5 to 6 units. The salinity of drainage effluents in the first year was high which was comparatively lower by the second year. The quality of the drainage effluent is expected to improve further and in about 3 to 4 years these waters can be used for irrigation.

The experiments on drainage aspect, use of chemical amendments in combination with organic fertilizers, various agronomic/horticultural practices with different species of crops were also conducted at Agricultural Research Station, Kasabe Digraj (Sangli) Maharashtra. The findings of research are:

- The subsurface drainage of perforated pipes (closed) decreased the salt content of soil to a larger extent and the soil was reclaimed. The performance of crops like rice, wheat, sugarcane, soyabean, sunflower was found better in reclaimed soil.
- In saline sodic soil the performance of suru, subabhool, eucalyptus and ramkathi babool was good and they reduced the salt content of soil.
- The ground water level was very close to the surface in monsoon season. The highest ground water level was recorded in the month of September, where as it went down in winter and summer. The salt status of soil water was lower in monsoon due to leaching and dilution effect. The highest salt content was observed in the month of June, due to higher evapotranspiration.
- Karnal grass can be grown on waterlogged and saline soils with frequent irrigation and 25 kg N/ha in split applications.
- Open drains are not helping in salt reclamation due to their maintenance and clearing problems.
- Subsurface drainage system (1.25 m depth and lateral spacing of 25 m) with integrated use of gypsum (50% of gypsum requirement) and green manuring (Dhaincha) is recommended for improvement of deep black saline sodic soils.

TDET (Technology Development Extension and Training) Projects

It is commonly believed that problems of waterlogging and soil salinization infest the commands of the major projects. Contrarily, if the situation is same, even the water brought into the command through minor

Table 3. Subsurface drainage activities in Maharashtra under lift Irrigation schemes

Project	Project related information	
Reclaim - I	Total project cost	Rs. 446.51 lakh (including main drain)
Dudhgaon Project	Total area	1100 ha
(Sangli)	No of beneficiaries	1326
	Outlet	Gravity
	Main drain	Open
	Collectors	80-455 mm diameter pipes
	Laterals	80 mm perforated pipes
Reclaim - II	Total project cost	Rs.553.33 lakh (including main drain)
Kasabe Digraj	Total area	1065 ha
Project (Sangli)	No of beneficiaries	1159
	Outlet	Gravity
	Main drain	Open
	Collectors	80-250 mm diameter pipes
	Laterals	80 mm diameter perforated pipes

irrigation works would result in rising water table and soil salinization would be a foregone conclusion. A large area of the black cotton soils in Maharashtra has been affected by the twin problems in lift irrigation commands operated by the farmers. Two pilot subsurface drainage projects sanctioned by Department of Land Resources, Ministry of Rural Development, Govt. of India under Technology Development Extension and Training (TDET) Program have been taken up in black soils of Krishna river basin in commands of lift irrigated schemes. The most important feature of this project is that the investments on these projects are shared by the Central Government, State Government and the beneficiary in ratio of 60:20:20. Banks have come forward to extend the loan facility to the beneficiaries. The SSD project at village Dudhgaon, District Sangli (Maharashtra) under Reclaim-1 for 1100 ha has been completed and farmers are already deriving benefits of improved yields. The SSD project at village Kasabe Digraj, District Sangli under RECLAIM-II for 1065 ha is under construction (Table 3). The depth of laterals varies from 1.0 to 1.5 m and lateral drain spacing ranges from 25 to 35 m. The collector drains outfall into an open main drain. Proper monitoring and evaluation of these projects has been initiated under the guidance of eminent personalities and experts in this field. M/s Rex Poly Extrusion Ltd., Sangli, is executing these projects.

Subsurface Drainage Activities in Karnataka

A number of subsurface drainage pilots were laid out in Tungabhadra command in Karnataka by the state CADA with funding from the Ministry of Water Resources, Govt. of India. It was observed that there was increase in crop yield (Table 4) and cropping intensities of crops (Table 5).

Table 4. Impact of land reclamation on crop yield

Place	Crop	Crop production (t/ha)		
		Before drainage	After drainage	Increase over pre-drainage (%)
Islampur(Karnataka)	Cotton	3.3	10.4	215
	Paddy	1.4	5.5-6.2**	290-340
	Sunflower	3.0	7.4	146
	Sorghum	6.8	11.6	70
	Wheat	4.0	6.7	68
Vaddarathi	Rice	3.5	8.4	140
Gundur	Rice	2.8	8.1	189
Siddapur	Rice	2.4	7.3	204
Gangavathi	Rice	4.0	7.9	98
Sindhanur	Rice	2.2	3.7,6.7-7.5#	223
Gorebal	Rice	2.3	7.2	213

** In phase I and Phase II, respectively; All other crops in ORP
# First year and range during subsequent years

Table 5. Cropping intensity as influenced by land reclamation

Area	Before drainage	After Drainage	% Increase over Pre-drainage
Islampur			
ORP	0	27, 35, 200**	-
Phase II	88	144, 156#	77

**In first, second and third year; # In first and second year
- Could not be calculated because initially there was no cropping in the area

Subsurface Drainage on Fields by Farmers' Own Investments

Experiences from Maharashtra

Subsurface drainage system was installed on 0.78 ha land of Shri Shripal Sheshappa Dudhagave of Kasabe Digraj in May 1997 by the scientists of Agricultural Research Station, Kasabe Digraj. The watertable was 0.42 m, EC 3.07 dS/m and ESP 7.37. This land was waterlogged and not much saline. The lateral was of 80 mm perforated pipe at 0.90 m depth and spacing between two laterals was 30 m. the layout was in herring bone pattern. The water table was lowered to 1.00 m within three years and good crop of sugarcane 100 t/ha was harvested after third year. The drainage cost was Rs. 32,200/ha.

The Agricultural Research Station, Kasabe Digraj also helped in installation of subsurface drainage on 1.1 ha land of Shri Balasaheb Deogonda Patil of Mouje Digraj in May 1998. The water table was 0.26 m from ground surface. EC was 9.54 dS/m with and ESP 8.77. This land was saline and water logged. The layout of the system was of gridiron, herringbone and parallel pattern. Lateral spacing was 20 to 30 m at the depth of 0.8 m. The cost of drainage was Rs. 78,109/ha. The water table was lowered and salinity was reduced after three years and sugarcane yield of 166 tones/ha was obtained, where yield of sugarcane was 30 t/ha prior to drainage.

The subsurface drainage system was also installed on 0.87 ha of farm of Shri Ganpat Tukaram Patil of Aitwade Khurd in June 1998. The land has water table at 0.17 m and EC 2.6 dS/m and ESP 5.4. Waterlogging was severe.. Agricultural Research Station, K. Digraj, laid the subsurface drainage. The interceptor drain of 100 m with perforated PVC pipe of 100 mm dia was laid around boundary of the plot. The field was covered under random design with 80 mm dia pipe was laid around boundary of the plot and lateral space was kept 20 to 25 m. The depth of the drainage system was kept at 0.90m. The water table was lowered down and good sugarcane crop 172 tones/ha was harvested after one year. The drainage cost was Rs. 57,000/ha. Similarly, nearly 100 acres of saline waterlogged black soils were covered under subsurface drainage with perforated corrugated PVC pipe in Kasabe Digraj, Mouje Digraj, Kavthe Piran, Samdoli, Savalwadi and Walva by the scientists from Agricultural Research Station, Kasabe Digraj of district Sangli in the year 2002-2003. The drainage cost ranged from 50,000 to 56,000/ha in the 100 acres of area so far covered under subsurface drainage.

Experiences from Gujarat

The subsurface drainage system has been installed on fields of Shri Arvind Bhai Patel and Shri Bharat Bhai Patel at village *Kim* in Navsari district of Gujrat state in the command of *Kosamba* branch under *Ukai Kakrapar* irrigation project with the technical support from Navsari Agricultural University. The soils are heavy with 55 percent clay. Earlier farmers used to grow cotton and pigonpea. However, they shifted to sugarcane and paddy with start of irrigation. The waterlogging and soil salinity problems appeared later on due to flat topography, over irrigation and low permeability of the soil. The soil salinity was around 11-15 dS/m and ESP ranged around 22 before the installation of subsurface drainage system. As per the University, threshold value of ESP for sugarcane crop is around 8 for the heavy soils prevalent in the area. The university recommends application of either gypsum or sugar factory waste to control sodicity besides the subsurface drainage for waterlogging and soil salinity. Farmers themselves did expenditure on the subsurface drainage system. The drain spacing for the system is 45 m and the cost of the system is around Rs. 25,000/- per ha. They also applied gypsum. The system works by gravity and drainage water is disposed into stream, which ultimately takes it to *Tapi* river, is 2-3 km away from the farmers' fields. At one of the manhole, which is closer to outlet, farmers have made provisions to put surface water into it, in event of surface water stagnation due to excess rainfall. The small silt basin is also provided and surface water is passed through silt basin before entering into manhole. The collector pipe thereafter is of rigid PVC pipe. Pump and pump stand are provided at outlet point. Whenever required fresh water is pumped from the stream /Nala and put into rigid collector through pump stand. The collector line is used as lift irrigation pipeline to irrigate the fields. Thus farmers are using collector line for surface drainage, subsurface drainage and irrigation. Such innovations in subsurface drainage technology are required to propagate the technology at farmers' fields. Because of multiple uses of the system they are also taking care of the system. With successful operation of the system the waterlogging problem has reduced and watertable has been lowered. The soil salinity has been reduced and sugarcane yield has increased. The farmers are happy and express the satisfaction over the performance of dual purpose subsurface cum irrigation system.

Conclusions

The black cotton soils (vertisols) are heavy soils with low permeability and are more prone to waterlogging and soil salinity if provided with irrigation without proper drainage. These soils can be reclaimed by subsurface drainage system. However drain spacing is kept smaller (i.e. 30 to 35 m) as compared to alluvial soils of Haryana and Punjab. At most of the places gravity outlets are available for the disposal of drainage water and it reduces the pumping cost of the system. It has been proved that subsurface drainage is a successful technology to reclaim waterlogged and saline vertisols.

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Spatial Data Representation Techniques Using *SURFER* for Poor Quality Land and Water

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Introduction

Both land and water are finite resources essential to sustain various forms of life on the earth. Their proper utilization is essential for sustainable food production and economic development. Recent estimates indicate that 6.74 m ha (NRSA, CSSRI, NBSS&LUP, 2006) area in India is affected by soil salinity and alkalinity. The ground water quality in the country has been estimated to have about 25% of ground waters as sodic and/or saline. In the state of Rajasthan alone, more than 80% of the ground water resources are of poor quality and are unfit for irrigation to agricultural crops (Singh, 2008). Both the temporal and spatial data on poor quality resources have been collected and analyzed by several research and development institutions. Mapping of such spatial information is the most common method for representation and better interpretation for researchers and planners. Several software tools are being used to geostatistically analyze these observations of the data, which are necessary to characterize the spatial distribution of poor quality soils and waters at farm and regional scales. Various geostatistical methods have been extensively used to describe the spatial distribution of soil or water properties in agriculture (Cambardella *et al.*, 1994; Meirvenne and Hofman, 1989). For example, the knowledge of salinity variability and characterization of spatial distribution in the fields are important for evaluating areas of low and high salt contents, and providing proper management recommendations. Such methods are also important to determine the spatial dependency between the measurements which are necessary for recommending optimum sampling scheme.

Surfer is a software package that runs under Microsoft Windows and is used for contouring and 3D surface mapping. It quickly and easily converts data obtained within or even outside a command area (generally regularly/ irregularly spaced XYZ or spatial data and/or observations) into outstanding contour, surface, wireframe, vector, image, shaded relief, and post maps (Fig.1). Virtually all the aspects of maps can be customized to produce exactly the desired presentation.

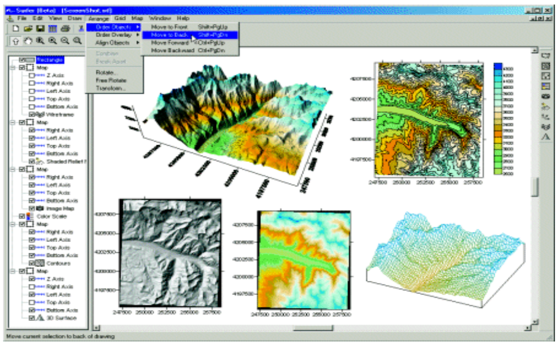


Fig.1. Sample terrain in Surfer 7.0 window showing contour, wireframe, image, shaded relief and 3D maps (clockwise from right top)

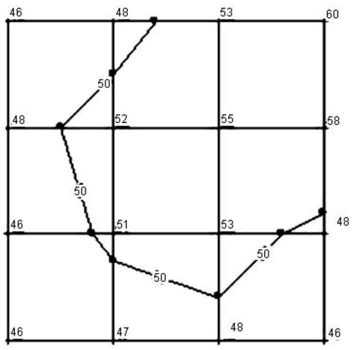


Fig.2. Example for path of a contour line (Z = 50) passing through a square grid

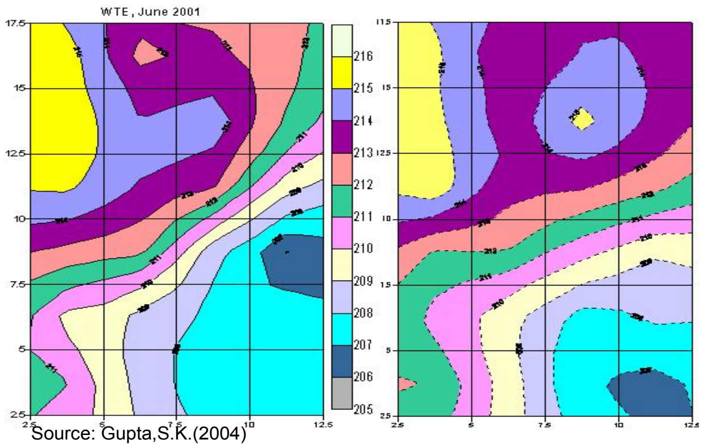
When a contour map is created, the grid or DEM (Digital Elevation Model) file is read into the plot window as an internal array of XYZ grid nodes. The grid nodes consist of rows and columns of Z values. The rows contain grid nodes with the same Y coordinate, and the columns contain grid nodes with the same X coordinate. Grid file columns and rows are sometimes referred to as X grid lines and Y grid lines, respectively. The intersection of a row and column is defined as a grid node. Grid files define the XY location of each grid node over the extent of the map, and the interpolated Z value at each node. A contour is a line (generally in smooth curves) generated by interpolating between grid nodes. In Fig.2, it is shown as an example with straight-line segments that define the contour line for a value at 50 units in the map. The dots have been added to show the ends of each line segment. When Surfer creates a contour map, the contour lines are drawn as a series of straight-line segments between adjacent grid lines. The point where a contour line intersects a grid line is determined by interpolation between Z values at adjacent grid nodes. It can be done with the help of several gridding options like *Natural Neighborhood* or *Universal Kriging*. The elevation data contained in USGS DEM files are regularly spaced, but the direction of the grid lines may not exactly coincide with the grid edges. This is due to the variable angle between the UTM coordinate system (used in some DEM files) and true north. This results in the potential for a regular, stair-stepped arrangement of the grid nodes along the edges of the map, which can translate to, blanked grid nodes along the edges of maps produced in Surfer. If the DEM file contains three-second arc coordinates, the coordinates are automatically converted to latitude/longitude coordinates in Surfer. The grid limits define the extent of contour maps. Once a grid file is created, it cannot produce a contour map larger than the extent of the grid file. However, the use the Map | Limits command can be used to specify a subset of the grid used to create the contour map.

Many features like physical and chemical properties of top soil and aquifer, surface topography, climate, vegetation, production, productivity, groundwater depth & quality, distribution of hazardous chemicals etc. could be requied to present in the form of a map. Any quantifiable spatial data of any such kind of property can be placed and analyzed using Surfer 7.0. It may be simple plotting of sample data location and/or its values to line or surface joining equal values to spatial variation analysis and much more. In the present chapter, the following major maps/ features/ facilities that can be dealt by the SUFER 7.0 are discussed.

1. Contour Map
2. 3D Surface Map
3. 3D Wireframe Map
4. Vector Map
5. Image Map
6. Shaded Relief Map
7. Post Map
8. Base Map
9. Map overlays
10. Gridding
11. Variograms
12. Fault and Break lines
13. Digital Elevation Model (DEM) Files
14. Worksheets and Object Manager
15. Additional Utilities and Features

Contour Maps

Surfer contour maps give full control over all map parameters. The Surfer intelligent defaults can be as such employed to automatically create contour map, or double-click a map to easily customize map features. Contour maps over any contour range and contour interval can be displayed, or specified the desired contour levels to be displayed on the map. And with Surfer we can add color fill between contours to produce dazzling displays of maps, or produce gray scale fills for dramatic black and white printouts (Fig. 3).



Source: Gupta,S.K.(2004)

Fig.3. Water table elevation contour map (June 2001) of some parts of Rohtak-Jhajjar Districts of Haryana – Observed and Simulated

3D Surface Maps

A three dimensional or 3D surface map uses shading and color to emphasize your data features. Change the lighting, display angle and tilt is possible. Overlay several surface maps are used to generate informative block diagrams, which is helpful to illustrate the geology of the terrain. As an example of this, Great Lake Ladoga on the margin of the Baltic (Fennoscandian) Shield is shown in Fig.4.

3D Wireframe Maps

Surfer wireframe maps are three-dimensional representations of a grid file. These are are block diagrams generated by drawing lines representing the grid X and Y lines (the grid columns and rows). At each intersection of a column and row (i.e. at each grid node), the height of the surface is proportional to the grid Z value at that point i.e., the number of columns and rows in the grid file determines the number of X and Y lines drawn on the wireframe map (Fig.5). A wireframe map can be used to display any combination of X,Y, and Z lines. It uses color zones, independent X,Y,Z scaling, orthographic or perspective projections at any tilt or rotation angle, and different inations of X, Y and Z lines to produce exactly the surface we want. Drape a color-filled contour map over a wireframe map to create the most striking color or black-and-white representations of your data. The possibilities are endless. Wireframe maps Wireframe maps are block diagrams generated by drawing lines representing the grid X and Y lines (the grid columns and rows). The number of columns and rows in the grid file determines the number of X and Y lines drawn on the wireframe map.

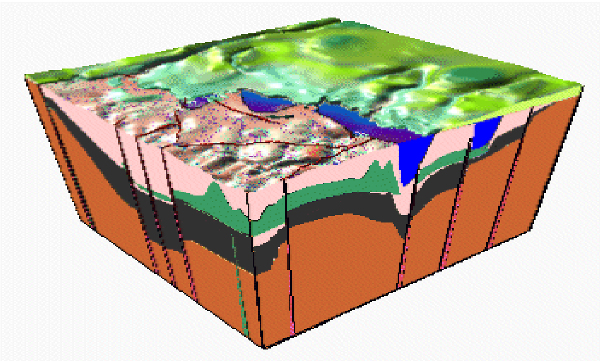


Fig.4. Series of overlaid surface maps creats a 3D surfaces

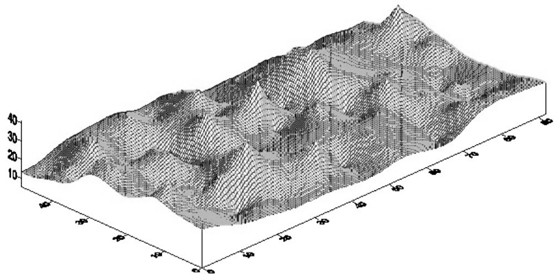
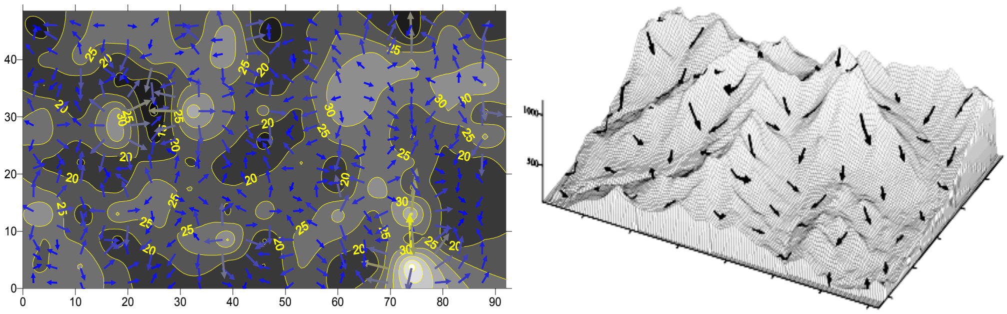


Fig.5. Emitter discharge distribution shown as a wireframe 3D map in a drip field

Vector Maps

A vector map is a graphical presentation comprised of a field of small arrows. Each arrow shows a direction and a magnitude associated with the location at which the arrow is drawn. For example, a vector map can depict the local gradients of a topographic surface: the arrows point in the direction of steepest ascent, and the size of the arrows are scaled to the magnitude of the local slopes. Surfer offers two types of vector maps: a 1-grid vector map and a 2-grid vector map. In a 2-grid vector map, the two components of the vectors (i.e. magnitude and direction, or DX and DY) are provided by two separate grid files. The two components of a 1-grid vector map are automatically generated from a single grid file by numerically calculating the gradient of the represented surface. By default, the 1-grid vector map draws vectors pointing in the direction of steepest descent, with the vector lengths are scaled by the magnitude of the local slope. At any given grid node, the direction of the arrow points in the direction of the steepest descent. The two components of the vector map, direction and magnitude, are automatically generated from a single grid by computing the gradient of the represented surface. The magnitude of the arrow changes depending on the steepness of the descent (Fig. 6(a)). Two-grid vector maps use two separate grid files to determine the vector direction and magnitude. The grids can contain Cartesian or polar data. With Cartesian data, one grid consists of X component data and the other grid consists of Y component data. With polar data, one grid consists of angle information and the other grid contains length information. Overlay vector maps on contour or wireframe maps to enhance the presentation (Fig.6(b)).



(a) (b)

Fig.6. (a) A vector map of emitter discharge overlaid on a contour map, (b) Vector map overlaid on a topographical wireframe map indicating steepness of slope

Image Maps

Surfer image maps use different colors to represent elevations of a grid file. Create image maps using any grid file format: GRD, DEM, SDTS DDF, GTOP30 HDR. Surfer automatically blends colors between percentage values so we end up with a smooth color gradation over the map. We can add color anchors at any percentage point between 0 and 100. Each anchor point can be assigned a unique color, and the colors are automatically blended between adjacent anchor points. This allows us to create color maps using any combination of colors. Any color fill we choose for an image map can be used with any other image map, even if the associated grid files cover distinctly different Z ranges. Image maps can be created independently of other maps, or can be combined with other maps. They can be scaled, resized, limited and moved. We can also add color to our image map to customize it.

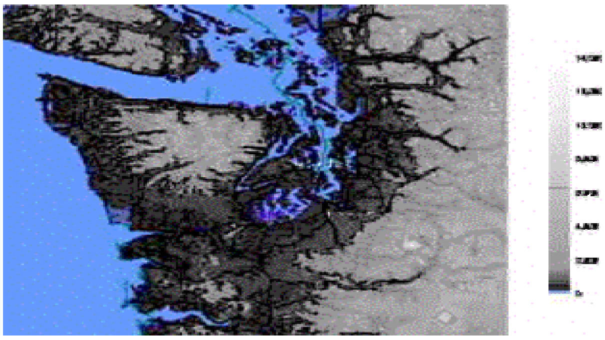


Fig.7. Example of an image map with scale indicating land, sea, rivurlets and the interface of affected land due to sea water intrusion

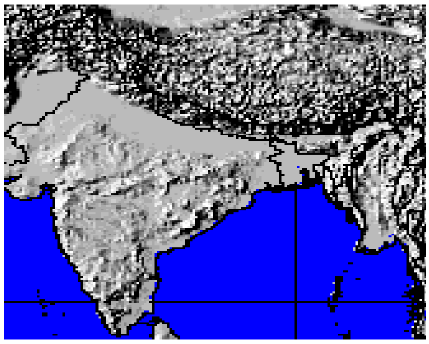


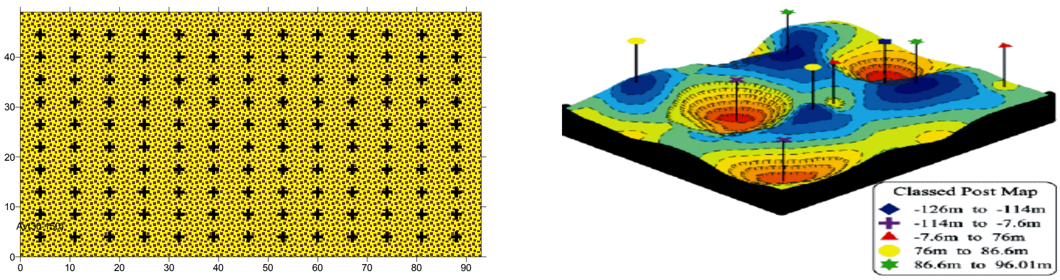
Fig.8. *S*haded relief map of India and adjoining areas indicating overlaid sea and land boundaris

Shaded Relief Maps

Surfer Shaded Relief maps create a shaded relief map from a grid [.GRD] file or USGS DEM file. These maps use different colors to indicate surface slope and slope direction relative to a user-defined light source direction. Surfer determines the orientation of each grid cell on the surface, and assigns a unique color to each grid cell. Colors on shaded relief maps are associated with light striking the surface. The light source can be thought of as the sun shining on a topographic surface. Surfer automatically blends colors between percentage values so we end up with a smooth color gradation over the map. We can add color anchors so each anchor point can be assigned a unique color, and the colors are automatically blended between adjacent anchor points. This allows us to create color maps using any combination of colors. Shaded relief maps can be created independently of other maps, or can be combined with other maps in map overlays (using the Overlay Maps command). Shaded Relief maps can be scaled, resized, limited, and moved in the same way as other types of maps in Surfer.

Post Maps

Post maps show X,Y locations with fixed size symbols or proportionally scaled symbols of any color. Surfer creates post maps independent of other maps on the page, or overlay the posted points on a base,



(a) (b)

Fig.9. (a) A post map indicating 13 x 10 plant locations in litchi field, (b) Classed post map of an area indicating class intervals spread over a sample area

contour, vector, or surface map. For each posted point, you can specify the symbol and label type, size, and angle, as the plus sign has been used in Fig.9 (a). It also creates classed post maps that identify different ranges of data by automatically assigning a different symbol or color to each data range. Fig.9 (b) shows an example of a classed post map overlaid on a wireframe map and 3D label lines have been added to lift the symbols up off the map surface.

Base Maps

Surfer can import maps in many different formats to display geographic information. We can combine base maps with other maps through map overlays, or can create stand-alone base maps independent of other maps on the page. We can load any number of base maps on a page. Base maps can be imported from DXF, GSI, BLN, SHP, LGO, BNA, GSB, DLG, LGS, MIF, E00, USGS SDTS DLG DDF, EMF, WMF, TIF, PCX, BMP, PLT, CLP, TGA, PCX, JPG, PNG, DCX, WPG, PCT, and other formats. It is easy to overlay a base map on a contour or surface wireframe map, allowing us to display geographic information in combination with the three dimensional data. Base maps in Surfer alone or overlay them on other maps.

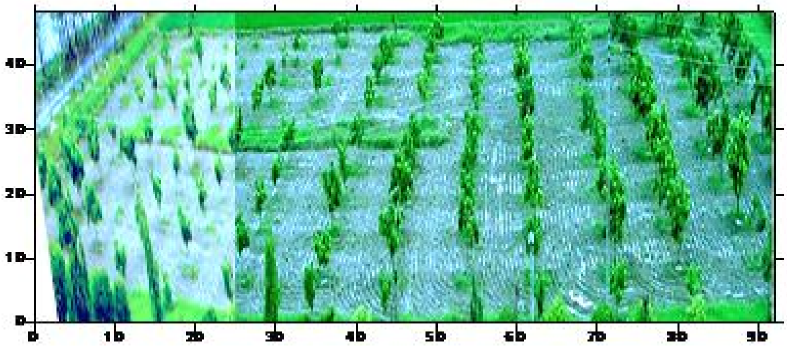


Fig.10. Example of a base map indicating 13 x 10 litchi plants in field, a jpeg photograph has been used as the background in the base map

Map Overlays

Map overlays give us a way to combine any number of contour, wireframe, vector, base, and post maps. Draping a filled contour map over a wireframe map produces the most striking display of 3D data possible. And because we can overlay any number of maps, we can show any amount of data on a single map. Using map overlays Fig.11 illustrates the contaminate spread in the Maydell mine area in the USA, this example was created by overlaying two contour maps, a basemap and a wireframe map in order to display the information.

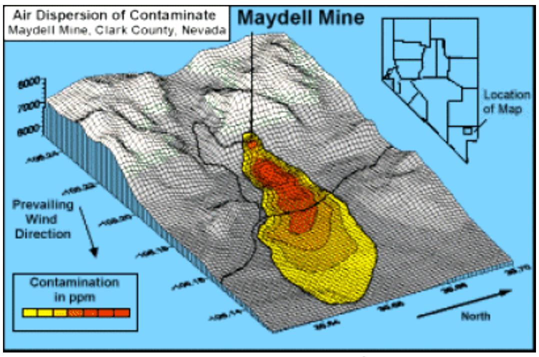


Fig.11. Example of a map overlay using contour maps of contaminants in the air, a base map showing roads/boundaries and a wireframe map of the topography

Gridding

The gridding methods in Surfer allow us to produce accurate contour, surface, wireframe, vector, image, and shaded relief maps from our XYZ data. The data can be randomly dispersed over the map area, and Surfer's gridding will interpolate data onto a grid. We have a multitude of gridding methods to choose from, so you can produce exactly the map we want. With each gridding method we have complete control over the gridding parameters. If our data are already collected in a regular rectangular array, we can create a map directly from our data. Computer generated contour maps have never been more accurate.

Variograms

Use the variogram modeling subsystem to quantitatively assess the spatial continuity of data. Variograms may be used to select an appropriate variogram model when gridding with the Kriging algorithm. Surfer uses a variogram grid as a fundamental internal data representation and once this grid is built, any experimental variogram can be computed instantaneously.

Faults and Breaklines

Faults and breaklines are specified when gridding data in Surfer. The data on one side of the fault will not be directly used to calculate grid node values on the other side of the fault. When the gridding algorithm sees a breakline, any data points that lie directly on the breakline take precedence over an interpolated value (Fig. 13). Use break lines to define streamlines, ridges, and other breaks in slopes. Unlike faults, breaklines are not barriers to information flow and the gridding algorithm can cross the breakline to use a point on the other side. The gridding methods that support faults are: Inverse Distance to a Power, Minimum Curvature, Nearest Neighbor, and Data Metrics. Breaklines are supported by: Inverse Distance to a Power, Kriging, Minimum Curvature, Nearest Neighbor, Radial Basis Function, Moving Average, Data Metrics, and Local Polynomial gridding methods.

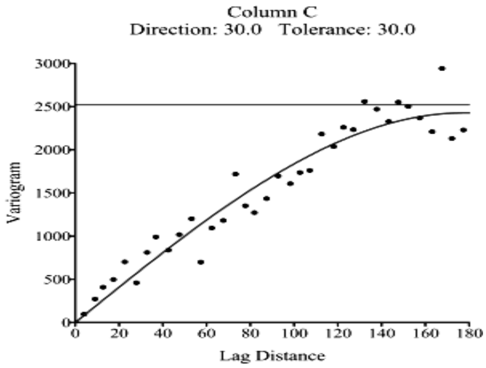


Fig.12. Variograms in Surfer to quantitatively assess the spatial continuity of data

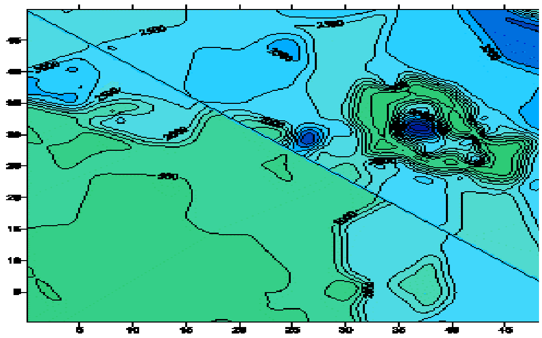


Fig.13. A contour map featuring a fault

USGS Digital Elevation Model (DEM) Files

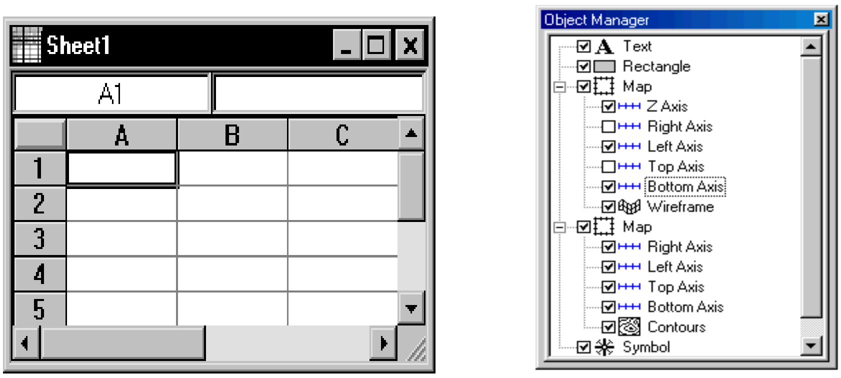
- Use DEM files with any Surfer command that uses GRD files
- Directly use the SDTS DEM file format in native form
- Display information about the DEM
- Create contour, vector, shaded relief, image, and wireframe maps from DEM files

Digitize Boundaries

- Find XY coordinates
- Automatically write coordinates to ASCII data files
- Automatically save digitized coordinates as BLN files
- Create boundary files for use with other maps
- Display different properties for base map features

Worksheet

Surfer includes a full-featured worksheet for creating, opening, editing, and saving data files. Data files can be up to 1 billion rows, subject to available memory. We can use the Windows Clipboard functions to Cut, Copy, and Paste data within the Surfer worksheet, or between applications [Fig.14 (a)].



(a) (b)

Fig.14. (a) Worksheet showing a blank active cell (b) Objective manager showing different elements

Object Manager

The object manager [Fig.14 (b)] makes the editing of any object simple. It displays all the objects in the document in an easy-to-use hierarchical tree arrangement. Select objects in the object manager to easily edit them and to show or hide them.

Additional Utilities and Features

- Export maps in DXF, SHP, BNA, BLN, MIF, GSI, GSB, EMF, WMF, CLP, CGM, TIF, BMP, JPG, TGA, PNG, PCX, DCX, WPG, PCT, formats
- Windows Clipboard support for copying maps to other applications
- Combine any number of maps on a single page
- Use the mouse to resize objects on the screen
- Define default preferences
- Define custom line styles and colors and save for use on other maps
- Add any number of text blocks at any position on the map, using TrueType fonts
- Include superscripts, subscripts and Greek or other characters in text
- Compute volumes, planar and surface areas
- Calculate residuals between data and surface
- Print to any Windows supported printer or plotter
- Easily clip boundaries or posted points to contour map limits
- Display and print subsets of completed maps, complete with subset axes
- Add arrowheads to lines
- Adjust the number of undo levels
- Use the reshape tool to edit areas and curves
- Floatable toolbars

System Requirements for *SURFER 7.0*

- PC running Windows 98, Me, 2000, XP, or higher
- 25 MB of free hard disk space
- 32 MB RAM minimum, 64 MB or higher recommended
- 800 x 600 minimum monitor resolution

Practical Exercise(s)

The most common application of Surfer is to create a grid-based map from an XYZ data file. The Grid | Data command uses an XYZ data file to produce a grid file. The grid file is then used by most of the "Map menu" commands to produce maps viz. contour maps, wireframe maps or shaded relief maps etc. (Fig.15). Post maps and base maps do not use grid files.

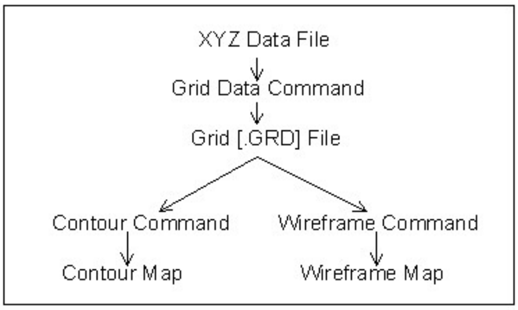


Fig.15. Relationship between XYZ data files, grid file, contour map and wireframe map

Creating an XYZ Data File

An XYZ data file is a file containing at least three columns of data values. The first two columns are the X and Y coordinates for the data points. The third column is the Z value assigned to the XY point. Although it is not required, entering the X coordinate in Column A, the Y coordinate in Column B, and the Z value in Column C is a good idea. Surfer looks for these coordinates in these columns by default.

Opening an Existing Data File

To look at an example of an XYZ data file, open TEST_PH.DAT into a worksheet window:

1. Choose the File | Open command, or click the Open tool. The Open dialog box is displayed. This allows us to select the XYZ data file to display in the worksheet window.

2. In the list of files, click TEST_PH.DAT and the name appears in the File name edit box. Click Open and the file is displayed in the worksheet window.
3. Notice that the X co-ordinate (Easting) is in Column A, the Y coordinate (Northing) is in Column B, and the Z value (Elevation) is in Column C. Although it is not required, the header text (the text in row 1) is helpful in identifying the type of data in the column, and this information is used in dialog boxes when selecting worksheet columns.

Creating a New Data File & Saving the Data File

The Surfer worksheet can also be used to create a data file. To open a worksheet window and begin entering data:

1. Choose the File | New command or click the New tool. Click the Worksheet option in the New dialog box. Click OK to display a new empty worksheet window.
2. The active cell is selected by clicking on the cell or by using the arrow keys to move between cells. The active cell is indicated by a heavy border and the contents of the active cell are displayed in the active cell edit box. When a cell is active, enter a value or text, and the information is displayed in both the active cell and the active cell edit box. The BACKSPACE and DELETE keys can be used to edit data while typing. Press the ENTER key and the data are entered into the cell. Surfer uses almost similar commands to that of MS Excel applications for spreadsheet saving and editing.

When we have completed entering all of the data:

1. Choose the File | Save command, or click the Save tool. The Save As dialog box is displayed if we have not previously saved the data file.
2. In the Save File as Type drop-down list box, choose the Golden Software Data (*.DAT) option from the list.
3. Type the name of the file into the File name edit box. Click OK and the file is saved in the Golden Software Data [.DAT] format with the file name we specified. The name of the data file appears at the top of the worksheet window.

Creating a Grid File

Grid files are required to produce a grid-based map. Grid-based maps include contour maps, image maps, shaded relief maps, vector maps, and wireframe maps. Grid files are created using the Grid | Data command. The Data command requires data in XYZ columns.

To produce a grid file from TEST_PH.DAT:

1. Choose the Grid | Data command. The Open dialog box is displayed. This allows us to select the XYZ data file used to produce the grid file.
2. In the list of files, click the file TEST_PH.DAT. The name appears in the File name edit box below the list of data files. Click Open and the Scattered Data Interpolation dialog box is displayed. Alternatively, we can double-click the data file name to display the Scattered Data Interpolation dialog box.
3. The Scattered Data Interpolation dialog box allows us to control the gridding parameters. Take a moment to look over the various options in each tab of the dialog box. Do not make changes at this time, as the default parameters create an acceptable grid file.

   - The Data Columns group under the Data tab specifies the columns containing the X and Y coordinates, and the Z values in the data file.
   - The Grid Line Geometry group under the General tab specifies the XY grid limits, the grid spacing, and the number of grid lines (also referred to as rows and columns) to include in the grid file.
   - The Gridding Method group under the General tab specifies the interpolation method to use and the parameters controlling the interpolation.
   - The Output Grid File group under the General tab specifies the path and file name for the grid file created.
   - The Generate Report option under the General tab specifies whether to create a statistical report for the data.
   - The Search tab specifies the search radius for each grid node.
   - The Faults and Breaklines tab specifies the file name that contains the fault or breakline used while gridding.

4. Click OK. In the status bar at the bottom of the window, a display indicates the progress of the gridding procedure. When gridding is complete, the grid file TEST_PH.GRD is created and Surfer beeps to indicate that the grid file has been produced. By accepting the defaults, the grid file uses the same path

and file name as the data file, but the grid file has a [.GRD] extension. If Generate Report is checked, a Data Filter Report is displayed.

Creating a Contour Map

The Map | Contour Map command creates a contour map based on a grid file. To create a contour map of the TEST.GRD file you just created:

1. Choose the Map | Contour Map | New Contour Map command, or click on the Contour tool . The Open Grid dialog box is displayed. The grid file you just created (TEST.GRD) is automatically entered in the File name edit box. Click Open, and the Contour Map Properties dialog box is displayed.
2. The default parameters in the Contour Map Properties dialog box create an acceptable contour map. To accept the default parameters, click OK. A contour map is created from TEST.GRD.
3. If we want the contour map to fill the window, choose the View | Fit to Window command. The view of the contour map is magnified so the map fills the entire plot window.

The following additional efforts can also be performed.

- Changing Contour Levels
- Changing Contour Line Properties
- Adding Color Fill between Contour Lines
- Add, Delete, and Move Contours
- Modifying an Axis
- Saving a Map
- Exporting 3D Contours

Creating a Wireframe Map

1. Choose the File | New command, or click the New tool . The New dialog box is displayed. Select Plot Document, and click OK. A new empty plot window is displayed.
2. Choose the Map | Wireframe command or click the Wireframe Map tool . The Open Grid dialog box is displayed. Choose the grid file TEST_PH.GRD from the list of files, and click OK. The Wireframe Properties dialog box is displayed.
3. Click OK to accept the defaults. A wireframe map based on TEST_PH.GRD is drawn. Wireframe maps are drawn with a Z-axis in addition to the other axes.

Changing the Orientation of a Wireframe Map

Although this example uses a wireframe map to illustrate orientation and tilt, we can perform this operation on most map types in Surfer (excluding image maps and shaded relief maps).

To change orientation and tilt:

1. Click the wireframe map and selection handles appear surrounding the map.
2. Choose the Map | 3D View command. The View dialog box is displayed. This box allows us to control the tilt, rotation, and projection type for the selected map.
3. Use the Rotation scroll bar to change the rotation to 210°. As we change the rotation angle, the graphic image in the dialog box changes to indicate the orientation.
4. Use the Tilt scroll bar to change the angle to 40°.
5. Click OK in the dialog box and the wireframe map is redrawn at the new orientation and tilt angles.

Changing the Scaling of a Wireframe Map

We can change the scaling of any map in each of the three cardinal dimensions. In this example, the Z scaling is changed, and the wireframe map becomes somewhat exaggerated in the Z dimension.

To change the Z scaling:

1. Click the wireframe map, and selection handles appear surrounding the wireframe.
2. Choose the Map | Scale command to display the Scale dialog box. This allows us to set the scaling in each of the three cardinal dimensions on the selected map. We can set scaling by entering the number of map units per inch, or by entering the length for the map in page coordinates.
3. In the Length edit box of the Z Scale group, type 3. The Map units value changes to reflect the change we made.
4. Click OK and the wireframe map is redrawn exaggerated in the Z dimension.

Adding Color Zones to a Wireframe Map

We can change the line colors of any wireframe map by applying color zones. In this example, we will change color zones gradationally and individually.

To add a color zone to a wireframe map:

1. Double-click on the wireframe map, and the Wireframe Properties dialog box is displayed.
2. Click on the Color Zones tab.
3. Click on the Line button to display the Line Spectrum dialog box.
4. Click on the Minimum Line Properties button and the Line Properties dialog box is displayed. From here, we can select the line color, style, or thickness.

5. Click on the Color button and select the color Blue. Click OK and to return to the Line Spectrum dialog box.
6. Click on the Maximum Line Properties button and change the line color to red using the steps above.
7. Click OK in the Line Spectrum dialog box.
8. In the Wireframe Properties dialog box, click the Apply Zones to Lines of Constant X and Y.
9. Click OK and the wireframe map is displayed with the gradational colors.

To change the properties of an individual Z value:

1. Double-click the wireframe map and the Wireframe Properties dialog box is displayed.
2. On the Color Zones tab, double-click the line sample for the contour level at Z = 70. The Line Properties dialog box is displayed.
3. From here we can select the line color, style, or width for the selected line. In the Width edit box, click the up arrow and change the width value to 0.030 in. Click OK and the Color Zones tab is updated to reflect the change.
4. Click OK in the Wireframe Properties dialog box and the map is redrawn. The color zone at Z = 70 is drawn with a thicker line, and is emphasized on the map.

Overlay Post and Contour Maps

When a new post map is created, it is independent of any other maps in the current plot window. When the two maps are displayed, notice that two sets of axes are also displayed, one set for each map. When we use the Map | Overlay Maps command, the two maps are combined into a single map overlay with one set of axes.

To overlay maps:

1. Choose File | Open to display the Open dialog box. Choose TEST_PH.SRF and click the Open button to display the contour map contained in TEST_PH.SRF.
2. Choose Map | Post Map | New Post Map or click the Post Map tool . The Open dialog box is displayed. This allows us to select the data file used to produce the post map.
3. In the list of files, click TEST_PH.DAT and the name appears in the File name edit box. Click Open and the Post Map Properties dialog box is displayed.
4. Click the Symbol button and the Symbol Properties dialog box is displayed.
5. Choose the filled circle symbol from the Symbol palette and click OK. The selected symbol appears in the Symbol button. This symbol appears at the posted data points on the map.
6. In the Fixed Size edit box of the Symbol Size group, specify a size of 0.09 in.
7. Click OK and the post map is drawn over the contour map. The contour map and post map are two separate maps on the page. If we look closely at the X-axis, you will notice the two sets of axis tick labels for the two maps.
8. To see the two separate maps, place the mouse pointer in the center of the maps and click. Press and hold the left mouse button and move the pointer slightly in any direction. Release the button and the two maps are offset.
9. Press the CTRL+A on the keyboard to select both maps.
10. Choose the Map | Overlay Maps command and the two maps are combined in a single overlay.

Creating a 1-Grid Vector Map

We can create a 1-grid vector map and overlay it on a wireframe map to produce a map showing the flow of water on a topographic surface.

1. Choose the File | New command, or click the New tool . The New dialog box is displayed. Select Plot Document, and click OK. A new empty plot window is displayed.
2. Choose the Map | Vector Map | New 1-Grid Vector Map command. The Open Grid dialog box is displayed. The grid file we just created (TEST_PH.GRD) is automatically entered in the File name edit box. Click Open, and the Vector Map Properties dialog box is displayed.
3. The default parameters in the Vector Map Properties dialog box create an acceptable vector map. To accept the default parameters, click OK. A vector map is created from TEST_PH.GRD.
4. Choose the Map | Wireframe command or click the Wireframe Map tool . The Open Grid dialog box is displayed. Choose the grid file TEST_PH.GRD from the list of files, and click OK. The Wireframe Properties dialog box is displayed.
5. Select Plot Lines of Constant Z. Deselect the Plot Lines of Constant X and Plot Lines of Constant Y. Click OK to accept the remaining default parameters. A wireframe map based on TEST_PH.GRD is drawn.
6. Press CTRL-A, or choose the Edit | Select All command to select both the vector map and the wireframe map. Choose the Map | Overlay Maps command to overlay the two maps.
7. If we want the map to fill the window, choose the View | Fit to Window command. The view of the map is magnified so the map fills the entire plot window.

Concluding remark

The large scale quantifiable and spatial data related to poor quality of land and water resources etc. can easily be placed and analyzed by using Surfer 7.0. This could be plotting of samples or the analysis of their spatial variation and even more. In the present chapter major maps, their features or the othor facilities that can be dealt by the SUFER 7.0 have been discussed in very brief. This chapter is designed to introduce the readers to some of Surfer's basic features. After you have completed the practical exercises, one would be able to begin creating own grids and maps.

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Fluoride and Nitrate Pollution in Groundwater and Their Implications: An Overview

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Introduction

Groundwater has been a major source for irrigation and drinking water supplies in the country as it meets about 59% and 90% demands of irrigation and drinking water, respectively. Chemical quality determines its suitability as a source of water for irrigation and drinking purposes. The composition of groundwater reflects inputs from the rain and irrigation, from water-soil and rock interactions in flow path, as well as from pollutant sources such as agriculture, land clearance, deforestation, mining, domestic and industrial wastes. Incidences of fluoride and nitrate contamination in groundwater have been reported increasingly from several parts of the country. Of late, national groundwater quality data published by the Central Ground Water Board has revealed the presence of unhealthy quantities of fluoride and nitrate in many parts of the country (CGWB, 2005). Twenty and twenty two states in the country have been affected with high fluoride and nitrate in groundwater, respectively. As such, any degradation of groundwater quality by excessive fluoride and nitrate can have serious implications on agricultural produce quality as well as on human and animal health through food chain, direct consumption or both. Due to growing concern of contamination of drinking water by fluoride and nitrate, tubewell or canal based public water supplies are being provided to ensure safe drinking water to almost each village. But such waters are often used for growing crops, leafy vegetables and fodders and affect crop produce quality in terms of higher fluoride and nitrate contents which cause fluorosis and blue baby diseases, respectively, in humans and animals upon continuous ingestion. Small amounts of total fluoride through food and water are beneficial in prevention of dental caries in children and adults whereas small amount of nitrate in water and food does not harm humans and animals. But continuous ingestion of higher amount fluoride and nitrate results in serious implications on human and animal health. Fluoride in groundwater is mostly from geogenic source while nitrate from anthropogenic source. The high concentration of fluoride is negatively correlated with calcium ion and positively with HCO_3, Na, SAR and RSC and is associated with HCO_3-Na groundwater type whereas high concentration of nitrate is associated with Cl-Na type water. This article reviews source and distribution of high fluoride and nitrate in groundwater and their association with different water types, implications on agriculture and public health, and suitable mitigation measures to contain the diseases.

Classification and Distribution of Groundwater

Groundwater quality parameters such as pH, EC, Ca, Mg, Na, K, CO_3, HCO_3, SO_4, Cl, fluoride and nitrate are determined using standard methods and procedures (APHA, 2005). The quality of groundwater is determined on the basis of the four hazards to agriculture and public health such as salinity, sodicity, alkalinity and specific ion toxicity hazard (fluoride and nitrate). Salinity hazard (total concentration of soluble salts) is the single most important criteria used for determining quality of irrigation water. It is measured in terms of electrical conductivity (EC) in deciSiemen per metre (dS/m). A water which might be suitable for irrigation on the basis of EC may not be suitable if the concentration of sodium is high and leads to sodicity hazard to soil. Its hazard is measured by sodium adsorption ratio (SAR) of the water using equation 1. Alkalinity hazard to soils is expected when irrigation water containing sum of carbonate and bicarbonate higher than the sum of calcium and magnesium ions. It is measured by residual sodium carbonate (RSC) using equation 2. It leads to development of alkali soils upon long-term irrigation. Specific ion toxicity hazard is assessed for individual ion and it is considered for fluoride ion of interest.

$$SAR = \frac{Na}{\sqrt{\frac{(Ca + Mg)}{2}}} \quad \ldots (1)$$

$$RSC = (HCO_3 + CO_3) - (Ca + Mg) \quad \ldots (2)$$

(Where, ions in the equations are expressed as milli equivalent per litre (me/l)).

Groundwater in the country is grouped into four classes viz. good, saline, saline-sodic and sodic based on EC, SAR and RSC, fluoride and nitrate and the guidelines for suitability of irrigation are given in Table 1. A national groundwater quality map for irrigation with three classes viz. saline, high SAR saline and alkali, was prepared on the basis of information available with Central Ground Water Board (CGWB) and State Ground Water Departments. Saline, saline-alkali and alkali classes of waters are termed as marginal and poor quality waters, which constitute greater parts in the arid and semi-arid states of Rajasthan, Haryana, Uttar Pradesh, Gujarat, Andhra Pradesh, Karnataka, Maharashtra, Tamil Nadu and Punjab whereas the groundwater over the major portion of the country is of good quality (Fig. 1 & Table 2). This map provides an insight into the poor quality groundwater scenario for irrigation of various states in the country. It also gives an idea to relate fluoride and nitrate contamination with these groundwater classes. However, the geochemistry of groundwater is governed by the diverse hydrometeorology, topography, drainage, geohydrology as well as anthropogenic activities like excessive surface water irrigation and overexploitation of groundwater.

Groundwater distribution depends upon the nature of geological formation, physiographic feature and climatic conditions. Interplay of geological pedological, topographical and agro-climatic conditions has a direct bearing on the chemical characteristics of groundwaters. According to an estimate by CGWB, only 58% of available ground water resources have so far been developed with highest being 178% in Delhi. The groundwater over major portion of the country is of good quality. Groundwater potential, annual draft and distribution of good, marginal and poor quality water in the states covering arid and semi-arid regions reveals that 25 to 84% waters are marginal and poor in quality (Table 2). Such waters are often associated with natural occurrence of fluoride and nitrate. Groundwater types in the states of arid and semi-arid regions vary with change of salinity (Table 3). Bicarbonates of magnesium and sodium are dominant in lower salinity waters whereas chloride and sulphate of sodium are dominant in higher salinity waters.

Table 1. Guidelines for groundwater suitability for irrigation

S No	Water quality	EC (dS/m)	SAR $(m\text{-}mol/l)^{1/2}$	RSC (me/l)	Fluoride (mg/l)	Nitrate (mg/l)
4.	Good	< 2	< 10	< 2.5	< 1.5	< 45
5.	Saline	> 2-4	< 10	< 2.5	< >1.5	< > 45
6.	High SAR saline (saline-sodic)	> 4	> 10	< 2.5	< >1.5	< > 45
7.	Alkali (sodic) water	< 4	< 10	> 2.5	< >1.5	< > 45

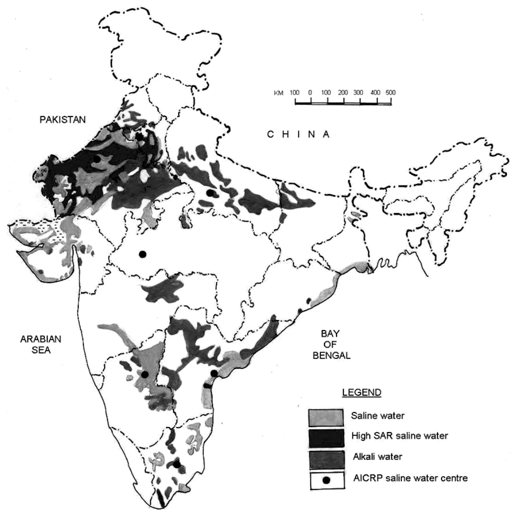


Fig. 1. Natural occurring marginal and poor quality groundwaters in India

Distribution and Association of High Fluoride in Groundwater

Most natural surface waters usually contain small amounts of fluoride and nitrate, unless polluted, but groundwater contains high concentrations of fluoride mostly from geogenic source, and seldom from anthropogenic source in industrialized areas whereas nitrate is mainly anthropogenic source, and not often from geogenic source. Fluoride content in groundwater varies from region to region and is dependent upon the factors such as amount of rainfall, air temperature, source of water recharge, type of geological formation and soil and rock minerals. When rainfall/irrigation water percolates through soils and rocks, it leaches out fluoride to groundwater. Groundwater continuously interacts with fluoride rich rock minerals within saturated zone and is contaminated with high fluoride. Natural occurrence of high fluoride in groundwater is not only a national problem but also a global problem. Globally, it has been reported in 25 countries of the world and in 12 Asian countries including China, Bangladesh, Sri Lanka, Pakistan, Iran and Iraq (WHO, 2006). In India, it is spread across different physiographical/ agro-ecological regions viz. Thar desert, Gangetic alluvial plains, Deccan plateau, etc and has been reported to occur in 203 affected districts in 20 states viz. Andhra Pradesh, Assam, Bihar, Chhattisgarh, Delhi, Gujarat, Haryana, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, Uttarakhand, West Bengal and Chandigarh. The first ever case of high fluoride groundwater in India was detected in Andhra Pradesh in the early 1930s. The higher concentration of fluoride in groundwater occurs mostly in the northwest part of the country (Fig. 2) due to fast chemical weathering and arid climate. The highest concentration of 48 mg/l has been reported from Rewari district in Haryana and the second highest (42.5 mg/l) from Muktsar district in Punjab (Table 4). In north-west India, 61 districts out of 79 (32, 4, 8 and 17 in Rajasthan, Delhi, Punjab and

Haryana, respectively) have been plagued with the problem. Of late, seventeen districts in Haryana state have been put on fluoride red alert from its geogenic source except in Panchkula, Ambala and Yamunanagar districts. The average concentrations of fluoride in irrigation groundwater in the state range between 1.52-12.80 mg/l with the highest concentration reported in the Karoli village of Rewari district. Groundwater is also contaminated with fluoride to some extent by local units/industries such as brick kiln, aluminium, steel and phosphatic fertilizers. These industries sometimes release their effluent water treated partially or fully onto the ground surface or into the groundwater. The rocks rich in fluoride are fluorspar (CaF_2) in sedimentary rocks, lime stones and sand stones), cryolite (Na_3AlFPO_6) in igneous and granite rocks, and fluorapatite ($Ca_3(PO)_2Ca(FCl)_2$) and hydroxylapatite and are the sources of fluoride.

Table 2. Groundwater potential, draft & distribution of various quality waters in arid and semi-arid region

State	Utilizable potential (m ha-m/yr)	Annual draft (m ha-m)	Distribution of groundwater (%)		
			Good	Marginal	Poor
Andhra Pradesh	3.65	1.49	68	25	7
Gujarat	1.58	1.15	70	20	10
Haryana	0.93	0.95	37	**8**	**55**
Karnataka	1.59	1.07	62	12	26
Madhya Pradesh	3.72	1.71	75	10	15
Punjab	2.38	3.12	59	22	19
Rajasthan	1.16	1.30	16	**16**	**68**
Tamil Nadu	2.31	1.77	#	#	#
Uttar Pradesh	7.64	4.88	32	**22**	**46**
Total:	24.96	17.44			

Note: # denotes data not available

Table 3. Ionic types in groundwaters in the northwest part of the country

EC (dS/m)	Punjab	Haryana	Rajasthan	Gujarat	U.P.
0-1.6	HCO_3-Cl-SO_4	HCO_3-Cl-SO_4	HCO_3-Ca-Mg	HCO_3-Ca-Mg	HCO_3-Ca-Mg
1.6-5	Cl- HCO_3- SO_4	Cl- HCO_3- SO_4	HCO_3-Cl	Cl- HCO_3	Cl-HCO_3- SO_4
	SO_4-Cl- HCO_3	SO_4-Cl- HCO_3	Cl-SO_4- HCO_3		
5-15	--	Cl- SO_4-Na	Cl- SO_4-Na	Cl- SO_4-Na	Cl-SO_4- HCO_3
			SO_4-Cl		
>15	--	Cl- SO_4-Na	Cl- SO_4	Cl- Na	Cl- SO_4-Na

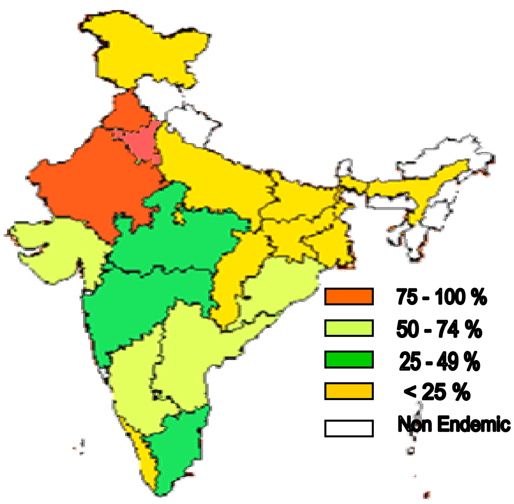


Fig.2. Area affected in state with natural occurrence of high fluoride (%) in the country

Table 4. Highest concentration of fluoride in groundwaters of affected states in decreasing order

Sl. No.	State (district)	Highest conc (mg/l)	Sl. No.	State (district)	Highest conc. (mg/l)
1.	Haryana (Rewari)	48.0	8.	Orissa (Koraput)	9.2
2.	Punjab (Muktsar)	42.5	9.	Bihar (Gaya)	8.1
3.	Rajasthan (Nagaur)	40.0	10.	Karnataka (Kolar)	7.8
4.	NCT (Delhi)	32.5	11.	Uttar Pradesh (Kannauj)	7.7
5.	Assam (Karbi Anglong)	23.4	12.	Andhra Pradesh (Krishna)	7.1
6.	West Bengal (Birbhum)	14.5	13.	Tamil Nadu (Erode)	7.0
7.	Gujarat (Mehsana)	12.9			

(Note: Conc. stands for concentration)

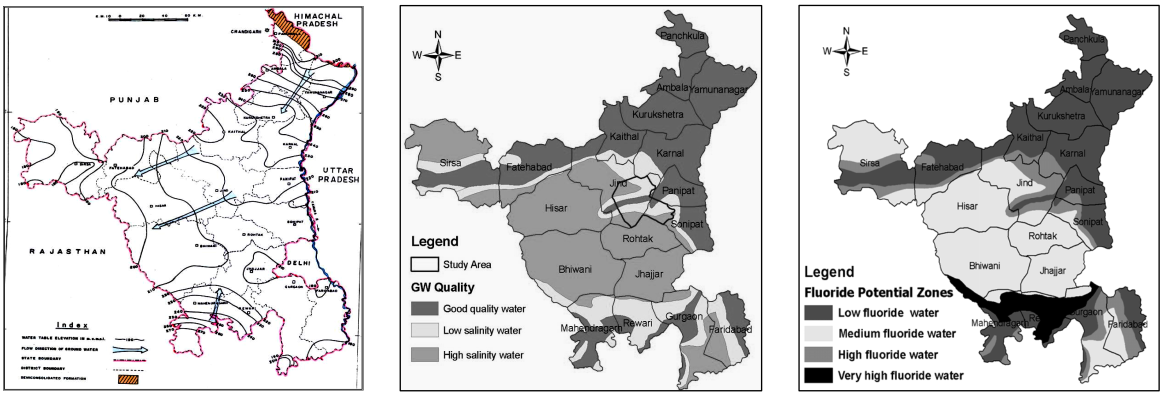
Geochemistry of groundwater is determined by the direction of groundwater flow in order to target the distribution of high fluoride areas and their association with different groundwater types, unless contaminated. The most of the Haryana state is covered under arid and semi-arid region except Panchkula, Ambala and Yamunanagar being sub-humid. The geologic formations of the state belong to three main groups viz. pre-cambrian rocks represented by Aravalli and Delhi systems in the south, tertiary rocks represented by Tundapathar series to the Shivalik rocks in the north, and quarternary alluvium. Quarternary alluvium occupies about 97 % of the area of the state. The north and north eastern parts and southern part of the state have higher elevation and the state has bowl shape topography with flat areas in south-central part creating a scenario of saline soils and groundwaters. Groundwater elevation contours in the state follow the topography. The highest water table contour is 496.1 m above the mean sea level in Panchkula district while the lowest is 176 m above the mean sea level in Sirsa district. Groundwater has three major flow directions viz. north to south, north-east to south-west and south south-west to north north-east (Fig. 3a). All these directions of flow result in natural ground water flow towards parts of Rohtak, Bhiwani and Hisar districts. This ultimately causes sluggish ground water movement resulting in large water logged areas.

In the northern part of the state, the groundwater is of good quality (EC< 2 dS/m, SAR < 10 (m mol/l)$^{1/2}$ and RSC < 2.5 me/l) and of HCO_3-Ca type (Fig. 3b). This type of groundwater is seldom rich in fluoride due to high concentrations of calcium and magnesium ions. Groundwater in parts of Sonipat, Jind, Karnal, Kaithal, Fatehabad and Sirsa districts is of low salinity (EC < 4, SAR < or > 10 and RSC either 2.5-4.0 or > 4) and of Na-HCO_3 type. This type of water also occurs in southern part of Bhiwani and eastern parts of Mahendragarh, Rewari, Gurgaon and Faridabad districts. High fluoride contents have mainly been associated with HCO_3-Na type of groundwater which has relatively low calcium and magnesium and high Na and HCO_3 concentrations. Such water types usually have high pH values above 7. This information on chemical composition of groundwater can be used as an indicator to identify areas of potential high fluoride problems. The composition of groundwater changes progressively along a flowpath from HCO_3-Na zone to Cl-Na zone ($HCO_3 \rightarrow HCO_3 + SO_4 \rightarrow SO_4 + HCO_3 \rightarrow SO_4 + Cl \rightarrow Cl$). The groundwater in parts of Rohtak, Jhajjar, Bhiwani and Hisar districts is of high salinity (EC either 2-4 or > 4, SAR < or > 10 and RSC < 2.5) and of Na-Cl type. This type of water contains moderate level of fluoride due to high sodium and low bicarbonate concentrations. Subsequently, four potential zones of fluoride have been identified (Fig. 3c) on the basis of groundwater types and their association with natural fluoride.

Implications of High Fluoride on Agriculture and Public Health

Agricultural crops viz. food, vegetables and fodders are often grown with fluoride rich groundwaters. High fluoride is tolerated by the most crops and does not affect crop germination and yield and soil properties, but the fluoride is up-taken excessively and accumulated the unhealthy quantities in plant parts which join the food chain that poses a serious threat to human and animal health. The fluoride content of food, vegetables and fodders vary from northern part to southern part of the state. Only in southern districts, significant amount is contributed from food whereas in the majority of endemic areas, the main contribution comes from drinking water. In non-endemic areas, all food and vegetables contain permissible quantities of fluoride and the total daily intake through an average human diet is small whereas in endemic areas, the fluoride content of food and vegetables are high. Therefore, the contribution of food to the total daily intake of fluoride is also high.

Fluoride content from all sources determines the daily human intake of fluoride. There is no safe prescribed limit of fluoride for irrigation water, food, vegetables and fodders by the national or world health agencies. Therefore, total daily safe fluoride intake for an average adult is suggested and it is 6.0 to 8.0 mg per day from all the sources (Raja Reddy & Deme, 2000). It is less for children and those affected with kidney disease. Staple diets rich in sorghum, ragi or bajra grown in south-western districts of the state contain high fluoride which aggravates endemicity of fluorosis. Fluoride content in food and vegetables was found to be moderate in the state, being the highest in Rajasthan and the lowest in Punjab. Within food crops, cereals, pulses and legumes retain the maximum fluoride content and the nuts and oil seeds also contain relatively higher fluoride content (Table 5). Tea and black salt are most commonly used and have exceptionally high fluoride contents which vary from 122-260 mg/l or more in different brands. Each cup of tea may supply 0.3-0.5 mg of fluoride. The daily intake of fluoride in endemic regions of the country varies from 10 to 35 mg from winter to summer months.



(a) (b) (c)

Fig.3. Groundwater flow direction (a), groundwater quality (b), and four potential zones of fluoride (c) in Haryana

Table 5: Fluoride content of food, vegetables and other edible items

S No	Food item	Fluoride (mg/kg)	S No	Food item	Fluoride (mg/kg)
1.	Wheat	4.6	13.	Carrot	4.1
2.	Rice	5.9	14.	Mint	4.8
3.	Maize	5.6	15.	Tea	60 - 112
4.	Gram	2.5	16.	Coconut water	0.32 - 0.6
5.	Soybean	4.0	17.	Coriander	2.3
6.	Cabbage	3.3	18.	Garlic	5.0
7.	Tomato	3.4	19.	Ginger	2.0
8.	Cucumber	4.1	20.	Turmeric	3.3
9.	Ladyfinger	4.0	21.	Rock salts	200–250
10.	Spinach	2.0	22.	Areca nut (supari)	3.8–12.0
11.	Brinjal	1.2	23.	Beetle leaf (pan)	7.8–12.0
12.	Potato	2.8	24.	Tobacco	3.2–38

(Source: Adapted from Susheela, 2003)

Fluorosis, caused by excessive intake of fluoride rich food, drinking water or both, is a public health disease. It is locally known as *bankapatti* in Rajasthan, *lunjpunj* in UP, *wah* in Gujarat, and *genu valgum* in Madhya Pradesh and Andhra Pradesh. It is a neglected disease in public health domain and has no treatment, but can be cured easily with a few interventions at individual level. Excess intake of fluoride can lead to three tyeps of fluorosis viz. dental, skeletal and neurological. Fluoride intake dependent upon consumption of food and drinking water is determined by various factors such as body size, physical activity, food habits and variations in air temperature and humidity. Since India being a tropical country, the daily fluoride intake is very high in the affected areas. Farmers and farm labourers eat nutritionally poor or unbalanced diet and drink lot of high fluoride water and are at risk of developing manifestations of fluorosis. In the country, 25 million population are actually affected with fluorosis and 66 million people are at risk including 6 million children in the 6-14 years age group in the country (UNICEF, 1999). Fluorosis in Haryana is taking its toll with a sharp rise in the number of people with dental fluorosis. The cases of skeletal fluorosis in form arthritis are on the rise in the state and are further aggravated by fluorosis. Due to growing concern of high intake of fluoride through drinking water, tubewell or canal based public water supply scheme are being commissioned to almost each village to supply safe drinking water under Rajiv Gandhi Drinking Water Supply Scheme. This has reduced fluoride intake through drinking water substantially. People in villages still uses drinking water from their private tubewells and hand pumps which pose threat to human health. Affluent farmers can afford to install deflouridation system to get low fluoride water or mineral water whereas poor farmers and labourers can not afford and will be affected most with the disease sooner or later. All children living in endemic areas may have developed dental fluorosis or would develop it soon. Those exposed to excess ingestion of fluoride beyond the age of 14 years would develop advance stages of fluorosis. Dental fluorosis affects the entire dental structure, resulting in intense pain and decay of teeth with chalky and friable nature. Skeletal fluorosis is formed due to higher intake of total fluoride (>10 mg/day) through diet and water and its symptoms are body pain, lethargy, tingling sensations, abdominal breathing and bending of bones hindering natural movements.

Remedial Measures

Fluorosis can not be treated but can easily be prevented by taking simple interventions. In case of dental fluorosis, a mass awareness campaign is needed to let people know the problem and possible solutions at their end. Nutritional enhancement of the diet by high organic calcium, magnesium and vitamin-C supplementation needs to be provided to children and adults to prevent further damages from fluorosis. Fluoride rich food, vegetables and other edible items should be avoided. Besides this, an alternate source of fluoride safe drinking water also needs to be provided. In case of skeletal and crippling forms of fluorosis, it is important to assess daily intake of fluoride from both food and water. Fluoride rich food, vegetables and drinking water, immediately be discontinued. The food with rich fluoride content such as sorghum, ragi or bajra and tea be avoided as far as possible to control the disease. A diet with high content of organic calcium, magnesium and vitamin-C needs to be given. An alternate source of safe drinking water from canal, rainwater harvesting tank or defluoridated water employing one of fluoride removal techniques (adsorption and ion exchange, precipitation, electro-chemical and membrane technique) needs to be provided to the affected people in the village. The Nalgonda (precipitation) technique at village level needs to be installed through panchayat institution. In long term, fluoride rich groundwaters may be diluted by enhancing groundwater recharge from rainfall and canal water through appropriate recharge structures. The incidences of l fluorosis are less where people have milk and dairy based food habit. Animals ingested with fluoride rich fodders and forages suffer from various stages of fluorosis viz. dental and skeletal. High fluoride can also cause the uptake of food from the paunch to decline and it can disturb the development of claws and causes low birth-weights.

Distribution and Association of High Nitrate in Groundwater

Most natural surface waters usually contain small amounts of nitrate, unless polluted, but groundwater contains high concentrations of nitrate mainly from anthropogenic source, and seldom from geogenic source in some states. Nitrate in groundwater varies from region to region and may be produced by excessive inputs from anthropogenic sources such as nitrogenous fertilizer, animal and domestic wastes in most cases but few cases of geogenic sources of nitrates are also reported. Concentrations may also be increased by evaporation under hot and arid conditions. The high concentrations were accompanied by high salinity and may reflect evaporative concentration processes rather than pollutant inputs. Groundwater continuously interacts with nitrate rich rock minerals within saturated zone and is contaminated with high nitrate. In the country, incidences of high nitrate concentration have been reported to occur in 148 districts of 22 states (Table 6) viz. Andhra Pradesh, Assam, Bihar, Chhattisgarh , Delhi , Gujarat , Haryana, HP , J & K, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, Uttarakhand, West Bengal and Chandigarh.

A recent study indicated that nitrate in groundwater in the country was in the range 0.1–1870 mg/l with an average of 65 mg/l whereas high nitrate has been reported from the northwest part of the country. In Punjab and Haryana, nitrate level in groundwater ranges from level <25 mg/l to 1800 mg/l whereas in Delhi, it ranges from <20–1600 mg/l (Datta, 2005). In Haryana, twelve districts viz. Ambala, Bhiwani, Jind, Gurgaon, Faridabad, Hissar, Sirsa, Karnal, Kurukshetra, Rohtak, Sonipat and Mahendragarh have been affected with excess nitrate concentration. The Mandori village in Sonipat district has nitrate content as high as 900 mg/l in groundwater. The districts affected with high nitrate in the various states are given in. A significant correlation exists between amount of nitrogenous fertilizers applied per unit area per year and nitrate concentration of tubewell waters of Punjab (Singh, 2002) In Haryana, the main causes attributed to nitrate contamination are improper and excessive use of chemical fertilizers to crops, indiscriminate disposal of human and animal waste on land, discharges from municipal sewage, industries, barn-yard and silo wastes, and decaying plant debris. Occurrence of high nitrate is associated with Cl-Na groundwater types in the states of arid and semi-arid regions. Nitrate concentration is influenced by geogenic source of potassium nitrate occurring in southern Haryana and other states. Lower concentration of nitrate is associated with bicarbonates type groundwaters. Due to its high mobility of nitrate, it also can leach into groundwater.

Implications of High Nitrate on Agriculture and Public Health

Nitrate in irrigation water is beneficial to plants but high nitrate content in water results in vigorous plant growth, delayed crop maturity, increased succulence resulting in lodging, poor grain filling and shriveled grains. At the same time, plant accumulates nitrates in plant tissues, particularly in their leaves and stems when high nitrates are present in soil through irrigation water than the required amount. Ingestion of nitrate itself in small amounts is not toxic to humans and animals. In high amounts, nitrate is a harmful constituent of food and water. If people or animals ingest nitrate rich food and leafy vegetables (Table 7) and water, it causes methemoglobinemia in infants (blue baby disease) and nitrate poisoning in adults and animals.

Infected persons show blueness around the mouth, hands, and feet. Diagnosis can be confirmed by spectrophotometric analysis of blood samples. Patients may show asthenia (loss of muscular strength), dizziness, headache, drowsiness, dyspnoea, chest pain, nausea, diarrhoea and troubled breathing. In extreme cases, there is marked lethargy, stupor, an increase in the production of saliva, loss of consciousness and seizures and ultimately, the patient may collapse.

Table 6: Districts affected by nitrate contamination in groundwater in the country

Sl. No.	State	Affected districts	Name of districts affected by excess nitrates (over 45 mg/l)
1.	Andhra Pradesh	10	Prakasam, Khammam, Nellore, Nalgonda, Nizamabad, Guntur, Kurnool, Karimnagar, Mahaboobnagar & Vijaywada
2.	Assam	1	Lakhimpur
3.	Bihar	6	Gaya, Patna, Nalanda, Nawada, Bhagalpur & Banka
4.	Chhattisgarh	1	Raipur
5.	Delhi	2	West, & Southwest
6.	Gujarat	8	Amreli, Banaskantha, Bhavnagar, Gandhinagar, Jamnagar, Junagarh, Kachchh & Mehsana
7.	Haryana	12	Ambala, Bhiwani, Faridabad, Gurgaon, Hisar, Jind, Kurukshetra, Karnal, Mahendragarh, Rohtak, Sonipat & Sirsa
8.	HP	1	Una
9.	J & K	1	Kathua
10.	Jharkhand	2	Palamu & Sahebganj
11.	Karnataka	12	Bijapur, Bangalore, Belgaum, Bellary, Chitradurga, Dharwar, Gulbarga, Hassan, Kolar, Mandya,Raichur & Shimoga
12.	Kerala	5	Idukki, Kottayram Palghat, Pathanamithitta & Mallapuram
13.	Madhya Pradesh	2	Sehore & Ujjain
14.	Maharashtra	23	Ahmednagar, Amravati, Akola, Aurangabad, Bhndara, Beed, Buldana, Chndrapur, Gadchiroli, Dhule, Jalgaon, Jalna, Kolhapur, Latur, Nagpur, Nanded, Osmanabad, Pune, Sangli, Satara, Sholapur, Thane & Wardha
15.	Orissa	14	Angul, Bargarh, Bolangir, Boudh, Cuttack, Ganjam, Jagatsinghpur, Kalahandi, Keonjhar, Malkangiri, Nawapara, Rayagada, Sambalpur & Sundargarh
16.	Punjab	5	Bhatinda, Faridkot, Ferozepur, Patiala, Sangrur
17.	Rajasthan	16	Ajmer, Alwar, Bharatpur, Bikaner, Bundi, Churu, Dholpur, Ganganagar, Jaipur, Jaisalmer, Jhalawar, Jhunjhunu, Jodhpur, Nagaur, Sawai Madhopur & Udaipur
18.	Tamil Nadu	7	Coimbatore, Periyar, Salem, NA Ambedkarnagar, T Kottabomman, Dindigul –Anna & VR Padayachi
19.	Uttar Pradesh	9	Aligarh, Agra, Banda, Etawah, Jhansi, Kanpur, Mainpuri, Mathura & Pilibhit
20.	Uttarakhand	1	Nainital
21.	West Bengal	9	Uttar Dinajpur, Malda, Birbhum, Murshidabad, Nadia, Bankura, Purulia, Howrah & Medinipur
22.	Chandigarh	1	Chandigarh
	Total	148	

Table 7. Nitrate content in crops, vegetables and fruits

S No	Crop/item	Nitrate content (mg/kg)
1.	Cereals	20-67
2.	Pulses	39-114
3.	Leafy vegetables	30-270
4.	Roots and tubers	31-2043
5.	Spices and pickles	145-4680
6.	Milk	1000 microgram/litre

Remedial Measures

Mild cases of blue baby disease or nitrate poisoning do not require immediate treatment. Nitrate rich crops, leafy vegetables, fruits and water should be avoided. The root and tubers, and spices particularly contain quite high nitrate and must be avoided. Affected patients usually recover within 24 to 72 hours. Severely affected person requires to be admitted to public health centres. Dietary intake of enhanced vitamin C and E is beneficial to help maintain lower levels of nitrate in blood. Farmers should ensure that food and vegetables are safe from high nitrate levels and they should be advised to adopt integrated nutrient management for growing food crops and vegetables with balance fertilizer application to the crop to reduce the nitrate content of crops. Nitrate can be removed from the drinking water by adopting one of three techniques viz. distillation, reverse osmosis and ion exchange. Nitrate water can be used for irrigation of leafy vegetables after some remediation by removing excessive nitrate ion. Remediation techniques include water table adjustments to increase denitrification, bioremediation, etc. Nitrate in groundwater can be diluted by enhancing recharge from rainfall and canal water.

Conclusions

Occurrence of high fluoride and nitrate in groundwater is a national problem and is further aggravating due to overexploitation of groundwater and excessive application of fertilizers, unsafe disposal of domestic and industrial effluents, etc. The high fluoride from geogenic source is mainly associated with HCO_3–Na type of groundwater whereas high nitrate is associated with Cl-Na type waters occurring in different parts of the country. Intake of such waters for drinking purpose has been reduced by providing safe drinking water through dedicated national drinking water mission programme. Irrigation of food, leafy vegetables and fodders with such waters results in unhealthy accumulation of fluoride and nitrate in agricultural produces which ultimately affect human and animal health leading to fluorosis and blue baby diseases, respectively. Rural people need to be sensitized of these diseases and their symptoms through mass awareness and action programmes at government and community level. The adoption of short-term remedial measures suggested with people participatory could address these problems and will save million of children and adults from suffering of fluorosis, blue baby diseases or both. Adoption of long-term remedial measures such dilution of fluoride and nitrate by enhancing groundwater recharge from rain and canal waters are necessary to solve these problems.

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Wastewater Use in Agriculture: Some Issues

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Introduction

Water is vital for life. In some societies water has special social, cultural and religious values, which distinguish it from other natural goods. This is quite true for India as rivers/ponds are not only worshipped but major festivals of India are celebrated on the banks of surface water resources. In most religious functions, water has special significance. Besides, everyone in one way or the other uses water and thus is a necessary component of the domestic, agricultural and industrial sectors.

It is said that water is abundant globally but is scarce locally. Moreover, only a miniscule fraction of the water available on the earth surface is used by the mankind other being too saline to use or is locked at places and in forms that man is unable to make its use under the current technologies available to him (Table 1). Although, agriculture is the major user of water claiming more than 70 per cent of water withdrawn from rivers, yet it is unable to compete economically for scarce water resource as industry and domestic sectors can pay more for water and can earn more per unit of water used. But food security being closely linked with water availability to agriculture, it will continue to be the major beneficiary of water resource development. At the same time, the sector would be increasingly called upon to use waters of low quality. Although both the quantity and the quality aspects of water are important but in this paper we review national scene with respect to water supply as related to its quality and its use in crop production.

Table 1. Estimate of global water distribution

Water source	Water volume (cubic kilometers)	Percent of freshwater	Percent of total water
Oceans, Seas, & Bays	1,338,000,000	--	96.500
Ice caps, Glaciers & Permanent Snow	24,064,000	68.7	1.740
Groundwater	23,400,000	--	1.700
Fresh	10,530,000	30.1	0.760
Saline	12,870,000	--	0.940
Soil Moisture	16,500	0.05	0.001
Ground Ice & Permafrost	300,000	0.86	0.022
Lakes	176,400	--	0.013
Fresh	91,000	0.26	0.007
Saline	85,400	--	0.006
Atmosphere	12,900	0.04	0.001
Swamp Water	11,470	0.03	0.0008
Rivers	2,120	0.006	0.0002
Biological Water	1,120	0.003	0.0001
Total	1,386,000,000	-	100.0000

Source: Gleick, 1996

Water Quality

In agriculture or for that matter in any sector, there is no such thing as "pure" water because even the rainwater will have many impurities as it falls through the air to the earth or flows on the surface of the earth or moves underground to meet the groundwater. The rainwater usually takes on the characteristics of the materials it has encountered on its way till it meets its final place of storage. Generally speaking, surface water doesn't have enough impurities that would affect the utilization of these water for most practical purposes in domestic, industrial or agriculture. But on the other hand, groundwater due to excessive dissolution of salts could turn saline/sodic and may become unfit for use in domestic, industrial or even agriculture unless managed with care. Such groundwaters are generally referred as naturally occurring wastewaters and are a characteristic of the arid and semi-arid regions where groundwaters are usually saline/sodic in nature. Saline and sodic water contains salts that impair plant growth but rarely contains pathogens. However, short and long-term use of such water can lead to soil salinization/sodication. Quality of water is usually defined with respect to specific use (Table 2). These are only preliminary guidelines but more specific and detailed guidelines are also available for such uses or some other uses such as land disposal and disposal in the water bodies. Central Soil Salinity Research Institute has developed detailed guidelines for use of saline/sodic including toxic groundwater for irrigation. Any water to be useful to the society has to have the parameters characterizing it, in a desirable proportion depending upon its use.

Table 2. Use based classification of surface waters in India

Designated Best Use	Class of water	Criteria
Drinking Water Source without conventional treatment but after disinfection	A	1. Total Coliforms Organism MPN/100ml shall be 50 or less 2. pH between 6.5 and 8.5 3. Dissolved Oxygen 6mg/l or more 4. Biochemical Oxygen Demand 5 days 20oC 2mg/l or less
Outdoor bathing (Organized)	B	1. Total Coliforms Organism MPN/100ml shall be 500 or less 2. pH between 6.5 and 8.5 3. Dissolved Oxygen 5mg/l or more 4. Biochemical Oxygen Demand 5 days 20oC 3mg/l or less
Drinking water source after conventional treatment and disinfection	C	1. Total Coliforms Organism MPN/100ml shall be 5000 or less 2. pH between 6 to 9 3. Dissolved Oxygen 4mg/l or more 4. Biochemical Oxygen Demand 5 days 20oC 3mg/l or less
Propagation of wild life and fisheries	D	1. pH between 6.5 to 8.5 2. Dissolved Oxygen 4mg/l or more 3. Free Ammonia (as N) 1.2 mg/l or less
Irrigation, Industrial Cooling, Controlled Waste disposal	E	1. pH between 6.0 to 8.5 2. Electrical Conductivity at 25oC dS/m Max.2.25 3. Sodium absorption Ratio Max. 26 4. Boron Max. 2mg/l

Source: CPCB, 2008

Domestic and Industrial Wastewater

Besides the naturally occurring saline/sodic ground waters, other kinds of wastewaters from domestic and industrial sectors have received prominence mainly because of shrinking water resources across the globe as well as their nuisance value in polluting the surface and groundwater resources. In the real term, the term "wastewater" is a broad, descriptive term that designates liquids and waterborne solids from domestic, industrial or commercial uses that have been adversely affected in quality by anthropogenic influence and have limited applications for use unless appropriately treated/managed.

Although not separable, two categories of wastewaters i.e. domestic wastewaters and industrial wastewaters have emerged mainly because of major differences in their quality. Domestic wastewaters originate principally from domestic, household activities but will usually include waters discharged from commercial and business buildings and institutions. Nearly 80 % water supplied to domestic purposes drains back into municipal sewer system. Surface and storm waters may also be present. Domestic wastewaters are usually of a predictable quality and quantity. These domestic wastewaters are sometimes sub-grouped as dark and grey depending upon the source in the household. Human wastes consisting mostly of feces and urine, which becomes part of the wastewater through toilet flushing is called dark water. On the other hand, household wastes derived from home laundry operations, bathing, kitchen wastes, from washing and cooking foods and dishwashing etc. is termed as grey water. The grey water will contain synthetic detergents but the bacterial contamination would be to a much lesser degree. Whereas grey water would pose minimal problems in its reuse particularly in agriculture such as irrigating lawns and kitchen gardens, the disposal assumes significance because dark water is usually discharged with grey water.

Characteristics of Domestic Wastewater

Domestic wastewater is a turbid liquid containing solid material in suspension representing a very small part usually less than 0.1 percent by weight of the total discharge. Initially, it is gray in color with unpleasant odor. Under certain conditions, as a result of biochemical changes caused by bacteria, the color changes from gray to black. At this time, water may smell foul and give unpleasant odor. Black solids appear on the surface or throughout the liquid. The parameters Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are usually associated with these kinds of wastewaters. BOD is a measure of the quantity of dissolved oxygen in milligrams per liter necessary for the decomposition of organic matter by microorganisms such as bacteria. COD is a water quality measure used not only to measure the amount of biologically active substances such as bacteria but also biologically inactive organic matter in water. It is the oxygen equivalent of the total organic matter in a water sample that is susceptible to oxidation by a strong chemical oxidant such as dichromate. Raw sewage has BOD around 200 ppm and COD 400 ppm. The ratio of COD/BOD describes organic toxicity because COD is a measure of total (toxic and nontoxic) organics and BOD of nontoxic organic load. Aim of any sewage treatment is to reduce this ratio.

Characteristics of Industrial Wastewater

Industrial wastewaters originate from manufacturing processes, are usually of a more variable character and are often more difficult to treat than domestic wastewaters. Industrial wastewaters vary widely in composition; strength, flow and volume, depending on the specific industry or manufacturing establishment. Industrial wastewaters must be examined on an industry-by-industry basis. However, in general domestic and industrial wastewaters have the same sewage system causing operational problems in the field or at treatment plants. Industries which produce significant volumes of wastewaters include paper and fiber plants, steel mills, refining and petrochemical operations, chemical and fertilizer plants, meat packers and poultry processors, vegetable and fruit packing operations and many more.

Urban wastewater might contain a variety of pollutants: salts, metals, metalloids, pathogens, residual drugs, organic compounds, endocrine disruptor compounds, and active residues of personal care products. Any of these components can harm human health and the environment. While farmers would suffer harmful health effects from contact with wastewater, the consumers are at risk from eating vegetables and cereals irrigated with wastewater.

Assessment of Wastewaters

The source wise wastewater generation in India reported in Table 3 reveals that large amounts of wastewater are generated per day and have the potential of use in agriculture.

Table 3. Source-wise wastewater generation in India

Source of generation	Amount (Million liter per day)	Treated (%)
Domestic	29000	21.3
Industrial	--	--
Thermal Power Plants	73,975	NA
Others	16,348	NA

Water Quality Monitoring Programmes

The main objectives of a water quality monitoring programme are:

- To assess the quality of water for use in different sectors/uses.
- To assess the nature and extent of pollution in different water bodies or their parts.
- To identify the sources of pollution for rational planning of pollution control strategies and their prioritization or to assess the effectiveness of pollution control measures already in place.
- To evaluate water quality trend over a period of time.
- To assess assimilative capacity of a water body thereby reducing cost on pollution control.
- To understand the environmental fate of different pollutants.
- To provide data to various organizations for use in planning health strategies

CPCB alone has 784 monitoring sites out of which at 254 sites water quality is monitored monthly, at 349 quarterly, at 178 half yearly and at 3 yearly. CWC monitors water quality at 371 stations, bi-monthly at 164, monthly at 179 and thrice in a month at 28. CGWB monitors 15355 sites yearly and State Ground Water Departments monitor 32826 sites yearly. NRCD monitors 110 sites on monthly basis. Besides, site and project specific measurements are made by a host of other field and research organizations in the country.

The existing water quality-monitoring network of various agencies is relatively well designed and covers many of the water quality problems and parameters in the country (Table 4) yet it is not adequate to cover many issues such as monitoring of ground water pollution; monitoring of trace pollutants like toxic metals and pesticides; and to identify the causes such as changes in land use, water use, hydrological conditions due to abstractive uses of water, growth of urban population, growth in industrialization, increase in agriculture activities, increase in use of chemicals in agriculture; and increase in use of chemicals at household level. Thus, monitoring of ground water should be addressed especially with reference to fluoride, nitrate, salinity, toxic metals and pesticides. For example, districts and villages affected by geogenic source of arsenic increased over the years and had spread spatially (Table 5). One of the main reasons attributed is to the decline in the water table yet no firm cause has so far been identified. Moreover, it may be prudent to avoid duplication and pool this data on appropriate maps to prepare first approximation of state of water quality of the surface and groundwater in India. An exercise in association with CGWB was made by CSSRI, Karnal that resulted in first approximation map of naturally occurring wastewaters of India. \similar state wise map of Andhra Pradesh and Karnataka has been brought out by AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture with its headquarter at Karnal and having 8 centers in 7 states of India.

Table 4. Parameters being monitored under National Water Quality Monitoring Programme

Field Observations (7)	Core Parameters (9)	Trace Metals (9)
Weather	PH	Arsenic, µg/L
Approximate depth of main	Temperature	Nickel, µg/L
stream / depth of water table	Conductivity	Cadmium, µg/L
Colour and intensity	Dissolved Oxygen	Zinc, µg/L
Odour	BOD	Copper, µg/L
Visible effluent discharge	Nitrate – N	Mercury, µg/L
Human activities around	Nitrite – N	Lead, µg/L
station	Fecal Coliform	Iron (Total) , µg/L
Station detail	Total Coliform	Chromium (Total) , µg/L
General Parameters (19)	Pesticides (7)	Bio-Monitoring for Rivers/lakes (3)
Turbidity, NTU	BHC (Total), µg/L	Saprobity Index
Sodium, mg/L	DDT (Total), µg/L	Diversity Index
Phenolphthalein Alkalinity, as $CaCO_3$	Endosulphan, µg/L	P/R Ratio
Total Dissolved Solids, mg/L	Dialdrin, µg/L	
Total Alkalinity, as $CaCO_3$	Aldrin, µg/L	
Total Fixed Dissolved Solids, mg/L	Carbamate, µg/L	
Chlorides, mg/L	2.4-D, µg/L	
Total suspended Solid, mg/L		
COD, mg/L	Alpha BHC, Beta BHC,	
Phosphate	Gama BHC	
Total Kjeldahl - N, as N mg/L	(Lindane), OP-DDT, PP-	
Boron, mg/L	DDT, Alpha	
Ammonia - N, as N mg/L	Endosulphan, Beta	
Magnesium, as $CaCO_3$	Endosulphan, Aldrin,	
Hardness, as $CaCO_3$	Dieldrin, 2,4-D, Carboryl	
Potassium, mg/L	(Carbamate),	
Calcium, as $CaCO_3$	Malathian, Methyl	
Fluoride, mg/L	Parathian, Anilophos,	
Sulphate, mg/L	Chloropyriphos	

Table 5. Districts/Villages affected by arsenic contamination from geogenic sources

Sl. No.	Incidents found in the year	Names of the districts /villages	State
1.	1980	Maldah, Murshidabad, Nadia, North 24 Parganas, South 24 Parganas, Bardaman, Howrah, Hooghly, Kolkata	West Bengal
2.	1999	Two districts of Chhatisgarh–Rajnandgaon and Durg.	Chhatisgarh
3.	2002	Bhojpur Districts of Bihar	Bihar
4.	2003-2004	Fourteen districts of Bihar-Paschimi Champaran, Purba Champaran, Sitamarhi Supaul, Aroria, Kishanganj, Purnia, Katihar, Patna, Bhojpur, Buxar, Saran (Chapra) Vaishali, Madhubani and Sahibganj Distt. of Jharkhand	Bihar & Jharkhand
5.	2003-2004	Eleven districts of Uttar Pradesh Pilibhit, Lakhimpur Baharaich, Shravasti Balrampur, Siddarthnagar, Maharajganj, Kushinagar, Ballia, Unnao, Lucknow.	Uttar Pradesh
6.	2004	Dhimaji, Karimganj	Assam

Source: CPCB, 2007

Wastewater Disposal and Use for Irrigation

Developed countries with surplus funds regard wastewater treatment as vital to protect human health, environment and prevent the pollution of surface water bodies such as lakes and rivers. But for most developing countries, this solution presents insurmountable problems and is prohibitively expensive. Under these conditions, applying wastewater to agricultural lands is a more lucrative/economical alternative as it provides a reliable source of water for agriculture. Water does not loose its utility after one/two use(s) and has the potential of recycling for few activities that don't require good quality water. Thus, use of wastewater in agriculture is a low cost method to dispose of municipal wastewaters compared to its land disposal or disposal in lakes/rivers/sea. In the Indian context many of its rivers have already turned into drains during non-monsoon season. The positive and negative effects of wastewater irrigation are summarized in Table 6. If the negative issues could be appropriately addressed then many of the reservations for wastewater use could be countered.

Millions of farmers around the globe irrigate with wastewaters either because they have no other source or it is cheap source of their livelihood. No precise estimates of wastewater irrigated area are available for India yet the widespread use could be gauged from the fact that along one river, the Musi in Andhra Pradesh, alone an approximately 40,500 ha area is irrigated with wastewater. According to another report, the rural areas downstream of Vadodara in Gujarat, India, present an interesting case where wastewater supports annual agricultural production worth Rs. 266 million (Bhamoria, 2005). Critics however, aver that irrigation with untreated wastewater can represent a major threat to public health (of both humans and livestock), food safety, and environmental quality. The microbial quality of wastewater usually measured by the concentration of the two primary sources of water-borne infection – faecal coliforms and nematode eggs might not suffice in the long run as a range of viruses and protozoa pose additional health risks. In sum, wastewater is a resource of growing global importance and its use in agriculture must be carefully managed in order to preserve the substantial benefits while minimizing the serious risks.

Table 6. Positive and negative effects of wastewater irrigation

Positive	Negative
It conserves water resource and provides a more reliable water supply to the cultivator	It is a health risk to the agricultural field workers and their families, crop handlers, consumers (of crops, meat and milk) and those living near affected fields.
It is low-cost method for disposal of municipal/industrial wastewater	Likely contamination of groundwater
It helps to reduce pollution of rivers, canals and other surface water bodies	Soil build-up of chemical pollutants (heavy metals)
It helps to conserve nutrients and reduces the need for fertilizer application	Excessive growth of algae and vegetation in drains/canals carrying wastewater
Crop yields are increased	

Management Practices

Minimization of Wastewater

The most appropriate technique to reduce the wastewater is to segregate wastewater according to its quality (Fig. 1). It would help in reducing wastewater volume in the domestic sector. Moreover, if the urban runoff streams are segregated, it may help recycling and reuse of majority of the urban runoff (Fig. 1). Besides, there are opportunities to reduce wastewater in industries. The quantity of the effluent generated in sugar industry can be reduced from 300 liters to 50 liters per ton of cane crushed, if recycling techniques are meticulously followed. The wastewater quantity generated in continuous fermentation distilleries is just half (7 liters) per liter of alcohol produced compared to alcohol produced in batch fermentation process distilleries. In pulp and paper industries, the paper mill wastewater is completely recycled into pulp mill by adopting fiber recovery system. It helps to reduce the wastewater from 200 cum to 50 cum per ton of paper produced.

The above mentioned strategy on one hand would reduce wastewater; on the other it would increase the waste concentrations, the total load remaining the same. Such a strategy may not always be bad as in many cases high concentration of waste strength would be a boon in disguise. It would help the economical conversion of the wastewater into a useful product. For example the conversion of spent wash to bio-fertilizers by addition of press mud, bagasse cillo, agricultural residues etc. Many industries are now trying to achieve the goal of "Zero-discharge" to get the label of clean processing/industry. Few incentives could help to spread this concept to many more industries.

Reduction of Health Hazards

In rural and peri-urban areas of most developing countries, the use of sewage and wastewater for irrigation is a common practice. Even in areas where other water sources exist, small farmers often prefer wastewater because its high nutrient content reduces or even eliminates the need for expensive chemical fertilizers. Although, volumes have been written on the pros and cons of this strategy, there is no denying the fact that this technology suits most under developed and developing countries. Across Asia, Africa and Latin America these wastewater micro-economies support countless poor people. Stopping or over-regulating these practices could remove the only livelihood source for many landless people around the world. Therefore, without disturbing or curbing the current use, all out efforts be made to sensitize the stakeholders so as to minimize the health hazards to them. Some guidelines that might help to achieve this objective are as follows.

- Wear shoes and gloves while working with wastewater.
- Regular treatment of farmers and their families with antihelmintic drugs to prevent worm infections.
- Crop restrictions avoiding crops that are eaten raw. Prefer crops that are not taken by humans/animals. Crops that are eaten after cooking could be preferred. Forest plantations could be another option.

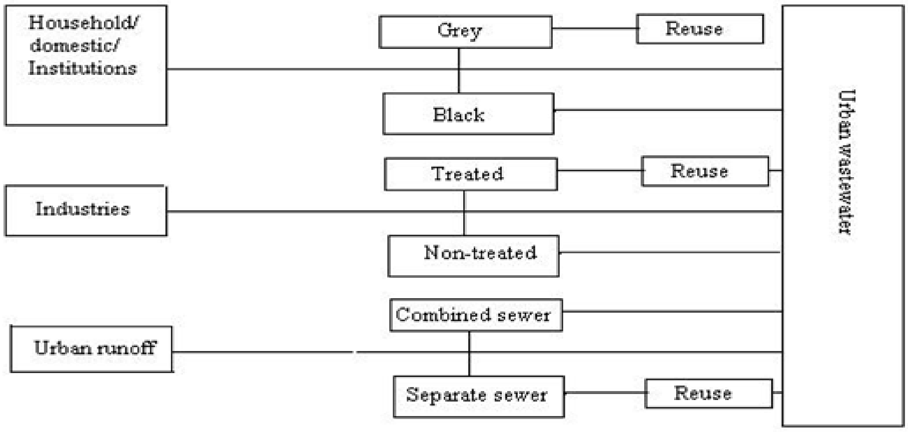

Fig. 1. Opportunities of minimizing wastewater production

- Withholding periods prior to harvest would reduce contamination of the products or allow sufficient time for pathogen die off.
- Adopt a suitable irrigation method such as drip irrigation. Even with drip irrigation, go for subsurface drip than surface drip.
- Even when surface irrigation cannot be dispensed with, broad bed-furrow method should be adopted. While plant could be shown in or near the irrigation furrow, plants should spread on the bed so that fruits don't come in direct contact with the wastewater.
- Washing/rinsing/disinfections of crop product before it reach the consumers.
- Better information on hygiene behavior and risks of wastewater irrigation to farmers, consumers and policy planners.

CSSRI experiences on most of these issues would be discussed in few of the lectures.

Water Treatment

It is argued that treatment of wastewater is the best alternative before its use/disposal. On the other hand, today there is no provision for collection and treatment of about 22000 mld of wastewater, which might increase to about 40,000 mld by the end of 11th Plan given the kind of urbanization mania spreading across the nation. Cost of collection and treatment of one mld cost about Rs. 50 million. It is besides the operation and maintenance cost, another about 10% of the above cost every year. Even after spending so much, one is not sure of the quality of the treated effluent. For example, the test conducted by CPCB at the Panipat treatment plant revealed deficiencies in certain parameters. Although, full results are not included, yet one could look at the remarks, which are self revealing.

Test results from 10 MLD Sewage Treatment Plant (STP) at Panipat (March 05)

General Characteristics

- Design capacity of STP: 10 ML/d; Average flow reaching STP: (?) ML/d
- Unit sizes and loading on main treatment units at full load condition:
- Treatment unit Number/Size HRT/SOR/Loading
- Screen and Grit channel
- UASB reactors 2 nos.: 24 x 18 x 5 m each 8 hr HRT
- Polishing pond 128 x 64 x 1.5 m 24 hr HRT
- Sludge drying beds 12 nos.: 14 m x 14 m each can handle about 176 m3 sludge per day with an 8 day filling/ drying/ emptying cycle

Results of analysis of composite samples after different stages of treatment (All values in mg/L except pH, and Colliform in MPN/100 mL)

Sample point	pH	BOD	COD	TSS	TDS	Fecal Colliform Total Coliform
Raw sewage	6.7	955	2187	326	$8x10^7$	$2x10^8$
After Grit channel	6.5	955	2249	382		
After UASB reactors						
After Polishing pond				365		
Standards for discharge streams	5.5-9	30	250	100		

Remarks

i) Plant is receiving sewage of exceptionally high strength indicating mixing of industrial effluents in sewerage system.
ii) Plant is functioning at an overall BOD/COD removal efficiency of 60-65 %. TSS in Polishing pond outlet is very high. Outlet structure of Polishing pond may be checked.
iii) Plant is not able to comply with the discharge standards due to above reasons.

Who Should Pay?

The cost of collection and treatment is enormous and beyond the reach of most developing countries. The present approach of financing the waste management by the government is neither adequate nor effective nor sustainable in tackling the massive problem. Current thinking that the major part of the cost on waste management should be born by the urban population according to 'polluter pays principle' seems more reasonable. Besides, water and sewage fees if charged can induce urban organizations to adopt water-saving technologies, including water recycling and reuse systems. Government policy could further help to manage waste in most economical manner. For example, if a policy is framed that calls for collection and utilization of grey water with in the household premises (irrigation of lawns and kitchen gardens), leaving disposal of black water only to the government bodies; it could minimize the collection/disposal/treatment cost of domestic effluents. A major portion of the effluent that currently ends up in the effluent stream is already utilized.

On the contrary, some might argue that waste management would not benefit the concerned households alone but would have major benefits to local/other citizens, environment, public health, water resources, water supply, irrigation, industries and tourism. Therefore, all the agencies involved should contribute to waste management. A mechanism therefore, should be evolved to coordinate with all the beneficiaries and charge them the benefit tax besides the water and sewage fees as suggested before.

Concluding Remarks

A fierce competition for high quality freshwater is developing between various sectors of economy. The competition is likely to grow with increasing population, expanding urbanization and industrialization. Since the water allocated to domestic and industrial sectors is non-consumptive in nature, an outcome would be increased production of wastewaters. Freshwater allocations to agriculture would dwindle and wastewater disposal would be a health and environmental problem. Treatment of wastewater would not be feasible considering its unplanned disposal and cost involved. As such, the wastewater reuse must be recognized and it should be included as a source of water for the region. Once it happens, it might solve many of the problems that we are facing today. Moreover, it could be exploited as a source of income to the municipality (Future Harvest, 2001).

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Characterization of Wastewater for Irrigation

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Introduction

Guidelines on treatment and discharge of wastewater are observed in developed world; but resource constrained developing countries like India; dispose either raw or partially treated wastewater in surface streams or make use in peri-urban agriculture. Disposal of wastewater in streams cause their eutrophication but land application for irrigation serves as a low cost reliable alternative. Though irrigation with wastewater is an age-old practice but it is getting renewed attention because of generation of huge volumes of wastewater by ever increasing global population, urbanization and industrialization. United Nations Population Division, 2000 report suggests that at present about 200 million m3 per day wastewater is generated by 2 billion urban populations of developing countries and most of it is not treated. Problem of wastewater generation and treatment in developing countries will further aggravate if the United Nations' millennium development goal of reducing the population without water supply, sanitation and sewers to half by the turn of this century is achieved (WHO, 2001), because about 88% of this growth in urbanization and industrialization is projected to take place in the cities of these resource poor developing countries (Rattan Lal 2006). Besides domestic wastewater, accelerated diverse industrialization generates effluents containing variable concentrations of organic compounds, dissolved toxins and unrecovered metals. These industrial effluents get mixed with sewage and storm water because in developing countries these are discharged through single system. Exponentially increasing urbanization and industrialization is not only using large areas of productive agricultural land but also producing large volumes of wastewater that have become a serious environmental threat in most countries. Wastewater generated thus is a direct source of surface water-logging, groundwater contamination and salinization or soil sickness around cities. Such unplanned disposal of municipal wastes causes development of many big lakes of wastewater in and around all big cities. In fact all the rivers have become big open sewer drains and lakes and ponds as sewage dumps. However, availability of such enormous volumes of variable composition raw or partially treated wastewater provides an opportunity for utilization of their irrigation and nutrient potential in the already water scarce semi-arid regions where supply of fresh water to agriculture is bound to reduce further from present share of 85 to 68% by 2050. Particularly the situation is likely to be alarmingly severe in 30 most densely populated developing countries like Egypt, India, Iran, Nigeria and Tunisia. Importance of wastewater for developing countries can be gauged from the facts that about 70% of present irrigation requirement in closed basin Middle Eastern countries is met by wastewater (Abu-Zeid *et al.* 2004). Similarly in India, production worth US $ 670 million and employment equivalent to 130 million days can be generated by augmentation of irrigation and supply of nutrients with partially treated sewage to vegetable, fodder and grain crops (Minhas and Samra 2004). But raw or partially treated such wastewater often has more than permissible levels of heavy metals (Fitamo *et al.* 2007). In their earlier reports Yadav *et al.* (2003) also recorded more than permissible contents of Cd, Cr, Ni and Pb in the partially treated wastewater disposed at different urban locations in Haryana. The sustained unregulated use of such wastewater also poses risk of accumulation of unrecovered non-essential metals in soils, crops grown and ground water. Thus before resorting to the use of wastewater in agriculture; its characterization for suitability for irrigation is very essential. As of increasing competition from other more sectors of economy, agricultural sector to meet its demands for irrigation water, will have to increasing rely on these wastewater as an alternate source for irrigation particularly in peri-urban areas. Thus inventories on these main sources of pollution have become essential from the point of view of irrigation.

Sources of Wastewater

In general wastewater is grey domestic (without human excreta), black domestic with human excreta, or industrial wastewater. Domestic wastewater consists of discharges from households, institutions and commercial buildings while industrial wastewater is the effluents discharged by variable manufacturing units and food processing plants.

Wastewater Quantity

Total wastewater generated from all major industrial sourced in India is 83,048 MLD that includes 66,700 MLD of cooling water generated from thermal power plants and out of remaining 16,348 MLD another 7,275 MLD is generated as boiler blow down water and overflow from ash ponds. Second bigger contributor is small scale engineering industries. Of this, electroplating units are most polluting units. Other significant contributors to industrial effluents are paper, textile, steel and sugar industries. Latest estimates suggest that about 22900 MLD of domestic wastewater is generated in different cities of our countries. Information on wastewater characteristics and its flow rates are important in designing and operation of collection and disposal facilities as well as in knowing their irrigation potential for agricultural purposes. Thus, the volume of sewage available for irrigation in different districts of Haryana was computed on the basis of their present population and 70% of the awter allowance per head in each district. Quantity of total sewage generated and projections for the year 2025 for Haryana state are presented in table 1. The total quantum of sewage generated is 485 MLD, with the maximum at Faridabad being 104 MLD and minimum at Mahendergarh at 6.3 MLD. This quntum is almost 4 fold than earlier predictions of 1986. Similarly projections for year 2025 indicate that this quantum will be around 728 MLD.

These effluents have the potential for irrigating about 650 ha of land on daily basis or alternatively about 0.24 million ha on annual basis. Considering average irrigation interval of 20 days, this wastewater would have potential for supplying supplemental irrigation to facility to about 11,700 ha per annum. Taking water requirement of vegetable, fodder and cereal productions systems in Haryana type of climatic conditions as 110, 105 and 165 cm, respectively, and average rainfall of 50 cm, the wastewater can augment irrigation supplies to 29,500, 32,500 and 1600 ha of land under respective production systems. Use of wastewater for irrigation will avoid pollution of water bodies and environmental hazards like public health and foul smell

Table 1. Distrisct-wise sewage generation in Haryana

District	Sewage generation (MLD)	
	Present	Projections for 2025
Ambala	25.7	38.6
Bhiwani	17.5	26.3
Faridabad	104.1	156.2
Fatehabad	9.8	14.7
Gurgaon	20.2	30.3
Hisar	33.2	49.8
Jhajjar	15.3	23.0
Jind	19.9	29.9
Kaithal	17.9	26.9
Karnal	30.8	46.2
Kurukshetra	20.8	31.2
Mahendergarh	6.2	9.3
Panchkula	19.3	29.0
Panipat	28.4	42.6
Rewari	8.2	12.3
Rohtak	28.1	42.2
Sirsa	21.1	31.7
Sonepat	30.4	45.6
Yamunanagar	28.3	42.5
Total	485.2	728.3

Composition of Wastewater

Though actual composition of wastewater may differ from community to community but all municipal wastewater contain; organic matter, nutrients (N, P, K and micronutrients), dissolved inorganic minerals, toxic chemicals and pathogens. However, the final composition of raw wastewater depends on the source of water supply, types and numbers of industrial units discharging effluents, and level of treatment given. Routine measurements of municipal wastewater pertain to water pollution parameters like BOD, suspended solids and COD. But agriculturally important chemical characteristics as elemental composition and compounds that affect soil properties and crop growth are sporadically monitored. Chemical characteristics of effluents of some industries are given in table 2.

Table 2. Chemical characteristics of some industrial wastewater

Industry	pH	EC (dS m^{-1})	SS (000)	BOD (000)	COD (000)	N (ppm)	P (ppm)	K (ppm)
Distillery	4.5	46.0	1.2- 4.0	45-75	27-110	1000-1900	280-310	6600- 10000
Fertiliser	9.5	--	2.23	0.259	--	108	3.4	15
Textile	11.0	--	1.0-1.5	0.22-2.0	0.75-8.0	--	--	--
Tannery	9.5	22	3.2	1.0-3.0	--	--	--	--
Paper	10.1	1.5	0.62-1.25	1.1-1.6	0.80	168	--	15-43
Dye	11.8	8-11	0.68-1.0	1.16-1.8	--	30-35	7-9	8-13
Dairy	8.0	1-5.14	0.69-1.32	0.9-2.2	--	43-180	14-59	13-39
Sugar	6.0	0.95	1.5-1.8	0.65-.82	0.06-.09	11-15	7-8	30-40
Food	5.2	0.81	--	--	--	12-20	2-4	9-12
Refinery	7.1	1.8	1.94	0.048	0.32	140	--	1.8
Eclectro plate	6-8.9	2.4	0.06-0.38	--	--	--	--	--

The major contributors of pollution in terms of BOD are distilleries followed by paper mills. Distillery effluents are very concentrated and thus difficult to treat. Paper and board mills also generate heavy organic pollution load. Other significant contributors of organic load are sugar mills and tanneries. Industries generating chemical pollution can be divided in two categories *i.e.* those generating high TDS as wastes of pharmaceuticals, rayon plants, chemicals, caustic soda, soap, detergents and smelters *etc.* while second type include those units which generate toxic wastes like pesticides, smelters, inorganic chemicals, organic chemicals, steel plants and tanneries. Distilleries, textile units, pharmaceuticals and rayon plants contribute to TDS; whereas thermal power plants followed by paper mills and tanneries generate suspended solids loads. Fertilizer plants generate toxic wastes as cyanide and arsenic. Steel plants and oil refineries contribute to phenols while engineering units, refineries and vanaspati industry release oils and greases in the environment. Tanneries add Cr and fertilizer units also add fluoride to the system. Similarly, caustic soda units release Hg in environment.

To identify the areas in Haryana those have loads of pollutants beyond the water quality standards, the composition of municipal wastewater being disposed in different districts was monitored. Considerable variations in their compositions were observed amongst the sewage water generated in different districts as well as seasons. In general, these wastewaters had low salt content and were neutral to slightly alkaline (Table 3). The cationic and anionic constituents in these followed the order of Na > Mg > Ca > K and HCO_3 > Cl > CO_3. The SAR and RSC of these wastewater averaged 3.5 and 5.3 me l^{-1} while Ca:Mg ratio > 1. all these parameters indicate that these water could be exploited for irrigation purpose without any adverse effect on soils. Sewage from Mahendergarh, Kaithal and Rewari districts had RSC > 6 me L^{-1} mainly because of groundwater quality. Contents of trace and heavy metals were within permissible limits. But in some of industrial townships like Ambala, Panipat, Sonepat and Faridabad had higher metal contents. Major sources of metals are industries, small workshops, road washings and human excreta.

Table 3. Average irrigation characteristics of sewage generated in Haryana

Parameters	Untreated		Treated	
	Range	Average	Range	Average
EC (dS m^{-1})	0.9-3.2	1.9	0.8-3.0	1.8
SAR	1.4-6.2	3.5	0.05-4.8	3.4
RSC (me L^{-1})	-- 8.6	5.3	1.1-8.2	3.4
Na	0.7-12.8	6.9	0.7-10.4	6.6
Ca	2.3-8.3	3.6	2.3-4.8	3.4
Mg	2.1-7.1	4.2	1.5-5.1	4.0
CO_3	-- 3.3	1.2	0.5-3.2	1.9
HCO_3	7.1-16.9	10.9	6.1-14.1	8.9
Cl	1.4-14.6	7.5	1.4-10.0	6.6

Pollution and Public Health Parameters

TDS in sewage ranged between 0.6 – 3.3 g L^{-1} and these are on higher side than permissible levels, this could be because of collection wastewater through open drains containing considerable quantities of clays and silt getting mixed with sewage. BOD and COD of wastewater ranged from 176 to 345 ppm and 233 to 457 ppm, respectively. Ambala sewage had maximum BOD nad COD. Most of nitrogen in wastewater is found in NH_4-N (39 ppm). These parameters indicate that these should not be allowed to be disposed in water bodies as these may deteriorate aquatic environment. Considering the agroclimatic conditions of Haryana, the most of wastewater generated are suitable for irrigation purposes.

Health hazards associated with disposal of raw or partially treated sewage are monitored in terms of *E. coli, F. coli*, total bacterial counts, *Salmonella* and *Shigella*. The populations of *E. coli* and *F. coli* are considerably higher 4 x 10^6 per 100 ml of wastewater. Bacterial counts and fungi were also high than permissible levels. Although other pathogenic bacteria were not detected but presence of high levels of coliform bacteria indicates towards health hazards from use of these wastewater.

Seasonal Variations

Considerable variations are noticed with of sampling. The pH increased from 7.6 during winter to 8.1 in summer and declined to 7.7 during post-rainy season. Salt content also increased from 1.6 in winter to 1.9 in summer and further to 2.0 dS m^{-1} in post-rainy season. Average BOD of sewage before entering STP was 222, 239 and 261 ppm during winter, summer and post-rainy season, respectively. Similarly, COD get reduced to 240 and 246 ppm in winter and post-rany seasons, while the values are around 384 ppm in summer. Lesser nitrification in winter results in higher NH_{4-N} (47.5 ppm) than summer (36.4 ppm) and post-rainy (28.2 ppm). Amongst cations, Na increased while Ca decreased during summer and post-rainy seasons, whereas K remained unchanged. In anions, Cl contents increase markedly in summer while CO_3 and HCO_3 was almost similar, thereby RSC of wastewater remain lower during summer. Higher contents of metals are observed during summer periods.

Treatment Effects

Quality of sewage improves with primary treatment given in terms of Reduction of BOD and COD. BOD reduced to 100 ppm that is the permissible limit for land disposal. Overall reduction in COD has been observed to the extent of 215 ppm from original value of 315 ppm but that still remains higher than permissible levels. Contents of N and K are reduced while P remains unchanged. Na, Ca, Mg, CO_3 and HCO_3 contents also do not change with primary treatment and thus SAR and RSC are also not affected. Contents of metals have been increased with treatment but pathogen loads reduced slightly. The major advantage of conventional STPs seems to be reduction of only organic loads while these remain ineffective in reducing the levels of soluble metals and other ions.

Nutrient Potential

In fact, additions of macro- and micronutrients and organic matter for conditioning of soils are inseparable from sewage irrigation and thus their use can diminish their requirements for fertilizers, sewage from different districts in general are rated high in terms of plant nutrients contents. Contents of major plant nutrients i.e. N, P and K, averaged 45.9, 6.9 and 62.4 ppm, respectively. Samples analyzed for micronutrients status indicate 0.17, 1.01 and 0.024 ppm, respectively of Zn, Fe and Cu. Thus potential for the supply of major nutrients like N, P, K with irrigation is 34.4, 5.2 and 46.7 kg ha^{-1} in addition to 130, 760 and 20 g of Zn, Fe and Cu, respectively (Table 4).

Table 4. Nutrient potential of sewage in Haryana

Nutrient	Contents (ppm)	Nutrient added (kg $irrig.^{-1}$)	Contribution (t $year^{-1}$)	Price (Rs t^{-1})	Value (Rs. Million)
N	45.9	34.4	8140	10434	84.93
P	6.9	5.2	1221	15625	19.08
K	62.4	46.7	11046	7330	80.97
Zn	0.17	0.13	3.1	48000	1.67
Fe	1.01	0.76	178.8		
Cu	0.024	0.02	4.3		

Supplied nutrients are expected to be utilized more efficiently as these are added in splits and the total nutrients added during crop growth period will be sufficient for successful crop production. Also it is a fact these effluents contain appreciable amounts of organic matter that improves soil conditions. From the concentrations of respective elements and quantum of sewage, it is estimated that these effluents have potential to contribute about 56.4 tonnes day^{-1} and 20,872 tomes $year^{-1}$ cumulatively of all nutrients. In Haryana 662679, 17178 and 3950 tomes $year^{-1}$ of N, P and K were used during 2001-2002, whereas the potential of sewage is worked out to be 8140, 121 and 11046 tomes $year^{-1}$. Thus approximately 2.4% of total micronutrients used can be supplied through sewage irrigation.

Conclusions

Sewage in Haryana have high irrigation and nutrient potential, thus if used efficiently can augment the awter supplies in peri-urban agriculture in addition to recycling of nutrients. Some of effluents had high BOD, COD, TDS, NH_4-N, toxic metals like Cd, Cr, Ni and Pb and pathogens those limit their disposal into water bodies. Monitoring of disposal sites is recommended for toxic elements accumulations and pathogens for their impacts on health associated features of the farmers and other workers utilizing this wastewater at their farms.

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Micro-irrigation System for Wastewater Use

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Introduction

Per capita land and water resources are decreasing at a very fast rate. These resources are also being degraded mainly due to unmanaged over-exploitation in the wake of resource exploiting green revolution. Per capita land resource has decreased from 0.33 ha in 1951 to 0.13 ha in 2001. Similarly, per capita water availability assessed at more than 5300 m^3 in 1951 had decreased to 1905 m^3 in 1999 and is likely to be less than 1500 m^3 by the year 2025. Therefore, to conserve water resource and to utilize salt affected land resource in a most productive manner, improved irrigation techniques including drip irrigation would play a very prominent role. Though the land area is constant like water, there is scope for utilizing the same in an intensified manner in project commands and rain fed areas to increase the production. Further, this can also be achieved by reclaiming the fallow, barren and uncultivable lands. All this would need water and hence optimum use of available water is very crucial.

In spite of major strides in planned development of surface and ground water resources, Indian agriculture continues to depend on its marginal quality waters (Minhas and Gupta, 1992).Underground water in arid and semi-arid region up to the extent of 25% is poor quality . This may be classified as saline, alkali, sodic, affected with specific ion toxicity and element toxicity. Other part of the marginal quality water is wastewater, which is generated after consumptive use of domestic, industrial and power sector. Till 2025 A.D. around 23 million ha. M will be used by this sector. The consumptive use of this water is around 20% and rest, which amount, about 19 M ha. m. may come under wastewater category (Table 1).

Table 1. Latest estimates of water need

Activity	Years		
	1990	2000	2025
Irrigation	46.0	63.0	77.0
Drinking and Livestock	2.5	3.3	5.2
Industrial	1.5	3.0	12.0
Energy	1.9	2.7	7.1
Others	3.3	3.0	3.7
Total	55.2	75.0	1o5.0

Source: Anonymous (1994).

The wastewater can be broadly grouped into two major categories-the sewage water and the industrial wastewater. In most cities and towns these two waters are disposed off together and resulting quality may change from place to place depending upon the nature of the industry. Contrarily, it is easy to manage the sewage water, as its quality characteristics are known. Though the quality of sewage water differs from place to place and season to season, it is neutral to slightly alkali in reaction, low in salt content and high in pathogenic microorganism. The water rarely contains heavy metals unless mixed with industrial wastewater, which may be toxic to plants and may cause adverse effect to human being by entering into food chain. It contains nutrients and organic matter, which may increase the soil fertility. The constituents of concern in wastewater treatment and wastewater irrigation are listed in Table 2.

Different Approaches of Disposal of Sewage Water

- Disposal into surface water body
- Disposals into low lying areas and ponds
- Soak pit disposal
- Sewage treatment plants
- Soil aquifer treatment system
- Oxidation ponds and fish culture
- Sewage for agriculture

Mostly in India, the municipalities collect sewage through sewer system and pump it out directly from the main sewer or collection tank (sump) into a nearby drain, stream or river body, which ultimately joins the river of the area. Almost all the rivers including Ganga and Yamuna and many sea beaches have thus been polluted to an alarming level. Where such outlets are not naturally available, it is simply dumped into near by low-lying area or pond. As a result of such an unplanned disposal of municipal waste, many big lakes of sewage can be seen in and around the big cities causing ground water and surface water contamination and environmental pollution. Soak pit disposal system is generally used for individual household. Sewage is allowed to go in to the pit without any pre-treatment, from where it is ultimately soaked into the soil, which contaminates the groundwater.

Table 2. Constituents of concern in wastewater treatment and irrigation with reclaimed wastewater

Constituents	Measured parameters	Reason for concern
Suspended solids	Suspended solids including volatile and fixed solids	Suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater is discharged in the aquatic environment. Excess amount of suspended solids cause plugging in the irrigation system.
Biodegradable organics	Biochemical oxygen demand, Chemical oxygen demand	Compose principally of proteins, carbohydrates, and fats. If discharged to the environment, their biological decomposition can lead to the depletion of dissolved oxygen in receiving waters and to development of septic condition
Pathogens	Indicator organisms, total and fecal coliform bacteria	Communicable diseases can be transmitted by the pathogens in wastewater: bacteria. Virus, parasites
Nutrients	Nitrogen Phosphorus Potassium	N, P, and K are essential nutrients for plant growth, and their presence normally enhances the value of water for irrigation. When discharged to the aquatic environment, nitrogen and phosphorus can lead to the growth of undesirable aquatic life. When discharged in excessive amounts on land, nitrogen can also lead to the pollution of ground water.
Stable (refractory) Organics	Specific compounds (e.g. phenols, pesticides, chlorinated hydrocarbons)	These organics tend to resist conventional methods wastewater treatment. Some organic compounds are toxic in environment ,and their presence may limit the suitability of wastewater
Hydrogen ion activity	pH	The pH of wastewater affects metal solubility as well as alkalinity of the soil. Normal range is 6.5-8.5, but industrial waste can alter pH significantly.
Heavy metal	Specific elements (e.g. Cd, Zn. Ni, Hg)	Some heavy metals accumulate in the environment and are toxic to plants and animals. Their presence may limit the suitability of wastewater to irrigation.
Dissolved inorganics	Total dissolved solid, electrical conductivity, specific elements (e.g. Na, Ca, Mg, Cl, B)	Excess salinity may damage some crops. Specific ions such as chlorine, sodium, boron, are toxic to some crops. Sodium may pose soil permeability problem.
Residual chlorine	Free and combine chlorine	Excess amount of free available chlorine (> 0.05 mg/l Cl_2) may cause leaf tip burn and damage some sensitive crops. However, most chlorine in reclaimed wastewater is in combined form, which does not cause crop damage. Some concerns are expressed as to the toxic effect of chlorinated organics in regard to groundwater contamination.

In sewage treatment plant sewage, water is stored in ponds, which are arranged in parallel and/or series. The size and depth of ponds varies to allow different retention time and make the possibility of aerobic and anaerobic decomposition of organic matter of sewage water. Sludge is removed from the sewage, which reduces its BOD and concentration of toxic elements. Depending upon the degree of purification, the effluent is called as primary, secondary and tertiary treated sewage wastewater. The treated wastewater can be used for irrigation purpose and/or safely discharged into the river body.

Sewage for Agriculture

Irrigation Methods

Different methods are used or could be used to apply good quality irrigation water. The efficiency of these methods differs from each other on account of variation in deep percolation and evaporation losses (Table 3). Thus to save irrigation water and energy and to enhance productivity, selection of advanced irrigation method would be necessary. This increase in productivity is attributed to conditions of optimum moisture in the root zone that affects in proper aeration to the plants and reduced periods of moisture stress.

This condition can be easily maintained by the drip irrigation, where it is possible to make frequent irrigation as per requirement of the crops.

Table 3. Application efficiencies of different irrigation methods

S. No.	Type of irrigation method	Application efficiency (%)
1	Flood, border, furrow, check basin, bed and furrow	<60
2	Sprinkler	80 –85
3	Drip	90 –95

The evaporation losses are the maximum in the case of flood, border, and check basin. The evaporation losses are reduced in the basin and furrows, as only a part of the soil is flooded. The evaporation losses are further reduced in the case of sprinkler irrigation as most of the water is held by capillarity. In the case of drip irrigation flooding can be altogether avoided, which reduces the evaporation losses. Moreover in most cases it would be not necessary to wet the entire field. For example in the case of vegetable crops, only 80% of the wetted area can serve the purpose where as in the case of fruit trees approximately 20% the area is required to be irrigated. In the case of subsurface drip irrigation there is maximum reduction in evaporation losses as emitters are buried in the soil which reduces the moisture content on the soil surface.

Expansion of Drip Irrigation in India

Research experiments on drip irrigation in India were initiated in the early seventies in many state agricultural universities and research organizations. The spread was quite fast during the last decade, when its coverage touched 0.3 million ha (Table 4). This spread is mostly for good quality water and saline water. The highest coverage is in the state of Maharashtra followed by Karnataka, Tamil Nadu, Andhra Pradesh and Rajasthan. According to Sivanappan (1999), about 28.5 m ha could be covered under drip irrigation, which is likely to be achieved by the year 2020/25. However, at an annual compound growth rate of adoption of drip irrigation assessed at present at 12 per cent, it would take about 8 years to bring additional one million hectare area under drip irrigation.

Table 4. Growth of drip irrigation in India

Year	1970	1985	1989	1994	1999	2002
Area (,000) ha	Nil	1.5	12.0	70.9	300.0	355.4

(Source: Kumar and Singh, 2002; Praveen Rao, 2002)

Crop Wise Area Distribution under Drip Irrigation

Area coverage under drip system for different crops in 1992 and 1998 are given in Table 5, showing an increase in its adoption particularly in fruits, vegetables, sugarcane and cotton. Major increase in drip irrigated area has been in banana, citrus, coconut, grapes, mango, and pomegranate under fruit crops. There is also a substantial increase in the area under cash crops of sugarcane and cotton.

Table 5: Area coverage (ha) under drip irrigation for selected crops in India

Crop	Year		Crop	Year	
	1992	1998		1992	1998
Sugarcane	3888	18000	Coconut	2596	48361
Cotton	383	5462	Grapes	12048	29630
Vegetable	1537	4515	Guava	1543	4930
Fruits	39500	186600	Mango	4747	21863
Arecanut	208	5665	Papaya	873	2115
Banana	6767	26565	Pomegranate	5437	15250
Bear	704	4700	Sapota	849	5125
Citrus	3879	22210	Strawberry	200	1700

Economic Analysis of Drip Irrigation in India

Reddy *et al.* (2004) made an economic analysis of the important crops grown with drip irrigation in India. Data on average yield, water requirement, water saving, fertilizer saving and their cost were collected from literature and prices of agriculture commodities were taken from Govt. of India reports. Yield pattern (Table 6) reveals that maximum yield increase was in vegetables (60%) followed by fruits (40%), sugarcane (33%) and cotton (27%). Similarly, water saving is ranged from 53 to 56%. The saving in fertilizer was about

30% for all the selected crops. Based on the above data, additional income expected using drip system were calculated and is presented in Table 5. Additional returns due to increase in yield ranged from Rs.16, 767 to 29,568 per ha, with maximum in sugarcane and minimum in cotton. The benefit from water saving ranged from Rs. 660 to 3612 per ha (approximate water price Rs. 3/ha-mm, Tiwari et.al.,1998). The benefit from fertilizer saving was estimated at Rs. 450 to 600 per ha for existing rate of fertilizer. The cost of fertilizer is estimated based on the recommended dose for the respective crops. The cost benefit ratio was calculated for these crops (Table 7). The maximum cost benefit ratio was found for fruits followed by sugarcane, vegetables and cotton. The net benefit is the maximum for sugarcane followed by fruits, vegetable and cotton.

Utilization of Sewage Water through Drip Irrigation

Water shortage associated with intensive depletion of underground aquifers has prompted the search for alternative water sources. It has led to secondary treated domestic wastewater being considered for irrigation of field crop and raw eaten vegetable crops (Oron *et al.*, 1991). Secondary domestic wastewater is now being used on a relatively large scale, mostly in developed countries, for field crops and landscape irrigation, groundwater recharge, and storage in recreational centers. In a few cases, tertiary or advanced treatment of the wastewater is required (Kirkpatrick and Asano, 1986).

The concept of water saving might seem to contradict the idea of maintaining maximum yield from irrigated crops. The conflict might be more significant in arid zones with limited natural, high quality, permanent water source. A possible remedy to this conflict is to use non-conventional water, such as domestic treated wastewater, applied by drip irrigation. Using a subsurface drip irrigation system can further increase the efficiency of water application. (Phene *et al.*,1985). The other advantages of use of drip irrigation system with sewage water are that no aerosols are formed, water logging due to runoff and deep percolation is negligible and the only contact with the water occurs when the product to be consumed touches the soil; the product of the plants growing above the soil being practically devoid of pathogens when the drip system is buried in the soil or covered by the plastic sheets (Capra and Scicolone, 2004).

Table 6: Total returns expected from selected crops under drip irrigation system

Input	Cost economics	Crops			
		Sugarcane	Cotton	Fruits	Vegetables
Yield	Yield (t/ha)	128	2.3	9	11
	Increase (%)	33	27	40	60
	Selling price (Rs/t)	700	27000	6000	4000
	Additional Returns (Rs/ha)	29568	16767	21600	26400
Water	Required (mm/ha)	2150	895	1200	400
	Saving (%)	56	53	55	55
	Benefit (Rs/ha)	3612	1423	1980	660
Fertilizer	Cost (Rs/ha)	2000	1700	1500	1500
	Saving (%)	30	30	30	30
	Benefit (Rs/ha)	600	510	450	450
	Total Return (Rs/ha)	33780	18700	24030	27510

Table 7. Benefit cost ratio for selected crops under drip system

Crop	Cost of drip system (Rs/ha)		Benefit (Rs/ha)		B:C Ratio
	Total	Annual	Total	Net	
Sugarcane	50000	14000	33780	19780	2.41
Cotton	50000	14000	18700	4700	1.34
Fruits	25000	7000	24030	17030	3.43
Vegetables	65000	18200	27510	9310	1.51

It is evident from above examples that some degree of treatment was provided to untreated municipal wastewater before it could be used for agricultural or landscape irrigation. This is the prevalent norms and practice in the developed countries. The degree of pre application treatment is considered to be an important factor in the planning, design, and management of wastewater irrigation system. Pre application treatment of wastewater is practiced keeping in view the following reasons (Asano *et al.*, 1985).

- Protect public health
- Prevent nuisance condition during storage
- Prevent damage to crops and soils

Present Status of Utilization of Sewage Water in India

Currently, about 30% of untreated sewage water are being utilized to grow vegetable crops around urban center using surface method of irrigation. This practice, besides a health risk to the farmers and the consumers of the product, it is causing enormous ground water contamination since excessive deep percolation losses can not be avoided. Moreover the productivity of land and water is quite less, which could be increased substantially by adapting drip irrigation. Around 60 % of sewage water is directly disposed off in surface water bodies and low lying areas causing groundwater and surface water contamination and inefficient use of our water resources. Visualizing the alarming level of environmental pollution, around 10 % of sewage water is being treated in conventional sewage treatment plants generating mostly primary treated sewage water. These waters are also utilized for irrigation purpose with surface method of irrigation.

A Case Study on the Use of Domestic Wastewater through Drip Irrigation

At Central Soil Salinity Research Institute, Karnal, sewage water is collected in sump through gravity and it is pumped into an unlined pond after every 24 hours. The amount of sewage water is around 83,000 lit / day. The quality of the domestic wastewater is shown in Table 8. The most of the sewage water in the pond was recharging the groundwater and there was foul smell near the pond.

Table 8. Composition of domestic wastewater at CSSRI Karnal

S. No.	Parameter	Values
1	pH	7.93
2.	EC (dS/m)	0.98
3.	BOD_s (mg/l)	198
4.	COD (mg/l)	249
5.	NH_4-N (mg/l)	12.9
6.	NO_3-N (mg/l)	2.43
7.	HCO_3 (m eq. /l)	7.89
8.	P (mg/l)	4.06
9.	K (m eq./l)	0.29
10.	Na (m eq./l)	2.38
11.	Ca (m eq./l)	2.19
12.	Mg (m eq./l)	3.20
13.	Zn (mg/l)	0.24
14.	Fe (mg/l)	0.94
15.	Mn (mg/l)	0.03
16.	Pb (mg/l)	0.16
17.	Cd (mg/l)	0.01
18.	Cr (mg/l)	N.D.
19.	E. coli /100 ml	10^{10}
20.	Total suspended solid (mg./l)	100

For safe, economical and efficient utilization of sewage water an experiment was conducted to irrigate lady finger and cabbage crop with untreated domestic wastewater through drip irrigation. Both surface and subsurface drip irrigation were tried. In subsurface drip irrigation emitters were laid 30 cm below the soil surface. A separate emitter was provided for each plant in both the methods of irrigation. The lady finger crop was grown during April to September. The amount of domestic wastewater applied was 53 cm whereas total crop water requirement was 89 cm (Table 9). The rest crop water requirement was met by rainfall. The Cabbage crop was grown during October to February. The amount of domestic wastewater applied was 19.4 cm while total water requirement was 26.83 cm (Table 10).The other part of the crop water requirement was met by rainfall. The yield of lady finger crop was higher i.e. 14.72 t/ha in the case of subsurface drip irrigation as compared to 8.0 t/ha in the case of surface drip irrigation (Table 9). In the case of cabbage crop the yield was higher in the case of surface drip irrigation i.e. 33.56 t/ha compared to 29.00 t/ha in the case of subsurface drip irrigation (Table 10). Low yield in the case of cabbage crop during subsurface irrigation may be due to the shallow root system of the cabbage plants and the depth of subsurface emitters (30 cm) which prevented adequate water supply.

Table 9. Water use efficiency in the case of lady finger crop during surface and subsurface drip irrigation

Total water requirement (cm)	Sewage water applied	Yield of lady finger (t/ha)		Water use efficiency (t/ha/cm)	
		Surface	Subsurface	Surface	Subsurface
89.11	53.07	8.05	14.72	0.089	0.174

Table 10. Water use efficiency in the case of cabbage crop during surface and subsurface drip irrigation

Total water requirement (cm)	Sewage water applied	Yield of cabbage (t/ha)		Water use efficiency (t/ha/cm)	
		Surface	Subsurface	Surface	Subsurface
26.83	19.41	33.56	29.00	1.27	1.16

Clogging of Emitters and Its Effect on Application Efficiency

One of the advantages of drip irrigation is its potential to attain high application efficiency. But clogging of the emitters may encounter this advantage. During three years of experimentation, the emitters were clogged to some extent resulting in decrease in application efficiency (Tables 11 & 12). Clogging of the emitters affected the hydraulics performance of the system in two ways: it reduced the discharge rate of the emitters as well as it affected the uniformity coefficient, which is inversely proportion to the coefficient of variation. In the case of surface drip irrigation emitters discharge rate reduced to 0.5% compared to 12% in the case of subsurface drip irrigation. The coefficient of variation increased to 0.16 and 0.23 in the case of surface and subsurface drip irrigation respectively from their initial values of 0.077 and 0.078 in the time span of 3 years. Clearly there was more clogging effect in the case of subsurface drip irrigation compared to surface drip irrigation. This could be due to the entry of soil particles in the subsurface emitters.

Table 11. Variation in discharge rate and coefficient of variation of emitters flow during three years of experimentation

Mean discharge rate				Coefficient of variation			
Surface drip		Subsurface drip		Surface		Subsurface	
Initial	After 3 years	Initial	After 3 years	Initial	After 3 years	Initial	After 3 years
3.85	3.83	3.87	3.37	0.077	0.16	0.078	0.23

Table 12. Estimated application efficiency (in percentage) during 3 years of experimentation in drip irrigation methods and its comparison to border irrigation

Surface drip irrigation		Subsurface drip irrigation		Border
Initial	After 3 years	Initial	After 3 years	
92	85	92	72	60

Deep Percolation Losses

The drip irrigation system saves the water in two ways: (1) reduction in evaporation losses could reduce the net application of irrigation water and (2) increase in application efficiency could further reduce the deep percolation losses. The estimated deep percolation losses are shown in Table 13. There was 48 cm of deep percolation losses in the case of border irrigation compared to only 20 cm in the case of subsurface drip irrigation after 3 years of use of the wastewater. Reducing the clogging of the emitters can reduce the deep percolation losses and it may attain the value of 4.3 cm.

Table 13. Estimated deep percolation losses in different irrigation methods

Crop	Surface drip		Subsurface drip		Border
	Initial	After 3 years	Initial	After 3 years	
Lady finger	4.0	8.5	3.0	14.4	35.3
Cabbage	1.5	3.1	1.3	5.6	12.9

Soil and Crop Produce Contamination

Soil and plant produce contamination depends to a large extent on the applied effluent quality, soil conditions, and the technology of application. The microorganism content in the effluent was quite high i.e. around 10^{10}/ 100 ml (Table 7) which reduced to 10^{4}/ 100 gm of soil in the case of surface drip irrigation (Table 14). In the case of subsurface drip irrigation, soil surface was found free from pathogenic microorganism indicated by E. coli (Table 14). Plant produces i.e. lady finger and cabbage balls were found free from contamination of pathogens in both the irrigation methods. Apart from crop produce, uncontaminated soil surface may also save farm workers to be affected by disease during inter culture operation in the case of subsurface drip irrigation.

Table 14 . Distribution of the pathogenic microorganism indicated by E.coli in the soil irrigated with surface and subsurface drip irrigation

S. No.	Distance from the plant, cm	Depth from the plant, cm	E.coli /100 gm of soil	
			Surface	Subsurface
1	0	0	10^4	0
2	0	30	10^3	10^4
3	25	0	10^2	0
4	25	30	10^2	10^2

Utilization of Sewage Water through Subsurface Drip Irrigation on Fruit Crops

In vegetable crops almost whole area is irrigated which increases the chances of contamination and closure spacing of dippers and laterals increases the cost of drip system. To get better results experiment is being conducted on fruit crops. The two fruit crops i.e. Guava and Amla were grown with spacing of 4.5 m and 6.0 m. In initial three years to utilize the space between the fruit crops, the papaya seedlings were transplanted with the spacing of 1.5 m as an inter fruit crops. In this case pressure-compensating drippers were used which may neutralize the better results in case of clogging as obtained in previous vegetable crop experiment.

Limitations

In the present study, the domestic wastewater used, was containing negligible amount of heavy metals. But many times the municipal wastewater may contain heavy metals of significant amount and for those cases the suitable management practices would be required for their sustainable use.

Conclusions

Drip irrigation technology ensures increased crop yield, high water use efficiency, reduced water and energy consumption. Drip irrigation has a potential of utilizing sewage water in agriculture. Disposal of the sewage wastewater is a serious problem especially in developing countries, which is causing groundwater and surface water contamination and creating environmental pollution. The conventional method of disposal of sewage water (sewage treatment plants) are cost intensive and beyond the reach of many municipalities. The use of sewage water through subsurface drip irrigation may help to solve the disposal problem and finding a solution, which may be economically viable. Though its adaptation for efficient utilization of good quality and saline water is steadily increasing in India still there are few challenges. Investment needs being high, the technology could be popularized through one window system of financial assistance including subsidy. Its large-scale expansion will reduce many of its shortcomings, which will also encourage the use of sewage water through drip irrigation.

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Bioremediation of wastewater for Removal of Heavy Metals through Microorganisms

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Use of wastewater in agriculture has been increased in recent years. However, wastewater, particularly from industries contains high concentration of heavy metals which enter into human beings and animals through food chain. Therefore, before its use in agriculture, it is desirable to remove these heavy metals from wastewater through low cost technology like efficient microbial culture. Biomass of microbes acts as adsorbent to remove heavy metals from wastewater. The ability to remove heavy metals from wastewater varies greatly among microbes. This needs to be exploited for removal of heavy metals from wastewater through efficient microbes.

Ninety three bacterial and eighty one fungal isolates tolerant to heavy metals (25 ppm) like Pb, Cd, Cr and Ni were isolated from sewage and sludge samples collected from Karnal, Panipat and Sonepat districts. Three efficient organic matter decomposing fungi namely *Aspergillus awamorii, Phanaerochaete chrysosporium* and *Trichoderma viride* were procured from Division of Microbiology, IARI, New Delhi. Out of ninety three bacterial isolates, 14 were tolerant to Cd, 8 to Cr, 44 to Pb, and 29 to Ni. Similarly, out of eighty one fungal isolates, 9 each were tolerant to Cd and Cr, 34 to Pb and 29 to Ni. Majority of microorganisms were able to tolerate heavy metals up to 400 ppm.

Table 1. Uptake and removal of lead by fungi from the medium having 400 ppm lead

Fungus	Pb uptake (mg/g)	Removal (%)
A.awamorii	69.2	17.3
T.viride	73.2	18.3
P.chrysosporium	61.2	15.3
F2	63.1	15.8
F3	113.1	28.3
F7	16.1	4.0
F8	12.8	3.2

Table 2. Fungal lead adsorption by biomass from water containing 100 ppm Pb after 6 hr at pH 5.0

Fungal biomass(mg/100ml)	Biosorption (%) *T.viride*	Biosorption (%) *A.niger*
5	3.3	3.7
10	8.9	13.7
20	17.1	11.2
50	25.1	12.2
100	43.2	23.3
200	48.4	38.7
500	89.8	68.8

Laboratory experiments conducted at CSSRI, Karnal for bioremediation of heavy metals through micro-organisms showed encouraging results. Removal of lead from liquid medium containing lead at 50, 100 and 400 ppm was studied using four fungal isolates (F2, F3, F7,F8) and three fungal cultures (*A. awamorii*, *T.viride* and *P. chryosporium*). The Pb uptake by fungi increased with the increase its concentration in the medium, the maximum being at 400 ppm. In terms of Cd removal per unit weight of the fungus, it ranged from 12.76 to 113.08 mg/ g dry weight fungus and the isolate F3 (113.08 mg/g) followed by *Trichoderma viride* (73.21 mg/g) were found to the most efficient (Table 1). The dried biomass (500mg) of *Trichoderma viride* and and *A.niger* removed 89.8 and 68.6 percent of lead from water containing 100 ppm of lead at pH 5.0 after 6 hours of contact (Table 2). Similarly, in another adsorption study, fungus *A.awamorrii* and *A.flavus* removed 25.1 and 44.4 per cent of Cd from water containing 100 ppm of Cd at 500 mg dose of fungal biomass (Table 3). The above results indicate potential of some of the fungi for removal of heavy metals like Pb,&Cd, from liquids through adsorption. These can be used for removal of lead from wastewater at low cost and in eco-friendly way.

Table3. Fungal cadmium adsorption from water containing 100 ppm Cd after 4 hr at pH 5.0

Fungal biomass (mg/100 ml)	Biosorption(%) *A.awamorii*	Biosorption(%) *A.flavus*
5	0.0	0.0
10	8.9	4.5
20	10.0	13.8
50	16.9	16.0
100	22.6	35.5
200	22.6	35.5
500	25.1	44.4

Prospects of Groundwater Recharge in Poor Quality Groundwater Areas

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Introduction

Indiscriminate exploitation of groundwater has resulted in alarming decline of water tables in about one seventh of India's geographical area which is projected to expand to two- fifth of groundwater blocks by 2020. The escalation in pumping costs due to continuously falling water tables and associated socio-economic and environmental impacts are threatening the sustainability of agriculture, most particularly in the north western states of Punjab, Haryana and Uttar Pradesh. Water tables are declining at an alarming rate in about one seventh of India's geographical area, most notably in these three states (Table 1) which currently account for one fifth of the 1098 overexploited and critical groundwater blocks of the country (Mehta, 2006). The sustainability of highly productive rice- wheat systems, fundamental to the livelihood of farmers in these states and to nation's food security, is under grave threat due to excessive use of groundwater. The chemical quality of groundwater is being seriously deteriorated in many parts through domestic, agricultural and industrial pollution; fluoride and nitrate contamination is widely spread with serious repercussions on agricultural productivity and quality as well as on human and animal health.

Table 1. Overexploited and Dark Groundwater Blocks of North Western Indian States

State	Total Blocks	Number of over exploited and dark blocks		
		1984-85	1997-98	2005-06
Haryana	111	31	41	43
Punjab	138	64	83	108
Uttar Pradesh	819	53	40	63
India	7928	253	445	1098
Haryana, Punjab, Uttar Pradesh (% of India)	1068	148 (58%)	164 (37%)	212 (19%)

(Source: Mehta, 2006)

Haryana and Punjab have similar topographical and hydro- geological situations, both comprising of high yielding fresh water aquifers where rice- wheat cropping is practiced and saline groundwater regions where aquifers with relatively poor transmission characteristics occur. The number of private shallow tube wells has increased twenty fold to about 0.7 million in Haryana and forty times to 1.3 million in Punjab over the last four decades. These two states have semi- arid climate with annual rainfall of 450- 800 mm, about 85 percent usually occurring between June and September. About two- third and one- third areas of Haryana and Punjab are underlain with saline ground water, a major part by high residual sodium carbonate (RSC) waters. In both states, there is a constant rise of water levels in the saline areas and a decline in the fresh water areas. In almost all fresh water districts of Punjab and Haryana, watertables have been declining at a rate of 20- 30 cm every year over the past decade (Abrol *et al.*, 2004) and at almost similar rates earlier. The farmers are being forced to use deep submersible pumps in place of centrifugal pumps resulting in huge additional expenditure and extra power consumption. Transitional zones with highly variable hydro- geo- chemical characteristics occur between fresh and saline water regions in these states. There is a big uncertainty about continued availability of good quality water at deeper depths since excessive pumping from deeper aquifers is causing a random propagation of salt water front from saline to fresh groundwater regions. Effective management interventions like reduction of production costs, increased water productivity, enhancement of groundwater recharge, adoption of conservation agriculture, crop diversification and marketing policies are urgently needed. Of these, groundwater recharge technologies are discussed in this lecture.

Artificial Groundwater Recharge

Enhancement of artificial recharge of groundwater using rain and available excess canal water is possible through various surface spreading and well injection techniques. Central Ground Water Board (CGWB) and a number of other agencies including research institutes, universities and NGOs have undertaken a number of artificial recharge studies in India (CGWB, 2002; 2004). Chadha (2002) presented a broad categorization of these systems based on hydro- geological conditions and source of water to be recharged. The most notable for north- western states include CGWB studies on well injection and induced recharge in Ghaggar river basin in Haryana, well injection in Mehsana Distt. and subsurface dykes in Kutch region of Gujarat, a number of pilot studies on vertical and lateral recharge shafts in combination with injection wells in Punjab and Haryana including a major study in Dhuri Link drain in Punjab, integrated watershed management studies in *Shivalik* foothills of Punjab, Haryana and Uttar Pradesh and a regional IWMI study involving use of diverted excess monsoon water of river Ganga in western Uttar Pradesh. In hard-rock regions of eastern Rajasthan, Gujarat, Madhya Pradesh and Andhra Pradesh, groundwater depletion has invoked widespread community based mass movement for rainwater harvesting and recharge (Sharma *et. al.*, 2005). Renovation of village ponds, a common feature in most villages of India, by de-silting its bed can result in considerable enhancement in infiltration and groundwater recharge (Bouwer *et al*., 2001).

Due to declining depths of groundwater in many regions, well injection techniques for enhancement of groundwater recharge are getting increasingly accepted due to failure or delay in arrival of naturally recharged water to deeper sandy layers. In most marginally saline groundwater regions of Haryana, low discharge (5- 12 litre per sec) shallow cavity wells are used for irrigation (Boumans *et al.*, 1988). The groundwater salinity invariably increases with depth leading to abandoning of many shallow tubewells due to *upconing* of salts from deeper layers. The farmers operate the well for several hours every day to skim the least saline water and stopping when salinity of pumped water increases. Despite low transmissivity (< 500 m^2/day) of these aquifers, there is considerable scope and need to enhance groundwater recharge and improve groundwater quality by injection through cavity wells (Taneja and Khepar, 1996). Kamra *et al.* (2006) reported recharge rates of 2 to 3 litre per sec of filtered water through shallow cavity tubewells which are about one quarter of the pumping rates. In coarse sandy aquifers, these rates can be considerably higher. An overwhelming inference, emerging out of a recently concluded project on groundwater skimming and recharging for saline ground water regions in 4 Indian states (Haryana, Andhra Pradesh, Gujarat, Tamil Nadu) (NATP, 2006) was that individual farmer based recharging schemes can be more widespread and socially viable. Further, socio- economic issues, farmers' involvement and incorporation of small and less costly recharge filters in the existing or abandoned dug wells/ tubewells are vital in enhancing groundwater recharge in semi- arid regions. Besides augmenting the resource, the quality of natural ground water can be substantially improved in marginal groundwater regions through appropriate technologies and management. In this lecture, brief features of a few individual farmer based groundwater recharge structures are presented which are being propagated extensively in fresh and marginally saline groundwater regions of Haryana, Punjab, Uttar Pradesh and Gujarat through a Ministry of Water Resources (GOI) project.

Individual Farmer Based Recharge Structures

Under the NATP project at CSSRI, it was experienced that individual farmer oriented recharging schemes have more chances of success than the community/ governement sponsored recharge systems. In this direction, an individual farmer based pumping cum recharging system and a recharge shaft was installed in farmers' fields at village Bindrala in Assandh block of Karnal district. A socio- economic survey in the area indicated inadequacy of canal water supply, declining water tables, failure of tubewells due to collapse of cavities, erratic electricity supply and salt water *upconing* from deeper saline layers as the major problems faced by the farmers.

Both structures were designed based on test boring upto 50 m depth, textural analysis of soil, chemical analysis of groundwater at different depths and resistivity profiling. At the project site, a medium sand aquifer was available between 30 to 39 m below ground level which had good quality water without serious problem of salinity or residual sodium carbonate (RSC). The upper confining clay layer was not strong for sustained and there were no instances of successful strainer tubewells. The general watertable in the area is at about 10 m depth and the declining water levels are forcing farmers to deepen the pumping units to about 6 m depth in masonary chambers.

(a) Groundwater Recharge Through Existing or Abandoned Tubewells

The groundwater pumping cum recharging system (Fig. 1) comprised of a pumping tubewell installed at 39 m depth in a gravel- packed borehole of 25 cm ϕ which is used for recharging of excess rain and canal water. The tubewell consisted of a 10 cm ϕ blank pvc pipe upto 30 m depth followed by 10 cm and 15 cm ϕ perforated pvc pipes wrapped with synthetic filter in the sandy zone from 30- 33 m and 33- 39 m respectively. The perforations constituted about 10 % of the pipe area and were provided as sets of narrow slits. The annular space between bore and well pipe was filled with 15 mm ϕ gravel (in blind pipe area) and with 5 mm ϕ gravel in the strainer area. The filtering unit consisted of two chambers each of 1.25 m x 1.25 m x 2.0 m size. The available excess surface runoff from rain or canal water, after passing through a graded filter consisting of layers of coarse sand, gravel and boulders in the first chamber, enters the adjoining sedimentation chamber to settle any residual sediments. The filtered water is then carried through a plastic pipe into the gravel pack filled annular space to recharge sandy zones at different depths. Water recharging through gravel pack filled annular space instead of well pipe is aimed at minimizing the clogging of the pumping unit. During rainy season of 2004, large amount of rainwater and excess canal water could be recharged through this system. The cost of the recharge filter was about Rs. 15000, which can be further reduced with alternate filter designs. However, considering the uncertainty about the effectiveness of the design of recharge filter due to limited experience, it was decided to test this filter first for groundwater recharge of abandoned tubewells.

A recharge filter was designed close to an existing farm pond in eastern portion of CSSRI farm to drain excess rainwater to an adjacent abandoned cavity tubewell (10 cm ϕ; 28 m deep). Runoff water from

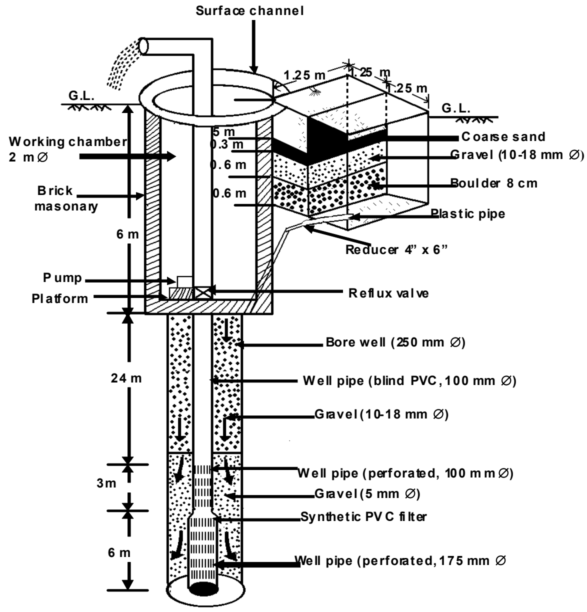

Fig.1. Pumping cum Recharging Structure at Bindrala village (Assandh block) of Karnal District

about 20 ha farm area is collected in the low lying farm pond which is also used for aquaculture. During occasional high intensity rainfall storms, the runoff amount is much more than the pond capacity and the resulting water stagnation adversely affects crop production and yields, particular of wheat due to winter rains. To meet such eventualities, the excess water after filling the pond is directed for recharge to an abandoned tubewell (Fig. 2) after filtration by passing through a grassed siltation zone of about 0.2 ha pond area and a designed recharge filter. The recharge filter consists of 0.5 m thick layers of boulders (5- 8 cm ϕ), gravel (1- 2 cm ϕ) and coarse sand each contained in a brick masonry chamber of 3.2 m x 1.9 m x 2.0 m size. The coarse sand in the recharge filter gets clogged by sediments in the runoff water and needs to be periodically washed/ replaced after each major rainfall event. A network of 10 observation wells upto 18 m depth was installed at different radial distances from the recharge structure to study the hydraulics and to estimate the recharge rates of the abandoned tubewell.

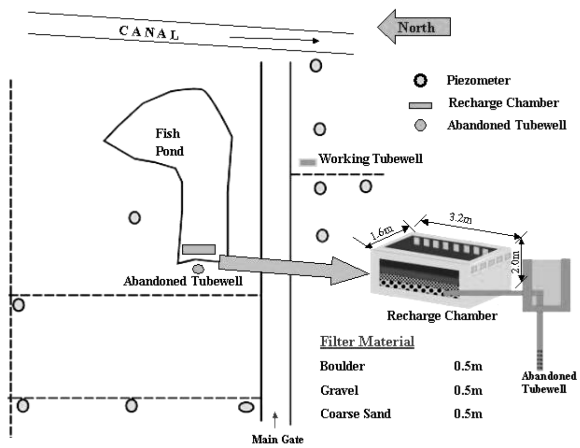

Fig.2. Groundwater recharge through an abandoned cavity tubewell at CSSRI farm

(b) Recharge Shafts

Effectiveness of large size vertical and lateral recharge shafts alone or in conjunction with injection wells have been successfully demonstrated by CGWB and other agencies in many parts of Haryana, Punjab and other states. Studies on usefulness of an individual farmer based recharge shaft of smaller size were undertaken by CSSRI at village Bindrala. The recharge shaft consisted of a bore hole of 45 cm ϕ and 45 m depth filled with gravel pack of 1.5 – 2.0 cm ϕ to carry filtered recharge water to favourable sandy zones. To safeguard against clogging, the surface runoff from rainfall or excess canal water is first passed through a graded filter consisting on coarse sand, smaller size gravel and large size boulders in a chamber of 1.65 m x 1.65 m x 1.8 m size. The borehole of the recharge shaft was installed in the middle of the filtering unit. The results on performance evaluation of the recharge shaft installed close to an irrigation channel in a farmer's field are encouraging. It is much simple in design and is easy to construct and maintain and serves the sole purpose of groundwater recharge without complexities of combined systems involving recharge as well as pumping. It can be constructed at convenient locations by individual farmers, preferably close to a pumping tubewell. The cost of the proposed recharge shaft varies from Rs. 15000- Rs. 20000/ depending upon the diameter and depth. This can be further reduced with alternate and improved designs and materials of filter and gravel pack. Recharge shafts of improved design are being propagated extensively under a CSSRI project discussed in the next section.

Farmers Participation Action Research Project (FPARP)

The sustainability of agriculture in north- western states of Punjab, Haryana and Uttar Pradesh is threatened due to alarming fall of water table, increasing pumping cost and related environmental impacts. The efforts on enhancement of groundwater recharge and water productivity based on multiple use of water, pond renovation, adoption of conservation agriculture and crop diversification are being strengthened in major way in farmers' fields through a Ministry of Water Resources (GOI) funded project in 100 villages in the state of Haryana (50 sites), Punjab (15 sites), Uttar Pradesh (10 sites) and Gujarat (25 sites). In first 6 months (till October, 2008), 25 sites have been identified in Karnal, Jind and Kaithal district of Haryana based on interaction with farmers, local tubewell mechanics and NGOs. Out of these, recharge shafts (Fig. 3), being installed at 16 sites, consist of bore hole of 45 cm ϕ and varying depths (depending on lithology) filled with gravel pack of 1.5 – 2.0 cm ϕ to carry filtered recharge water to favourable sandy zones. To safeguard against clogging, the surface runoff from rainfall or excess canal water is first passed through a graded filter consisting on coarse sand and smaller size gravel and big size boulders in a chamber of 1.65 m x 1.65 m x 1.8 m size. The borehole of the recharge shaft was installed in the middle of the filtering unit. To prolong the effectiveness of the shaft against clogging from subsurface layers, a high pressure pvc pipe of 12.5 cm ϕ, slotted at sandy zones, is provided in the middle of the hole for compressed air circulation for cleaning the clogged sediments from the gravel pack in the bore hole after a couple of years. Cavity tubewell type recharge structures having provision for filtration of runoff have been proposed for 6 sites while integrated farming systems involving farm ponds for agriculture / vegetables/ horticulture / fish culture have been proposed in marginally saline groundwater regions at 3 sites. A detailed questionnaire for collected relevant information on the soil, hydro-geology, crop production and farmers' incomes has been prepared to evaluate the impact of introduced interventions.

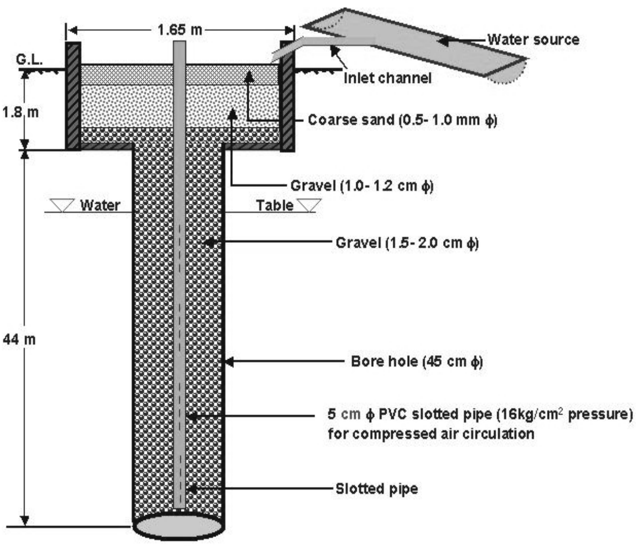

Fig. 3. Design of proposed recharge shaft to be installed in farmers' fields in Haryana under FPARP project

Recharge shafts, complete in all aspects have already been installed at 4 locations in Assandh block of Karnal district where groundwater is marginally saline/ alkaline. Recharge of rainwater in later part of monsoon considerably raised the groundwater levels and improved groundwater quality in the vicinity of these structures. The recharge shaft is simple in design and easy to construct and maintain and serves the major function of groundwater recharge. After every major storm the filtered sediments collected on the surface of coarse sand need to be cleaned and replaced with new or washed sand. It can be constructed at convenient locations by individual farmers, preferably in depression areas where runoff of surrounding areas collects. The cost of the recharge shaft can vary from Rs. 35000 – 40000 for 45 cm ϕ shafts of 30 - 40 m depth. Installation of recharge structures is in progress at others sites. Similar activities are underway in Gujarat and Uttar Pradesh under the supervision of Regional Research Stations of CSSRI at Bharuch and Lucknow.

Conclusions

The sustainability of agriculture in north-western states of Punjab, Haryana and Uttar Pradesh is threatened due to alarming fall of water table, increasing pumping cost and related environmental impacts. A number of activities and projects on groundwater recharge have been executed by governmental agencies and NGOs to arrest and sustain the ground water decline in falling water table areas. Incorporation of properly designed inexpensive filters in the existing or abandoned cavity or strainer tubewells or installation of small recharge shafts by farmers with small land holding can significantly enhance groundwater recharge in these areas. CSSRI has developed the design of a number of individual farmer based relatively less expensive recharge structures for fresh and marginally saline groundwater regions of Haryana. A groundwater recharge filter consisting of layers of boulders, gravels and coarse sand has been installed at CSSRI farm to manage excess surface runoff of monsoon and winter rains and to enhance groundwater recharge through an abandoned cavity tubewell. The efforts on enhancement of groundwater recharge through above discussed structures and strategies on multiple use of water are being strengthened in major way through a Ministry of Water Resources (GOI) funded project in 100 villages in the state of Haryana, Punjab, Uttar Pradesh and Gujarat. Design features of an individual farmer based recharge shaft, being installed extensively under this project, are presented in this lecture.

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Water Quality Determination for Irrigation Usage

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Introduction

In determining the water availability for irrigation, both quality as well as quantity must be evaluated; however, quality is often neglected. Quality of the water refers to its suitability for use and tells the effects, which it is going to impose on soil and plant growth if used for irrigation. The amount and kind of salt present determines the suitability of water for irrigation. The parameters which decide the suitability of water for irrigation are:

1. Electrical Conductivity (EC)
2. Residual sodium concentration (RSC)
3. Sodium adsorption ratio (SAR)
4. Specific ion toxicity viz., Boron, Chloride and sodium

Electrical Conductivity (EC)

Electrical Conductivity (EC) determines the amount of salts present in water. If the total quantity of salts in the irrigation water is high enough then the availability of water to the crops is decreased and crop yields are affected.

Residual Sodium Concentration (RSC)

It is one of the methods to evaluate the sodicity hazards of carbonate and bicarbonate rich waters. Carbonates and bicarbonates affects the soil permeability thus water availability to the crops. The residual sodium carbonate may be calculated by subtracting the quantity of Ca^{++} + Mg^{++} from total of carbonate and bicarbonate determined separately in a given sample and expressed in me L^{-1}. Thus,

$$RSC = (CO_3 + HCO_3) – (Ca + Mg)$$

Presence of such anions in irrigation water results in precipitation of calcium of the soil and thus increase sodicity hazard. Waters with >2.5 RSC are not suitable for irrigation. As per Eaton (1950), water containing 1.25 to 2.50 meq L^{-1} are marginal and those containing less than 1.25 meq L^{-1} RSC are probably safe. Good management practices and proper use of amendments can result in successful use of the marginal waters.

Sodium Adsorption Ratio (SAR)

The SAR procedure encompasses the infiltration problems due to an excess of sodium in relation to calcium and magnesium. High SAR waters can cause severe permeability problems. Meeting the crop water under these conditions may become extremely difficult. SAR can be calculated by the following equation:

$$SAR = \frac{Na}{\sqrt{(Ca+Mg)/2}}$$

Where Na, Ca and Mg are in meq L^{-1}

For SAR values greater than 6 to 9, the irrigation water is expected to cause permeability problem on the shrinking swelling types of soil. Permeability refers to the ease with which water enters and percolates down through the soil and is usually measured and reported as infiltration rate. An infiltration rate as low as 3 mm/hour is considered low while a rate above 12 mm/hour is relatively high. At a given SAR infiltration rate increases as water salinity increases.

Laboratory Determinations Needed to Evaluate Water Quality

Calcium and Magnesium

At an optimum pH of 10 the ethylene diamine tetra acetate (EDTA) forms soluble complexes with Ca and Mg ions. At the same pH the dye eriochrome black T (EBT) has a blue colour in the absence of Ca and Mg ions but forms red compounds with them which are less stable than the EDTA-Ca and EDTA-Mg complexes. So, if EDTA is slowly added to the solution containing Ca+Mg and EBT, Ca and Mg ions are gradually transferred from the dye complexes to more stable EDTA complexes until, when all have been transferred, the red colour of the dye complex gives way to the pure turquoise blue colour of the dye itself.

Reagents

1. Ammonium chloride-ammonium hydroxide buffer solution. Dissolve 67.5 g of ammonium chloride in 570 ml. of concentrated ammonium hydroxide and make to 1 liter.
2. Standard calcium chloride solution, 0.01 N. Dissolve 0.500 g of pure calcium carbonate (calcite crystal) in 10 ml. of approximately 3 N HCl and dilute to a volume of exactly 1 liter.
3. Eriochrome black T indicator. Dissolve 0.5 g of EBT and 4.5 g of hydroxylamine hydrochloride in 100 ml. of 95% ethanol.
4. EDTA solution (Versenate), approximately 0.01N. Dissolve 2 g of disodium dihydrogen ethylene diamine tetra acetate in water and dilute to a volume of 1 liter. Standardize it against 0.01 N standard calcium chloride solution.

Procedure

Pipette a 5 ml of aliquot 125 ml. Erlenmeyer flask. Add 10 drops of ammonium chloride-ammonium hydroxide buffer and 4 drops of EBT indicator. Titrate it with EDTA, using a micro burette. The colour change is from wine red to green. No tinge of wine red colour should remain at the end point.

Calculations

meq L^{-1} of Ca+Mg = (ml. of EDTA used x normality of EDTA x 1000) / ml. in aliquot.

Carbonate and Bicarbonate

When the pH value of a sample of water extract of a soil is above 8.4, carbonate ion is present, normally as sodium carbonate. If the sample is titrated with a standard mineral acid to a pH of 8.4, the carbonate ion is converted to bicarbonate and the amount of acid used is a measure of the carbonate present. The end point is judged in the titration using phenolphthalein indicator, which changes from pink to colorless.

$$CO_3^{-2} + H^+ = HCO_3^-$$

Bicarbonate ion also reacts with mineral acid and releases carbon dioxide into the solution

$$HCO_3^- + H^+ = H_2O + CO_2$$

The pH value at complete neutralization is about 3.8. Thus, bicarbonate may be measured by titration with mineral acid to a pH of 3.8 using an indicator unaffected by carbon dioxide. Methyl orange is suitable.

Reagents

1. Phenolphthalein, 1% in 60% ethanol.
2. Methyl orange, 0.01% in water.
3. Sulphuric acid, approximately 0.01 N, standardized.

Procedure

Pipette out 2ml of aliquot (saturation extract) into a porcelain crucible. Add 1 drop of phenolphthalein. If the solution turns pink, add standardized sulphuric acid drop wise with the help of micro burette until the colour just disappears. Designate this burette reading as *y*. Add 2 drops of methyl orange indicator and titrate to the first orange colour. Designate the new burette reading as *z*. save the titrated sample for the chloride determination.

Calculations

1. Mill equivalents per liter of CO_3 = (2*y**normality of H_2SO_4*1000)/(ml. in aliquot).
2. Mill equivalents per liter of HCO_3 = (*z*-2*y*)*normality of H_2SO_4*1000/(ml. in aliquot).

Sodium

Sodium is readily excited in a flame and emits characteristic radiations of 589.6 nm wave length producing an intense yellow light. The emitted light is passed through a sodium filter (yellow glass), the intensity of the emission may be measured photo electrically and related to the concentration of sodium in the solution.

Apparatus: Flame photometer with sodium filter

Reagents

1. Standard sodium solution, 1000 ppm. Dissolve 2.54 g of NaCl in water and make the final volume 1 liter.
2. Working standard solution containing 10, 20, 30, 40 and 50ppm sodium. Take 5, 10, 15, 20 and 25 ml. of 1000 ppm sodium solution in separate 500 ml. volumetric flasks and make the volume with distilled water.

Procedure

Bring the flame photometer into use according to the maker's instructions. Spray a standard sodium solution and water alternately and operate the sensitivity controls until the standard reads a selected point on the photometer scale and the water reads zero. Spray the other sodium standard solutions and record the scale readings. Spray the samples for analysis and record the readings.

Calculations

Prepare a graph relating sodium concentrations in ppm to the flame photometer scale readings obtained with the standard sodium solutions. From this graph obtain the sodium concentrations of the sample under analysis.

Adjustable Sodium Adsorption Ratio (Adj. SAR)

Sodium remains soluble and in equilibrium with exchangeable soil sodium at all the times. Out side influences have little effect on Na solubility or precipitation. Calcium, however, does not remain completely soluble or in constant supply but its content is constantly changing due to dissolution of soil minerals or precipitation as $CaCO_3$. Soon after irrigation, dissolution or precipitation may occur, changing the supply of calcium and establishing equilibrium at a new Ca concentration different to that in the applied water. SAR equation does not take into account the changes in Ca resulting from precipitation or dissolution during or following irrigation therefore somewhat in error. Therefore, SAR procedure has been modified and now called Adjusted Sodium Adsorption Ratio (adj. SAR). The adj. SAR is calculated using following equation:

$$\text{Adj. SAR} = \frac{Na}{\sqrt{(Ca+Mg)/2}} [1 + (8.4 - pHc)]$$ Ayers and Wescot (1976).

Where pHc = $(pk'_2 - pk'c) + p(Ca+Mg) + p\ alk$.

pk'_2 and pk'c are the negative logarithms of the second dissociation constant of H_2CO_3 and solubility product of $CaCO_3$, respectively both corrected for ionic strength. p (Ca+Mg) and p alk are the negative logarithm of the molal concentration of Ca+Mg and equivalent concentration of titratable bases (CO_3+HCO_3).

pHc is calculated using table which relate to the concentration values from the water analysis. The table values are then substituted in the pHc equation. $(pk'_2 - pk'c)$ using the sum of Ca + Mg +Na in me/l, p(Ca+Mg) using the sum of Ca + Mg in me/l and p alk is using the sum of CO_3 + HCO_3 in me/l are obtained from table 3 page 11 of Ayers and Wescot (1976). However, pHc is a theoretical parameter that is a calculated pH of the irrigation water in contact with lime and in equilibrium with soil CO_2. Values of pHc above 8.4 indicate a tendency to dissolve lime from the soil through which the water moves; values below 8.4 indicate a tendency to precipitate lime from the water applied.

Adj. R_{Na}

SAR is more and more frequently reported as R_{Na} and not SAR. The terms are synonymous. The Adj. SAR procedure presented by Ayers and Wescot (1976) is no longer recommended as it over predicts the sodium hazard. It was suggested that if this procedure is used it should be further adjusted by 0.5 factor to evaluate more correctly the effects of HCO_3 on calcium precipitation (adj. SAR x 0.5). As an alternative procedure, newer adj. R_{Na} (adjusted Sodium Adsorption Ratio) procedure of Suarez (1981) is recommended. It adjusts the calcium concentration of the irrigation water to the expected equilibrium value following irrigation and includes the effects of CO_2; of HCO_3 and of salinity (ECiw) upon the calcium originally present in the applied water but now a new part of the soil water. The procedure assumes a soil source of calcium – from soil lime ($CaCO_3$) or other soil minerals such as silicates – and no precipitation of magnesium. It can be used to predict more correctly potential infiltration problems due to relatively high sodium (or low calcium) in irrigation water supplies. The equation for calculation of adj. R_{Na} equation is as follows:

$$SAR = \frac{Na}{\sqrt{(Cax+Mg)/2}}$$

Where Na = Sodium in the irrigation water in meq L^{-1}

Ca_x = a modified Ca value taken from the table 11 page 62 (Ayers and Wescot, 1985) reported in meq L^{-1}. Cax represents Ca in applied irrigation water but modified due to salinity of the applied water (ECiw), its HCO_3/Ca ratio (HCO_3 and Ca in me/l) and the estimated partial pressure of CO_2 in the surface few millimeters of soil (PCO@ = 0.0007 atmospheres)

Mg = magnesium in the irrigation water reported in me/l

To use the Ca_x table, first find HCO_3/Ca ratio and ECiw from water analysis. The content of HCO_3 and Ca taken in meq L^{-1} and ECiw in dSm^{-1}. An appropriate range of calculated HCO_3/Ca ratios appears on the left side of the table and range of ECiw across the top. Note Ca_x value against the nearest HCO_3/Ca ratio and corresponding to ECiw from the table. The Cax value shown represents me/l of Ca that is expected to remain in solution in the soil water at equilibrium and is to be used in the equation.

Solved exercise

Water analysis report of a given water sample is

Ca	=	2.54 meq L^{-1}	Mg	=	1.34 meq L^{-1}
Na	=	6.87 meq L^{-1}	EC	=	1.1 dSm^{-1}
CO_3	=	0.38 meq L^{-1}	HCO_3	=	4.21 meq L^{-1}

Find RSC, SAR, Adj. SAR and adj. RNa

RSC = $(CO_3 + HCO_3) - (Ca + Mg)$ in me/l
= (0.38+4.21) – (2.54+1.34) = 4.59 – 3.88 = 0.71 me/l

$$SAR = \frac{Na}{\sqrt{(Ca_x+Mg)/2}}$$ Where Na, Ca and Mg are in me/l

$$\frac{6.87}{\sqrt{(2.54+1.34)/2}} = 4.93$$

$$Adj.\ SAR = \frac{Na}{\sqrt{(Ca+Mg)/2}}\,[1+ (8.4-pHc)]$$

Sum of Ca + Mg +Na = 2.54+1.34+6.87 = 10.75 me/l
($pk'_2 - pk'c$) obtained from the table using sum of Ca + Mg +Na = 10.75 me/l is 2.3
Sum of Ca+Mg = 2.54+1.34 = 3.88 me/l
p(Ca+Mg) obtained by using sum of Ca+Mg = 3.88 me/l is 2.7
Sum of $CO_3 + HCO_3$ = 0.38 + 4.21 = 4.59 me/l
p(alk.) obtained by using the sum of $CO_3 + HCO_3$ = 4.59 me/l is 2.3
pHc = 2.3+2.7+2.3 = 7.3
Adj. SAR = 4.93 [1+(8.4-7.3) = 4.93[2.1] = 10.35

Adj. RNa

EC is 1.1dS/m, HCO_3/Ca ratio 4.21/2.54 = 1.66
Cax value from table corresponding to the nearest values of HCO_3/Ca and ECiw is 1.43

$$= \frac{Na}{\sqrt{(Ca_x+Mg)/2}}$$

$$= \frac{6.87}{\sqrt{(1.43+1.34)/2}} = 6.87/1.18 = 5.82$$

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Estimation of Biological and Chemical Oxygen Demand in Wastewater

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Introduction

Some waters particularly those discharged by various industries as effluents, domestic waste water and sewage may also contain some specific nutrients and /or organic substances. These waters though unsuitable for reuse in industry or for domestic purposes, may be useful for irrigating the field crops if assessed thoroughly. These waters mostly have high biological oxygen demand (BOD) and chemical oxygen demand (COD) and would be more depleted of oxygen when added to poorly drained soils. High BOD waters when used on soil can cause poor aeration.

Biological and Chemical Oxygen Demand of Water

Any Oxidizable material present in a natural waterway or in an industrial wastewater will be oxidized both by biochemical (bacterial) or chemical processes. The result is that the oxygen content of the water will be decreased. Basically, the reaction for biochemical oxidation may be written as:

oxidizable material + bacteria + nutrient + O2 ==> CO2 + H2O + oxidized organics such as NO_3 *or* SO_4

Since all natural waterways contain bacteria and nutrient, almost any waste compounds introduced into such waterways will initiate biochemical reactions (such as shown above). Those biochemical reactions create what is measured in the laboratory as the biochemical or biological oxygen demand. Both the BOD and COD tests are a measure of the relative oxygen-depletion effect of a waste contaminant. Both have been widely adopted as a measure of pollution effect. COD typically correlates to BOD, which is one of the reasons the method was initially developed. It has been found to be a very useful tool in municipal wastewater treatment process monitoring and modeling, and to aid in process control.

To measure oxygen demand, the BOD method relies on enzymes produced by bacteria to catalyze the oxidation of organic matter during a five-day incubation period. In contrast, COD methods use chemical oxidants to oxidize organic matter. BOD simulates the actual treatment plant process by measuring the organic material that can be oxidized with the oxygen in the sample when catalyzed by bacterial enzymes. Although COD is comparable to BOD, COD actually measures chemically oxidizable matter.

A ratio can usually be established between the two analytical methods once COD and BOD data has been gathered over time. Many municipal laboratories are also finding that parallel COD and BOD testing is beneficial because the COD test can be used to target a specific BOD range, thereby eliminating the need for multiple BOD dilutions. It should be emphasized that there is no generalized correlation between the 5-day BOD and the ultimate BOD. Likewise, there is no generalized correlation between BOD and_COD. It is possible to develop such correlations for a specific waste contaminant in a specific water stream but such correlations cannot be generalized for use with any other waste contaminants or any other water streams**.**

Sample Collection Procedure

Water samples for irrigation quality assessment should be collected with utmost care. Water samples should be collected preferably in the plastic bottles after rinsing them with the same water 3-4 times. Care should be taken to collect the sample only after continuous discharge of the source 10-20 minutes. From shallow ponds, lakes, reservoirs, canals and rivers water sample should be collected from the centre of the width after avoiding the floating material on the top.

Practical suggestions

- Water sample should not be collected in dirty, used, leaking and contaminated bottles.
- Time interval between collection and analysis should be short (not more than 24 hours)
- Begin analysis within 6 hrs of collection if not possible store at or below 4^0C.

Sample Preparation and Pretreatment

Check the pH, and adjust it between 7.0 to 7.2 using a solution of sulphuric acid or sodium hydroxide of such strength that the quantity of reagent does not dilute the sample by more than 0.5%. If possible avoid samples containing residual chlorine by sampling ahead of chlorination process. If residual chlorine is present dechlorinate sample by using Na_2SO_3.

Take 50 ml of sample and acidify it with 10 ml of 1+1 acetic acid. Add about 1 g of potassium iodide. Titrate with sodium sulphite using starch as indicator. Calculate the volume of Na_2SO_3 required per ml of sample and add accordingly to the sample.

Dissolved Oxygen

Oxygen itself is not a pollutant in water but its deficiency is an indicator of several types of pollution in water. Dissolved oxygen levels in natural and waste waters depend on the physical, chemical and biochemical activities in water body.

Determination

The dissolved oxygen is determined by Winkler's method or iodometric titration. The sample is treated with manganous sulfate, Alkaline –iodide-azide reagent and finally sulphuric acid. The first two chemicals combine with dissolved oxygen to form a compound when acid is added, releases free iodine (from the potassium iodide). This iodine released is titrated against sodium thiosulfate solution.

Reagents

1. *Manganous sulphate solution:* Dissolve 480 g of $MnSO_4$ $4H_2O$ in distilled water and dilute to 1 liter.
2. *Alkaline-iodide-sodium azide solution*: Dissolve 40 g of NaOH, 20 g of potassium iodide in distilled water, add 0.5 g of reagent grade sodium azide to the cooled solution and make up the volume to 1litre.
3. *Starch solution:* Dissolve 2g of laboratory grade soluble starch powder and 0.2 g salicylic acid in 100ml of hot distilled water.
4. *Sodium thiosulphate solution (0.025N):* Dissolve 6.2 g of $Na_2S_2O_3$ in water and make up the volume to 1 liter using boiled distilled water. Keep in a coloured bottleStandardize with standard $K_2Cr_2O_7$.

Procedure

Fill a 300 ml BOD bottle with sample and close it with stopper avoiding entrapping of air. Remove the stopper and add 1 ml of manganous sulfate and 1ml of alkaline - iodide-sodium azide solutions at the surface of liquid. Stopper the bottle and shake thoroughly. Allow the brown precipitates of $MnO(OH_2)$ to settle halfway. Allow flock to settle a second time.

Add 2 ml of concentrated sulphuric acid to dissolve the precipitates by allowing the acid to run down the neck of the bottle above the surface of liquid. Re-stopper and shake well until the precipitate has dissolved. Pour 100 ml of the above solution in a 250 ml conical flask. If the solution is reddish brown, titrate it against 0.025 N sodium thiosulfate solution until pale yellow colour develops. Add a small amount of starch indicator and proceed to titration. Titrate till the first disappearance of blue colour and record the volume of sodium thiosulfate used.

Calculations

a. If whole the contents of the BOD were used for titration

$$DO\ (mg\ L^{-1}) = \frac{\text{ml of the titrant (sodium thiosulphate)} \times \text{Normality of titrant} \times 8 \times 1000}{\text{Volume of BOD bottle} - \text{Volume of } \textit{Manganous sulphate solution} \text{ and KI added}}$$

Determination of BOD

The biochemical oxygen method measures the ability of naturally occurring microorganisms to digest organic matter, usually in 5 - day incubation at 20^0C by analyzing the depletion of oxygen expressed as mgl^{-1}. The DO is measured at the beginning and recorded. After 5 days the DO is again determined. The BOD is then calculated on the basis of reduction in DO and the size of sample. The DO is determined by using the Winkler' titaration.

Apparatus

(a) Incubation bottles of 300ml capacity with ground glass stoppers.
(b) BOD Incubator controlled thermostatically at 20 ± 1^0C.

Reagents

Distilled water alone is unsatisfactory as a diluent. It is recommended to use BOD free water by passing the distilled water through a column of activated carbon and redistill it.

1. Phosphate buffer stock solution: Dissolve 42.5 g potassium dihydrogen phosphate in 700 ml distilled water and 8.8 gm NaOH. This should give a solution of pH 7.2.Add 2 g ammonium sulphate and dilute to 12 litre.

2. Magnesium sulphate solution. Dissolve 82.5 g magnesium sulphate in 1 litre of distilled water.
3. Calcium chloride solution: Dissolve 27.5 g anhydrous calcium chloride in 1 litre of distilled water.
4. Ferric chloride Solution: Dissolve 0.125 g ferric chloride ($FeCl_3 . 6H_2O$) in 1 litre of distilled water

Preparation of synthetic dilution water

Aerate the required volume of BOD free distilled water in a container by bubbling compressed air for 1-2 days to attain dissolved oxygen saturation. After aeration keep it at 20^0C for at least one day. At the time of use, add 1 ml each of phosphate buffer, magnesium sulphate, calcium chloride and ferric chloride for each liter of dilution of water. The sequence of adding these nutrients should be the same as given above.

Determination

Two BOD bottles will be used for the blank, six for the three dilution of the sample and two for a duplicate of one of the dilutions. Add some dilution water to each BOD bottle, and then add the necessary amount of well mixed sample. Fill each bottle to the top with dilution water and stopper. Avoid entrapping air bubbles. Place one set of bottles in the incubator in the dark for 5 days at 20 ± 1^0C. Determine and record the DO on the duplicate set of bottles with Winkler titration. At the end of incubation period, remove the BOD bottles from the incubator and determine the DO on each bottle.

Calculate the BOD of the samples.

Seeding

Samples which already do not contain enough of the proper bacteria can be analyzed for BOD only after addition of seed which is nothing more than a solution containing sufficient population of suitable bacteria.

Calculations

BOD without applying seed correction:

$$\text{BOD (mgl}^{-1}\text{)} = \frac{(D_1 - D_2) - (B_1 - B_2) * 100}{\% \text{ sample}}$$

BOD applying seed correction:

$$\text{BOD (mgl}^{-1}\text{)} = \frac{(D_1 - D_2) - (C_1 - C_2) * 100}{\% \text{ sample}}$$

D_1 = DO of diluted sample on 0 day
D_2 = DO of diluted sample on 5th day
B_1 = DO of diluted blank on 0 day
B_2 = DO of diluted blank on 5th day
C_1 = DO of diluted seed control on 0 day
C_2 = DO of diluted seed control on 5^{th} day
F = Ratio of seed in sample to seed in control = % seed in D_1/% seed in C_1

A volume correction is applied in case of low BOD samples where larger volume of sample is incubated. The following modified equation is to be used for applying the volume correction:

BOD without applying seed correction:

$$\text{BOD (mgl}^{-1}\text{)} = \frac{(D_1 - D_2) - (B_1 - B_2) * A * 100}{\% \text{ sample}}$$

BOD without applying seed correction:

$$\text{BOD (mgl}^{-1}\text{)} = \frac{(D_1 - D_2) - (B_1 - B_2) * F * A * 100}{\% \text{ sample}}$$

Where A is the fraction of dilution water added and given as

$$A = \frac{100 - \% \text{ sample added}}{100}$$

Determination of COD

Chemical oxygen demand measures the ability of hot chromic acid solution to oxidize both biodegradable and non-biodegradable (refractory) organic matter. COD determination has an advantage over BOD test because here the results can be obtained in less than 5 hours as compared to 5 days for BOD. The COD is usually higher than the BOD. But the amount will vary from waste to waste.

A sample is refluxed with a known amount potassium dichromate in sulphuric acid medium and the excess of dichromate is titrated against ferrous ammonium sulphate. The amount of dichromate consumed is proportional to the oxygen required to oxidize the organic matter.

Apparatus

1. 250 to 500 ml Erlenmeyer flask with standard (24/40) tapered glass joints.
2. Reflux condensers (12-inch) with standard (24/40) tapered glass joints
3. Electric hot plate.

Reagents

1. *Standard potassium dichromate (0.25N):* Dissolve 12.259 g of oven dried ($K_2Cr_2O_7$) in distilled water and dilute to 1 litre.
2. *Catalyst*: Add 5.5 g of Ag_2SO_4 /kg H_2SO_4. Keep overnight for dissolution.
3. *Mercuric sulphate crystals.*
4. *Ferrous Ammonium sulphate (0.25N):* Dissolve 98 g of [Fe $(NH_4)_2$ $(SO_4)_2$] in distilled water. Add 20 ml conc. H_2SO_4, cool and dilute to 1litre. Standardize this solution daily against standard $K_2Cr_2O_7$.
5. *Ferroin indicator:* Dissolve 1.485g of 1-10 Phenanthroline monohydrate and 695 g $FeSO_4.7H_2O$ in water and dilute to 1000ml. This indicator solution can also be already prepared.

Procedure

Place 0.4 g $HgSO_4$ in a reflux flask. Add 20ml or an aliquot of sample diluted to 20 ml with distilled water. Add 10 ml standard $K_2Cr_2O_7$ followed slowly by a catalyst consisting of 30 ml sulphuric acid which already contains silver sulphate. For complete and better oxidation of organic matter, it is necessary that the final concentration of H_2SO_4 is 50%. This slow addition along with swirling prevents loss of volatile compounds. Connect the flask to condenser and reflux for 2 hrs. Remove the flask and add about 80ml distilled water. Cool and titrate against standard ferrous ammonium sulphate using ferroin indicator. The colour changes sharply from green to wine red. Reflux a reagent blank under identical conditions preferably simultaneously with the sample.

Calculation

$$\text{COD (mgl}^{-1}\text{)} = \frac{(a-b)\, N^* \, 8000}{\text{Vol. of sample (ml)}}$$

Where "a" is the volume of *Ferrous Ammonium sulphate* in ml required for blank.

"b" is the volume of sample required for sample, and

"N" is the normality of FAS used.

The results are expressed as mg/l of O_2 reported to the nearest whole number.

Physiological Mechanisms of Salinity and Sodicity Tolerance in Crop Plants

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Introduction

Salinity and sodicity stresses are ever-present threats to crop yields, especially in countries where irrigation is an essential aid to agriculture. Although the tolerance of plants to saline conditions is variable but crop species are generally intolerant of one-third of the seawater salinity. Salt tolerance is genetically and physiologically a complex mechanism in halophytes and relatively less tolerant crop plants showing a wide range of adaptations. Plants growing under saline and sodic conditions invariably face increased concentrations of toxic ions in their tissues resulting from increased uptake of ions mainly Na and Cl under salinity, and Na under sodicity. Three major hazards associated with salinity are; osmotic (water) stress arising from more negative osmotic potential (higher osmotic pressure) of the rooting medium, specific ion toxicity – excess of Na^+, Cl^-, SO_4^{-2} or other ions, and nutritional imbalance.

Glycophytes and Halophytes

Majority of plants are relatively salt sensitive and almost all crop plants are unable to tolerate persistent saline and sodic conditions. Depending upon their responses, plants can be categorized into glycophytes and halophytes. The term halophyte literally means salt plants, but is used specifically for plants that can grow in presence of high concentrations of sodium salts and are described as native flora of saline soils. Examples of halophytes are *Atriplex, Sueda, Salicornia* and *Artemesia* species. On the other hand, the plants that can not grow in presence of salts are called Glycophytes or Sweet plants (Sharma and Goyal, 2003). Almost all crop species are glycophytes. Glycophytes have a selective advantage in non-saline soils over halophytes, because their growth rates are generally faster. In addition to the level of salinity, nature of salt responsible for salinization also has an important role to alter growth and development of plants.

Effect of Salinity on Plants

Salts in soil water may inhibit plant growth through two ways. First, the presence of salt in soil solution reduces the ability of plant to take up water, and leads to reductions in growth rate. This is referred to as osmotic or water-deficit effect of salinity. Second, excessive amounts of salt entering plants' transpiration stream can injure cells of transpiring leaves and may cause further reductions in growth. This is called the salt-specific or ion-excess effect of salinity (Greenway and Munns, 1980, Sharma and Gupta, 1986). The definition of salt tolerance is usually the percent of biomass production in saline soil relative to plants in non-saline soil, after growth for an extended period of time. For slow-growing, long-lived, or uncultivated species it is often difficult to assess the reduction in biomass production, so percent survival is often used. As salinity is often caused by rising water tables, it can be accompanied by water-logging. Water-logging itself inhibits plant growth and also reduces the ability of roots to exclude salt, thus increasing uptake rate of salt and its accumulation in shoots.

Variability in Salinity and Sodicity Tolerance of Crops/Species

Another criterion of salt tolerance of crops is their yield in saline versus non-saline conditions. Evaluation of salt tolerance of crops, vegetables and fruit trees have been made by the USDA Salinity Laboratory (Fig. 1) and Central Soil Salinity Research Institute, Karnal (Tables 2 and 3). According to these evaluations each species has a threshold salinity below which there is no reduction in yield, and thereafter yield reduction follows a particular trend with increasing salinity. Within crop species there exists a great variation in the ability to grow and yield under salinity or sodicity in soil and poor quality water. Even within a crop, different varieties or cultivars may differ widely in their tolerance to salinity or sodicity stress. Crop species like lentil, green gram, chick pea and other pulses are very sensitive to these stresses. Their growth is affected even at soil salinity of EC 4 dS m^{-1} or ESP 15. Wheat, rice and cotton are tolerant to moderate levels of salinity. Beet, barley and spinach can withstand high levels of these stresses.

Growth suppression is typically initiated at some threshold value of salinity, which varies with crop tolerance and external environmental factors which influence the need of the plant for water, especially the evaporative demand of the atmosphere (temperature, relative humidity, wind speed *etc*.) and the water-supplying potential of the root zone; and increases as salinity increases until the plant dies. The salt tolerances of various crops are conventionally expressed (after Maas and Hoffman 1977), in terms of relative yield (Y_r), threshold salinity value (a), and percentage decrement value per unit increase of salinity in excess of the threshold (b); where soil salinity is expressed in terms of EC_e, (dS m^{-1}) as follows:

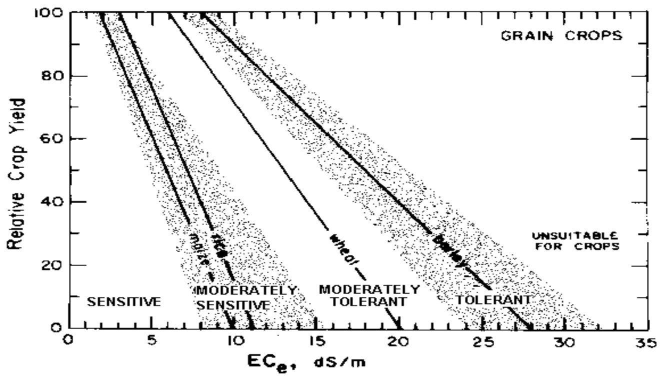

Fig. 1. Salt tolerance of grain crops (after Maas and Hoffman, 1977)

$Y_r = 100 - b (EC_e - a)$

Where Y_r is the percentage of the yield of crop grown under saline conditions relative to that obtained under non-saline, but otherwise comparable, conditions. This use of EC_e to express the effect of salinity on yield implies that crops respond primarily to osmotic potential of the soil.

Cultivated crops can be categorized into sensitive, moderately-tolerant and tolerant species according to their specific salt tolerance and these ratings are different for saline soil, sodic soil and saline water irrigated soil conditions. The order of resistance is not the same in all soils and this is at least partly due to the fact that relative ranking of a given species is not the same for different salts. Most plants are less resistant to NaCl than to Na_2SO_4, but some show the reverse relationship. Sodium carbonate is almost always more toxic to crop plants than NaCl and Na_2SO_4. Relative tolerance of major crops to salinity and sodicity stresses are presented in tables 2 and 3. Growth of some plants may be stimulated at low levels of salts even. For example, growth of cabbage, spinach, wheat and turnip may be stimulated in slightly saline environments.

Assessment of Tolerance

Ultimately, salt tolerance of crops is tested as yield from farmers' fields. However, evaluating field performance under saline conditions is notoriously difficult because of the variability of salinity within fields and enormous potential for interactions with other environmental factors, ranging from gaseous pollutants, soil fertility and drainage to temperature, light flux density and transpirational water loss. Consequently, prediction of 'field' performance is commonly carried out in trial plots, or using a solution-based method where salinity of medium can be readily adjusted to required values (Maas and Hoffmann, 1977). The latter often precludes measuring yield through lack of space and estimates of tolerance obtained from such experiments may not always be borne out by response of plants in the field. Evaluating tolerance is made more complex by variation in sensitivity to salt during the life cycle. For example, it has long been known that grain yield in rice is much more depressed by salt than is vegetative growth (Khatun and Flowers, 1995) and germination is relatively salt resistant. In tomato, tolerance at germination is not correlated with the ability to grow under salt stress because both are controlled by different mechanisms, although some genotypes have similar tolerance at germination and during vegetative growth. These examples suggest that while the assessment of tolerance is complicated by changes occurring during the ontogeny of a plant and may be technically difficult under field conditions. There is evidence of a genetically complex trait (Shannon, 1985), showing heterosis, dominance and additive effects.

Similarly, there is physiological evidence to support the view that salt tolerance is a complex trait. Halophytes show a wide range of adaptations from the morphological to the biochemical adaptations that include the ability to remove salt through glandular activity. Although control of ion uptake is exercised at the root, the ability to secrete ions has evolved into a successful strategy for salt tolerance. Some halophytes utilize salt-secreting glands to remove excess ions from their leaves, reducing the need for very tight balancing of ion accumulation and growth (Flowers and Yeo, 1988). Within less tolerant species, intra-specific variation in tolerance is also associated with variation in a wide variety of physiological traits.

Growth Reduction under Saline Conditions

Effects of saline soil are two-fold *i.e.* effects outside roots, and effects of salt taken up by plants. Salts in soil solution (osmotic stress) reduce leaf growth and to a lesser extent root growth, thus decrease stomata conductance and thereby photosynthesis (Munns, 1993). Rate at which new leaves are produced depends largely on the water potential of the soil solution in same way as for a drought-stressed plant. Salts themselves do not build up in the growing tissues at concentrations that inhibit growth. This is because meristematic tissues are fed largely by phloem from which salt is effectively excluded, and rapidly elongating cells can accommodate the salt that arrives in the xylem within their expanding vacuoles. So, the salt taken up by the plant does not directly inhibit growth of new leaves. Salt within the plant enhances the senescence of old leaves. Continued transport of salt into transpiring leaves over a long period of time eventually results in very high Na^+ and Cl^- concentrations, and they die. The rate of leaf death is crucial for survival of the plant. If new leaves are continually produced at a rate greater than that at which old leaves die, then there might be enough photosynthesizing leaves for the plant to produce some flowers and seeds. However, if the rate of leaf death exceeds the rate at which new leaves are produced, then the plant may not survive to produce seed. For an annual plant there is a race against time to initiate flowers and form seeds, while the leaf area is still adequate to supply necessary photosynthates. Perennial species enter a state of dormancy and survive stress, however, relative salinity tolerance of plants is given in table 1.

Table 1. Relative salinity tolerance of different plants

Tolerant (5 - 10 dS m^{-1})	Medium Tolerant (3 - 5 dS m^{-1})	Sensitive (1.5 - 3 dS m^{-1})
Barley, Sugarbeet, Cotton, Wheat, Safflower, Sorghum, Bajra, Rape, Mustard	Rice, Sugarcane, Ground nut, Maize, Sunflower, Guar, Tobacco, Castor, Soybean, Oat	Linseed, Sesame, Cowpea, Gram, Pea, Bean, Mung, Pigeonpea, Black gram
Sugarbeet, Amaranthus Spinach, turnip	Tomato, Brinjal, Cucumber, Cauliflower, Cabbage, Knol- Khol, Potato, Sweet Potato, Peas, Cucurbits, Carrot, Onion, Lady finger, Cucurbits	Radish, Beans

Two responses occur sequentially, giving rise to a two-phase growth response to salinity. The first phase of growth reduction is quickly apparent, and is due to the salt outside the roots. It is essentially a water stress or osmotic phase, for which there is surprisingly little genotypic difference. Then there is a second phase of growth reduction, which takes time to develop, and results from internal injury (Fig. 2). An experiment was conducted with two genotypes of contrasting Na^+ uptake rates and known differences in salt tolerance. After soil salinization during first 3-4 weeks, there was large growth reduction in both genotypes, called 'Phase 1' response, and it is due to osmotic effect of the salt. Genotypes differed after 4 weeks, one with low Na^+ uptake rate continued to grow, although still at a reduced rate compared to the controls in non-saline solution, but the other with high Na^+ uptake rate produced little biomass and many individuals died. This is 'Phase 2' response, and is due to genotypic differences in coping Na^+ or Cl^- ions in soil, as distinct from osmotic stress.

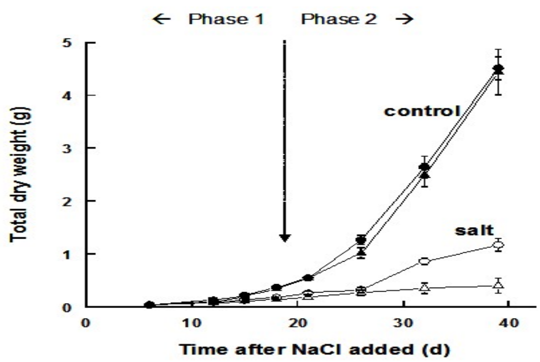

Fig. 2. Two accessions of diploid wheat progenitor *Ae. tauschii* grown in hydroponics (control solution - closed symbols; 150 mM NaCl - open symbols; circles denote tolerant accession; triangles the sensitive one. Arrow marks time where salt injury symptoms seen on sensitive accession; at the point, proportion of dead leaves was 10 and 1% in sensitive and tolerant accessions, respectively, Munns *et al.,* 1995).

Physiological Mechanisms of Injury to Plant under Salt and Water Stresses

The interaction of salts with plant physiological processes is obviously complex. There are many salt species, many mechanisms, and many organs, tissues and cells involved. Reasons for the observed reduced growth and damage to tissues include; reduced water uptake *i.e.* physiological drought, injury to cell membranes due to Na^+ to K^+ selectivity, Ca^{2+} to Na^+ selectivity, transport and leakage. Osmotic adjustment through solute accumulation in symplast, or apoplast (cell wall) resulting in cell dehydration, damage to developed tissue, decreased photosynthetic surface and lack of sufficient metabolites for growing tissue. Cost of osmotic adjustment, compartmentation and exclusion, hormonal balance in the plant and nutrient deficiencies, especially N and K are also equally important.

Plants growing under saline conditions invariably face increased concentrations of toxic ions in their tissues. This results from increased uptake of ions mainly like Na^+ and Cl^- under salinity, and Na^+ under sodicity. Concentration of salts accumulation is higher in sensitive crops than the resistant ones. In chickpea, salt tolerance depends on exclusion of Na^+ and Cl^- from shoot; Na^+ was more excluded than Cl^- as Cl^- concentrations were 2-4 times higher than Na (Sharma and Kumar, 1992; Sharma, 1997). In wheat, Na^+ was more than Cl^- in the top and also more in shoots of sensitive than resistant genotype (Sharma, 1996) indicating that concentrations of Na^+ and Cl^- determine relative salt resistance. Lots of evidences correlating reduced Na^+ with salt tolerance are available (Jeschke, 1984; Schachtman *et al.,* 1991; Sharma, 1996). In wheat grown under saline conditions, lower Na^+ and Cl^- levels are maintained in apical tissue by preferential exclusion of ions; otherwise leaf to leaf gradient in Na^+ and Cl^- became steeper with increase in external salinity. Correlation analysis on individual plants indicate that excluding Na^+ at low salinity, and Na^+ and Cl^- at high salinity, were significant with growth performance.

It is difficult to distinguish between Na^+ and Cl^- toxicity, but data on chickpea indicated that injury was more with Cl^- than Na^+. Increase in accumulation of chloride with longer duration of salt exposure has been observed at second and third sampling stages in older plants. Decreasing rates of plant growth and increasing concentrations of ions with prolonged exposure to salinity suggest their failure to adapt to salinity, more so in the salt sensitive genotype (CSG 8890). Chickpea plants showed higher salt sensitivity despite negligible effects on their K^+ concentrations. Chloride is the prevalent anion accompanying Na^+ and K^+ and its concentration was in the same range as the sum of Na^+ and K^+. There is sufficient evidence that salt tolerance is a multi-gene trait. Plants differ markedly within and between species in their salt tolerance. Depending on the source of salinity and pattern of rainfall or irrigation in farmer's fields, crop plants may experience salt stress transiently at different stages of the growth cycle, or continuously throughout the season, however, impact depends on intensity and duration of stress and stage of the crop resulting in short and long term responses.

Short-Term Growth Responses

Earliest response of plants after exposure to salinity is reduction in leaf growth because of water deficit: the response is very rapid (within minutes, Matsuda and Riazi, 1981), and is usually proportional to the osmotic potential of the external solution, and is rapidly reversible (Munns *et al.* 1981; Rawson and Munns, 1984). The rate of leaf area expansion is a short- term response *i.e.* it is set within a day of exposure to salinity. Plants exposed to salinity show immediate cessation of growth and loss in water status, and may be followed by recovery if the stress is of a moderate level (Table 2). Plants may suffer severe injury and mortality if the stress is of a higher level.

Table 2. Plant fresh and dry weight, leaf diffusive resistance (LDR.), transpiration rates and leaf water potential (LWP) of third fully expanded leaves

Days after salinization	Fresh wt (g)	Dry wt. (g)	LDR (S cm^{-1})	Transpiration ($g/cm^2/s$)	LWP (-MPa)
Normal	47.8	8.2	1.7 ± 0.2	11.7 ± 2.1	0.8 ± 0.2
2	43.3	8.7	15.8 ± 2.2	1.2 ± 0.3	1.8 ± 0.3
4	53.2	9.0	6.0 ± 0.6	5.1 ± 1.6	1.6 ± 0.2
6	57.4	9.6	5.3 ± 0.6	7.0 ± 1.1	1.4 ± 0.2
9	66.9	12.1	3.7 ± 0.4	7.9 ± 1.0	1.4 ± 0.2

Therefore, it should be a standard practice when applying saline solutions to plants in pot culture to minimize osmotic shock by increasing salinity concentrations in gradual small increments over a period of several days unless the experiment is specifically aimed at determining the effects of sudden osmotic shock to the plants.

Long-Term Growth Responses

In longer- term, being weeks for a short-lived annual to months or years for a long-lived species, prolonged transpiration will cause salts to build up in the leaves. Thus a specific effect of ions on leaves and parts will occur. Salt concentrations in plants usually continue to increase with time. In non-halophytes the fully expanded leaves are adversely affected long before the young leaves, as salt concentrations at a given time of exposure to salinity are always higher in the oldest leaves, and the oldest leaves die long before the effects on younger leaves become apparent. The higher salt concentrations in the older leaves may result entirely from a product of time by transpiration rate or at least partly from exclusion of specific ions from xylem supplying to younger leaves (Yeo and Flowers, 1982).

Salt concentrations in individual leaves usually increase with time. Glycophytes show no signs of regulation of the salt concentration in their leaves unlike many halophytes which can maintain constant salt concentrations (Flowers and Yeo, 1986). Thus, for non-halophytes it is inevitable that ion concentrations will eventually build up in the older leaves, and they will die. Concentrations at which this occurs will depend upon the ability of the species to compartment salts in the vacuole, and the time it takes to happen will depend mainly on the salinity level, the ability of roots to exclude salt, and the ambient conditions affecting rate of transpiration. Salt build up in the cytoplasm interferes with metabolism, and in cell wall causes loss of turgor and then excessive loss of water. Death of many older leaves limits productivity due to decreased photosynthetic leaf area. This results in the decline in the production of carbohydrate and ultimately production per plant falls below the levels that plants are not able to sustain growth.

Under saline conditions, water deficit is usually experienced first, followed by toxicity effects, and then nutritional effects. However, the temporal separation of these effects and their relative severity are determined by genotype and environment. Plants growing under saline conditions are invariably faced with the increased concentrations of toxic ions in their tissues. This results from increased uptake of ions like mainly Na and Cl under salinity, and Na under sodicity. Concentrations of salts are higher in the sensitive crops than the resistant ones.

Because of the differences in the effect of salinity on various enzymes, cells and organs it is difficult to distinguish between the osmotic and ionic effects of salinity on various plant processes. The most common method available for distinguishing between secondary osmotic and primary salt injury is to compare the effects of isotonic solutions of salts with those of organic substances. Organic substances like mannitol, sugars and preferably polyethylene glycol (having molecular weights in the range of 6,000 to 10,000) are used.

Crop Improvement for Salinity and Alkalinity Stresses

The genetic improvement of salt tolerance in crops can be achieved both by using traditional breeding methods as well as modern tools of genetic engineering and molecular biology. The prerequisites for genetic or breeding approaches are existence of sufficient heritable variation in a particular character and a means by which genetic information can be transferred in a stable form. Measurable differences must exist between individuals that can produce viable offsprings so that stable transfer of salt tolerance can be demonstrated. Promising studies have been undertaken with rice, wheat, wheat grass, barley, gram, mustard and tomato. Generation of stress-tolerant and high yielding breeding lines/varieties in crops and physiological indices and field evaluation of suitable crop varieties for use in biological reclamation technology is essential.

Genetic improvement of salt tolerance of crops can be achieved by selection among agronomic cultivars; evaluation of germplasm collected from areas having similar stress situations; use of wild germplasm sources to develop new cultivated species; hybridization and ploidy changes, cell culture; and somaclonal variation, somatic hybridization, molecular biology and recombinant DNA *etc*.

Future developments in genetic engineering may provide useful tools for speeding up the breeding programme as some genes responsible for tolerance traits have been identified in some crops. Better understanding of the physiological mechanisms governing plat responses to salinity, alkalinity and other abiotic stresses will help in further enhancement of tolerance of crops thereby increasing the productivity of these soils.

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Salinity/ Sodicity Tolerance in Wheat

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Introduction

Selection of suitable crop varieties is of great economic importance in exploiting saline alkali lands. Crop genotypes/ cultivars differ in their ability to grow on salt affected soils based on inherent tolerance mechanisms. Plant breeders can exploit this variation to develop suitable wheat varieties for such areas. In India 6.73 million hectare area is affected by either salinity or sodicity out of which 3.77 and 2.96 m ha are afflicted, respectively by sodic and saline soil.Wheat is one of the major crop grown in these soils. Breeding wheat varieties for salt affected soils may help to a great extent in stabilizing production for the rapidly growing population of the country. Wheat yields are very poor and uneconomical in initial 4-5 years of reclamation and management practices will continue to play an important role in getting better yields of wheat in such soil. However, salt tolerant varieties play a very important role by requiring lesser inputs in the form of chemical amendments. Moreover under situations where the poor quality water is the only source of irrigation, salt tolerant varieties offer the best technology for the farmers to adopt. Therefore it is now a great concern to breed wheat varieties for salt affected soils, which may help to a great extent in stabilizing production for the rapidly growing population of the country. In India lot of work related to mechanisms of salt tolerance (Sharma, 1987) and screening and evaluation of genotypes under stress has been carried out and documented (Mishra, 1994, 1996; Mishra *et al.,* 1997, Singh, 1991, 2005 and Singh *et al.*, 2005).

Estimation of Salt Tolerance and Threshold EC or pH and Salt Tolerance Index

Salt tolerance is the ability of the plant to withstand the effects of high salts in the root zone or on the plant's surfaces without a significant adverse effect. It is a complex function of yield decline across a range of salt concentrations. The salt tolerance in a particular crop can be measured on the basis of the following two parameters.

Crop yields are generally not decreased significantly until the ECe or pH or ESP exceeds a specific value for each crop. This value is known as the threshold level for that crop which varies widely for different crops. However, the ralative tolerance of a crop is evaluated on the salinity/alkalinity level at which 50% decrease in yield may be expected as compared to yield on normal soil under comparable growing conditions. In wheat the threshold salinity level is 6.0 dSm^{-1} and 50% yield reduction is observed at 14.0 dSm^{-1}.

Threshold EC is the salinity that is expected to cause the initial significant reduction in the maximum expected yield Y_{max}.

Slope (s) : This is percent of expected yield to be reduced for each unit of added salinity above the threshold value.

The relative yield (Y) at any salinity (ECs) exceeding EC, can be calculated as

$$Y = 100 - s(ECs\text{-}EC,), \qquad 1$$

The salt tolerance Index

$$S = Ys/Yc \qquad 2$$

$$S = (1-(Ys/Yc))/(1-D) \qquad 3$$

Where Ys : Yield under salinity
Yc : Yield under non saline
D : **Mean** of all gentypes under stress/ mean of all genotypes under normal

Genotypic Selection for Salt Tolerance

The major concern for breeding under stress is to increase the selection efficiency under stress. Unlike breeding for normal environments selection under actual field condition may not be rewarding always. Although the ideal situation will be to screen for grain yield under actual stress environment but the level of soil heterogeneity in such fields are very high. This results in the selection of some of the genotypes which are not otherwise tolerant. These genotypes get selected due to normal soil patches in between stress. Therefore there is need to select genotypes under artificially created environments along with target sites.

In situ Field Evaluation

The field gradient of soil salinity is determined by the soil tests at small intervals of space and a long strip running full length across the salinity/sodicity gradient is allotted to each genotype. The plots generally measured 2 to 3 rows of each variety, 20-30m long. This allows exposure of all genotypes to a varying salt stress conditions to a comparable degree. The layout of such a test is generally an augmented design in which a set of check variety is replicated many times or an incomplete block design such as simple lattice with a set of check varieties (both tolerant and sensitive). It is further possible to cut across the long plots in several parts to obtain varietal performance at varying levels of soil sodicity. There has thus been an overall increase in selection efficiency. While advancing the materials to minimum numbers, the limited varieties are evaluated in randomized block design with 3-4 replications involving national and local checks for initial yield evaluation. The involvement of more number of checks has been found better in data processing and finalizing the tolerant lines. Selected genotypes are further evaluated as station trial on bigger plot basis to evaluate their yield potential.

Screening in Microplots

Soil heterogeneity and spatial variability hinders the reliability of the response of the genotypes in true and dependable way. At CSSRI mini field environments have been developed with varying levels of controlled salinity and sodicity environments. It is possible to create and maintain desired levels of salinity and sodicity in these microplots simulating field conditions minus the soil heterogeneity. Although the plot size is very small but there is good control over micro environment.

Screening in Pots

For more precise study of the individual plant response under a constant stress, round porcelain pots of 20 or 30 cm diameter, with a capacity of 8 or 16 Kg. soil with a provision to allow or plug off leaching from bottom, are used.

Screening in Trays

For large scale screening of varieties at germination and seedling stage, shallow-depth wooden germination trays provided with polythene sheet lining on the inner face are being used. They are very useful in control of salinity, sodicity and moisture. They allow a simulation of germination response of the field. These study give indications about relative germination and survival rates. These trays are used for seedling stage studies only.

Germination Studies As a Selection Criteria

Large number of investigations on differential responses of crops or varieties has been reported at germination stage and attempts have been made to utilize this information in extrapolating tolerance limits for the final performance of those crops or varieties. More than often such attempts are likely to be frustrating because tolerance characteristics at the two stages may be quiet unrelated, for example in our experiments, we have found that one variety is comparatively more tolerant at germination but another variety is relatively better than that for grain yield. Therefore, the tolerance of crops/varieties has to be assessed in relation to the specific component and specific situation at particular stage of plant development and trait which is responsible for the economic yield. Standardization of screening techniques is an essential pre-requisite before the screening is undertaken and plant variables are adequately monitored so that performance of a genotype is suitable assessed. The evaluation can be made by measuring different parameters like germination under salt stress, absolute yield under salt stress and yield and growth under salt stress conditions compared to be performance under normal soil conditions.

Soil salinity/alkalinity may affect germination by (a) increasing the osmotic pressure of soil solution to the point that will restrict the intake of water or by (b) causing toxicity to the embryo. Both factors retard/prevent the germination, resulting in poor stand of the crop. Among the vegetative growth phase, seedling stage is the most efficient stage for screening large number of genotypes for salt tolerance. Germination rate is another way to distinguish between genotypes under stress. For measuring germination rate/emergence rate counting of germinated seeds starts on 6th day when the first coleoptiles emerged and continued until the 24th day when data is recorded on 6 days interval during the period of observations for the calculation of germination rate index. Total germination in case of different varieties under study is expressed as percentage of germinated seeds. Germination rate or emergence rate is calculated by a slight modification of the method suggested by Maguire (1962). Singh and Rana (1989) used this method in wheat and found it very useful for screening of large number of genotypes for salinity and alkalinity conditions. Genotypic values of this index are calculated as follows:

$$\frac{\text{Percentage of emerged seedlings}}{\text{days to first count}} + \frac{\text{\% of additionally emerged seedlings}}{\text{days to second count}} + \frac{\text{\% of additional emerged seedlings}}{\text{days to final count}}$$

The values obtained at each count are summed up at the end of the germination test to obtain the emergence index. With the help of these values, it is possible to differentiate between two genotypes which are having some value of germination percentage under same salt stress conditions. Means faster in germination is considered to be better under salt stress conditions.

Physiological Parameters for Salt Tolerance

Under saline solution, the concentration of non-essential or toxic ions are greater than that of essential elements, for example, Na concentration in saline soil solutions may exceed that of K and yet the Na: K ratio in plants growing on these soils may be near one or even less. This high specifically for K uptake is present in wide range of plants. Higher K/Na ratio would characterize a tolerant variety and a low ratio value, the relatively susceptible one. The salt tolerant Kharchia materials of wheat have relatively low Na/K ratio in comparison to susceptible varieties HD2009, or HD4530. In preliminary analysis of leaf samples of 10 varieties (through ICP technique) grown under drained sodic conditions, clear toxicities due to Al and Fe in most varieties was observed in the microplots at CSSRI Karnal. Additional toxicities of Na, B and Mn also occur in several varieties. Grain yield under sodic stress was found to be correlated with leaf Ca, Mg and S concentrations. Selection for grain yield under sodic stress can be done indirectly by selecting genotypes based on there higher K/Na ratio, leaf Ca, Mg and S concentrations and lower Na, Al and Fe concentrations in the initial growth stage.

Yield Components, Character Association and Combining Ability Studies

Tolerance to salt stress conditions is very complex genetic phenomenon. Germination, plant stand, vegetative growth, fertility and other yield components are important criteria for diversity of tolerance to salt stress conditions. Character association has been found to undergo changes under the influence of sodicity and salinity. Sodicity tolerance have been found to be correlated with tillers/plant and biomass per plant (Singh *et al.* 2006). Intensive selection should be exercised in developing improved varieties for salt affected soils based on the yield attributing characters. Singh and Rana (1987a); Singh 1988 and Singh and Chatrath (1997) reported combining ability of grain yield and contributing traits in diallel sets of bread wheat varieties under salt stress conditions. Both additive and non additive gene effects were found important for the inheritance of all the studied traits. Best general and specific combiners were found as parents HD 2285, KRL 1-4, PBW 65 and cross KRL 3-4 x KRL 1-4 respectively.

Genetic Variability for Salt Tolerance

A large number of Indian and exotic varieties have been screened at CSSRI, Karnal under sodicity and salinity. These varieties have been categorized under four categories: tolerant, medium tolerant: medium sensitive and sensitive for the purpose of standardization and making comparisons. The list of some of the known varieties belonging to different classes has been given in the following table.

Tolerant[1]	Medium Tolerant[2]	Medium Sensitive[3]	Sensitive[4]
Kharchia 65	KRL 19	HD 2009	HD 4502
KRL 3-4	KRL 1-4	HD 2285	HD 4530
KRL 99	KRL 35	HD 2851	Raj 911
		HD 2329	Moti
		UP 2338	Hira
		PBW 343	Mexicalli 75
		PBW 502	Altar 84
		WH 542	

1. Grows well and sets viable seed upto soil pH_2 9.6 or ECe 8.5 dS m^{-1}
2. Grows well and sets viable seed upto soil pH_2 9.3 or ECe 6.5 dS m^{-1}
3. Grows well and sets viable seed upto soil pH_2 9.1 or ECe 5.5 dS m^{-1}
4. Grows well and sets viable seed upto soil pH_2 8.5 or ECe 5.0 dS m^{-1}

In wheat it has been demonstrated that diversity for salt tolerance was greater among countries within regions while diversity among different species of wheat was greater than among ploidy levels (Singh and Chatrath, 1993). Screening more germplasm from the arid and semi arid regions especially from salt affected soils has been advocated (Sayed, 1985).

Breeding for Salt Tolerance

Genetic adaptation of crops to salinity requires that sufficient heritable variability exists within species to permit selection of salt tolerant strains and those plant characteristics which confer salt tolerance, be identified. By exploiting the inherent variability in wild species such as crested wheat grass, it has been suggested that the production under saline conditions could be more than double. In case of salt resistance, it would seem that it is essential to work hand to hand with the plant physiologists and soil scientists to provide appropriate conditions for selection and development of effective selection parameters for salinity tolerance.

Germplasm Collection and Evaluation

The present day varieties have a relatively narrow genetic base and are poorly adapted to adverse environments such as salinity. However, endemic genotypes from problem environments may provide the basic germplasm for breeding salt tolerant varieties with acceptable yield potential. Genetic resources collected as populations samples of specific stress environments should be maintained as population without the loss of their genetic integrity. The environments where the genetic resources are to be rejuvenated should provide equal opportunities for all seeds to grow and produce progenies; otherwise genetic drift may occur due to poor performance of certain portion of the population.

The classification of germplasm or genetic material with respect to tolerance under stress is a very important task. It is not possible many times to screen genetic material under different salinity/stress levels under field conditions. Nevertheless, a soil scientist can describe precisely what is causing the stress in terms of salinity, pH and mineral toxicity/deficiency. It is possible to duplicate the salt stress under laboratory conditions. Thus various levels of combinations can be experimentally constructed and screening of genotypic can be done

Varietal Improvement for Salt Tolerance

Evaluation and breeding work starts with the introduction, collection, evaluation and systematic cataloguing of available Indian and exotic germplasm. All the conventional breeding methods can be followed i.e. introduction, selection, hybridization, mutation and shuttle breeding approach for the development of salt tolerant varieties. At CSSRI Karnal, two salt tolerant wheat varieties, KRL 1-4 and KRL 19 have been developed by Pedigree method of selection and released through CVRC. KRL 1-4 and KRL 19 have been well taken up by farmers through different seed agencies or directly of Haryana, U P and Rajasthan. CSSRI has been producing and distributing nucleus, breeder and labeled seed of these varieties. So far more than 700 quintals of breeder/labeled seed has been distributed to seed agencies and farmers. Farmers can grow KRL 19 and KRL 1-4 under salt stress and can generate additional yields up to 7.0 - 8.0 qt/ha which may fetch higher economic returns in comparison to traditional wheat varieties.

Two salt tolerant genetic stocks KRL 35 and KRL 99 have also been registered at NBPGR using this method. In addition a modified bulk pedigree approach can be employed under stress conditions, where individual F2 plants can be harvested as bulk up to F4 generation followed by individual plant selection and handling the population as in pedigree method.

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Use of Molecular Markers in Enhancing Salt Tolerance in Rice- Progress and Prospects

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Introduction

Rice is an important crop in the world and remains the principal staple food in Asian countries. During the last few decades, world rice production has doubled from 257 to 600 million tones. This has mainly been achieved through the application of Mendelian genetics and conventional plant breeding methods coupled with improved production technologies. A study conducted by IRRI, Philippines showed an upward trend in rice yield in Asia starting from 1967 to 1997 and the annual rate of yield increase was estimated as 53 kg/ha which was attributable to genetic improvement of rice. Presently we need to sustain yield in irrigated areas and raise its level in stress areas with due consideration of nutritional aspects. However, we need to produce 25% more rice by 2025 to match the growing population. Moreover, this increase in rice production has to come with less land, less water, less chemicals and less labour. Furthermore, many biotic and abiotic stresses including salinity are a continuing threat to rice productivity and sustainability.

Rice is a model crop and endowed with ample genetic variability for the adaptability attributes to bear the extremes of temperatures, altitudes, photoperiods, water stress (submergence to drought) and soil types (acidity, sodicity, salinity, nutrients toxicities and deficiencies) etc. Among cereals, it has the smallest genome (430Mb) which facilitates genome sequencing, gene detection and transfer through molecular approaches. Breeding and selecting suitable and tolerant varieties of rice can bring about enhancement of productivity with less cost on a sustainable basis from salt affected areas. However, salt tolerance is an attribute which is governed by different physiological mechanisms and genes (Ren *et al*, 2005, Moradi and Ismail, 2007, Ismail *et al*, 2007) and is thus amenable to genetic improvement (Gregorio *et al.*, 2002, Flowers, 2004). In the Indian context, Singh *et al.* (2004 a) have extensively reviewed the progress and future thrust areas of harnessing biological phenomenon of salt tolerance in enhancing agricultural productivity. Salt tolerance is controlled by multitude of mechanisms like Na exclusion, K mining ability, lower Na/K ratio, low Cl uptake, tissue tolerance and higher growth vigour, donors for these traits have been identified (Singh *et al.,* 2004b). It is imperative to pyramid all these traits together in a single genotype to achieve a higher level of tolerance either through recombination breeding (Singh *et al.,* 2004 b) or heterosis breeding (Gautam and Singh, 2004). However, combining all the tolerance attributes into a single cultivar to achieve “super-tolerance” is practically very difficult through conventional breeding.

The complete deciphering of rice genome sequence, the first in any cereal crop has opened up new vistas in its genetic improvement through molecular markers approach (IRGSP, 2005). With this global initiative in which India was also partner, the entire rice genome (sum total of all 12 chromosomes of rice) has now been sequenced/ spotted for the presence of known biochemical sequences of DNA which are called SSR (simple sequence repeat) markers. It is now possible to locate/map the genes of agronomic importance including for salt tolerance with the help of these molecular tags/markers. Furthermore these markers once established for their role, can also be extremely useful in foolproof screening of tolerant types. These are also of great importance for the trait transfer in other useful genetic backgrounds through marker-assisted selection or breeding. More so, these molecular markers/tags are extremely useful while pyramiding together genes governing almost similar phenotypes or traits which is otherwise extremely difficult through conventional breeding. About 7 varieties of rice have been released the world over through marker assisted selection mostly for bacterial blight (BB) resistance. In India, two such BB resistant rice varieties have been developed and released recently which harbor different resistance genes brought together through molecular marker technology.

Nevertheless, tolerance to abiotic stresses like salinity, submergence, drought, cold and problem soils is controlled by traits that are difficult to measure and governed by several genes. Different genes controlling a single stress tolerance factor e.g. salinity have differential contribution to the overall performance (Table 1). However in this quest, large effect genes or QTLs (quantitative trait loci) are the desired targets for the breeders and molecular biologists to justify the expense of molecular marker assisted breeding. The large effect QTLs for abiotic stress tolerance in rice are becoming the future targets of systematic and foolproof transfer in rice varieties through marker assisted breeding. Among various biotechnological approaches, marker assisted selection (MAS) is becoming increasingly important tool in the hands of plant breeders to accelerate breeding programs particularly where agronomic traits are highly influenced by the environments and are difficult to select through conventional breeding.

A useful QTL for any trait should ideally (i) have large effect on total trait expression, (ii) have uniform expression across different environments and genetic backgrounds, (iii) be < 1 cM away from marker to reduce linkage drag and (iv) within QTL as many markers as possible be present for fine mapping of big QTL for use in marker assisted selection.

The progress and practical achievements on breeding salt tolerant rice varieties at CSSRI, Karnal have also been recently mentioned elsewhere at some length (Gautam *et al.*, 2007). Therefore, the present paper mostly dwells on the current progress on harnessing the advancements in molecular approaches for better understanding of salinity tolerance in rice and for making future gains in the improvement of this trait.

Table 1: Useful genes/QTLs associated with abiotic stress tolerance in rice

Abiotic stress tolerance	QTLs discovered on chromosomes	Description
Submergence tolerance	4,5,6,7,9	Major QTL on chromosome 9 (*Sub1)* accounts for 70 % contribution
Salinity tolerance	1,3,4,10,12	Major QTL on chromosome 1 (*Saltol)* accounts for 65 % contribution
P-deficiency	6,12	Major QTL on chromosome 12 (*Pup1)* accounts for 80 % contribution
Zinc deficiency	5	
Cold tolerance	4,7,12	
Al toxicity	1,3,7,8,12	
Fe toxicity	1	
Flooding elongation	1	
Drought tolerance	4,12	

Mapping Salt Tolerance QTLs at IRRI, Philippines

IRRI has been conducting a significant research program on both salinity and submergence tolerance in collaboration with different countries including India. Excellent research outcome has also emerged in understanding the physiology and genetics of these traits. A major QTL called as *Saltol* was detected on chromosome 1 through a recombinant inbred line population derived from tolerant Pokkali x sensitive IR29 cross (Bonilla *et al.,* 2002). Since then near isogenic lines (NILs) have been developed for *Saltol* and fine mapped. Other QTLs in this population have also been reported to reside on chromosomes 3,4,10 and 12 which are useful in conferring seedling stage tolerance. However, it is pertinent to mention that *Saltol* and other reported QTLs are effective at seedling stage and for all practical purposes, we need to have strong QTLs showing advantage and yield benefits at reproductive stages. Subsequently, reproductive stage QTLs were targeted in few other studies (Islam, 2004). Similarly, *Sub1* a potential QTL for submergence tolerance was detected on chromosome 9 which has been recently cloned (Xu and Mackill 1996, Xu *et al.,* 2006). The successful transfer and advantage of *Sub1* have been validated in the field experiments in different countries in Asia demonstrating 1-2 t ha^{-1} yield advantage.

Molecular Diversity among Salt Tolerant Rice Genotypes

The understanding of molecular diversity between genotypes would facilitate a sound program on traditional and hybrid rice breeding for salt tolerance. We wanted to know molecular similarity within a physiological mechanism group and to know molecular differences across mechanistic groups. Therefore, we undertook a study to understand molecular diversity between 20 different salt tolerant varieties through ten SSR (simple sequence repeats) and eleven ISSR (Inter- simple sequence repeats) markers for utilizing this information in breeding salt tolerant rice varieties. In the ISSR analysis out of 11 primers screened for amplification of all the genotypes, 9 primers gave reproducible and scorable amplification products. Hence they were used for the further analysis. A total of 43 bands were obtained (average of 4.8 bands per primer) among which 39 were polymorphic (90.7%) across the 20 rice genotypes. The highest and the lowest number of polymorphic bands per assay unit was 9 and 2, respectively. In the SSR assay, a total of 11 fragments were obtained from the 10 SSR assay units. The number of polymorphic bands per assay unit ranged from 1 to 2 with an average of 1.1.

A summary of the genetic similarity estimates between pairs of genotypes, calculated for each marker system showed that SSR or micro-satellite data gave lower average similarity than ISSRs. Estimates of genetic similarity of ISSRs based on the 39 polymorphic markers between 20 rice cultivars ranged from 0.55 for PR108/CSR19 to 0.94 for Pokkali/CSR20 with an average of 0.81. The estimates revealed by the 11 polymorphic SSR bands showed the average value (0.94) and also the range of genetic similarity (from 0.86 to 1.00 for CSR22/CSR18 and CSR24/CSR20 respectively) reflecting their hyper variability and their high resolution power. Among ISSR primers tested, 17898B revealed maximum diversity (0.31) followed by 844A (0.29) whereas amongst the SSR markers, RM1209 revealed highest genetic difference (0.34) followed by RM6011 (0.32). These results will be of great utility while breeding suitable salt tolerant rice cultivars by crossing parents from different molecular clusters.

Molecular Mapping of St Genes through Mapping Populations

Our aim has been to map the important genomic regions/QTLs controlling salinity tolerance traits in rice. This involves collaborative work between CSSRI (mainly for phenotyping) and NRC on Plant Bio-technology, New
Delhi (for genotyping).

Table 2: Range, mean and yield reduction of traits of CSR27X MI48 RILs at different salinity levels.

Traits	Range			Mean			% Reduction	
	N*	M	H	N	M	H	M	H
Grain yield/5 plants (g)	17.5 – 57	12 – 44	10 – 26	35.8	23.6	16.2	34.2	54.8
1000-Grain weight (g)	18.5 – 30.7	15 – 27	10.25 – 21.5	23.4	20.8	16.5	11.3	29.8
Spikelet fertility (%)	41.8 – 89.5	31.9 – 85.5	24.2 – 77.8	74.0	67.0	61.0	9.5	17.6
Vigour Score at vegetative stage	1 – 9	–	1 – 9	4.86	–	6.3	–	-29.6
Vigour Score at reproductive stage	1 – 9	–	1 – 9	5.06	–	5.8	–	-15.6

*N = Normal, M= Moderate stress(ECe~6 dS/m), H = High stress (ECe~12 dS/m).

Initial mapping studies were based on 200 F2 plants and corresponding families from CSR27 (salt tolerant) X MI48 (salt sensitive) cross in which a total of 17 parameters were analysed. A total of 42 QTLs were identified on 6 chromosomes at an average marker interval of 20 cM through SSR markers. Of these 4 intervals located on chromosomes 1,2,3 and 8 were found to have genes with major effects each accounting for more than 50% of total variation for the individual parameters. Remarkably, a major QTL on chromosome 8 was reported for the first time in this analysis. Presently, these QTLs are being fine mapped through genotyping and corresponding phenotyping of 216 RILs (recombinant inbred lines) using SSR, SNP (single nucleotide polymorphism) and CAPs (cleaved amplified polymorphism) markers.

At CSSRI, Karnal the summary findings of the systematic phenotyping of 216 recombinant inbred lines (RILs) derived from CSR27X MI48 cross are reported here. A total of 225 genotypes including RILs along with parents and check varieties were phenotyped in replicated simple lattice design in each 3 environments in saline microplots [normal, moderate salinity (ECe~6dS/m) and high salinity (ECe~12 dS/m)].These were also screened in the soil-free saline hydroponics under controlled glass house conditions for seedling and reproductive stage response for growth vigour and physiological studies. Data for these lines on different traits as recorded last year were compiled and analysed (Table 2). On overall basis, grain yield the end product of plant was most sensitive to controlled salinity showing about 54 % and 34 % reduction respectively under severe and moderate stress followed by test weight and spikelet fertility compared to control. On overall mean basis, Na and K accumulation was also enhanced significantly in the straw samples as a result of higher stress. About 30 % and 15 % reduction for growth vigour was noticed at seedling and reproductive stages, respectively indicating that seedling stage is relatively more sensitive to salinity under tested population under soil-free saline medium. The frequency curve for growth vigour at vegetative and adult stage in saline hydroponics, Na and K contents followed normal distribution implying that the traits are under polygenic control. However, grain yield under high salinity and Na/K ratio at both moderate and high stress levels exhibited a skewed distribution indicating that some potential QTLs with large effects play important role for such variation. Other useful mapping populations like CSR27/CSR11, CSR11/MI48, IR4630/CSR11 and Pokkali/IR28 are also being maintained to map other physiologically important traits associated with salt tolerance.

Conclusions

Following the discovery of complete molecular map of rice, attempts at mapping of genes/QTLs controlling tolerance to salinity and other abiotic stresses are now increasing. However, these efforts are restricted due to their polygenic control and lack of rapid and reproducible screening techniques. Mapping genes that confer yield and survival advantage under salinity and sodicity stresses at reproductive stages will be practically of far reaching importance. In this context, search for contrasting tolerant and sensitive parents is expected to result in the development of ideal mapping populations for tagging the target genes through recently developed molecular markers. This is also expected to expedite gene pyramiding, marker assisted selection and systematic breeding for these attributes. Expeditious integration of QTLs conferring tolerance to multiple stresses in a single cultivar is also now possible with the help of marker assisted selection and breeding.

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Advances in Sugarcane Production Technologies under Poor Quality Water/ Soil

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Introduction

The total geographical area of the country is 329 million ha out of which 184 million ha is considered suitable for agriculture and the net cultivated area in 2007-08 was 142.2 million ha. The per capita availability of land for agriculture at present is 0.14 ha will reduce further as population increases and land is claimed for urbanization and industrialization. Nearly 175 million ha of land suffered from various degradation processes like wind and water erosion, ravines, shifting cultivation, water logging and salinity. In Indian agriculture scenario, sugarcane plays a pivotal role in the national economy not only because of the important commercial crops but also as a renewable source of energy and has the potential to generate employment through industrialization in rural areas of the country.

How Does Sodic Soil Affect Sugarcane

Sodic soils have both physical as well as chemical problems. Sodium in excess of 15% on the exchange sites (ESP greater than 15) when accompanied by carbonates and bicarbonates displaces calcium and magnesium from the exchange sites the clay colloids become dispersed as a result of which the micro pores start closing down leading to poor soil physical conditions. The water movement slows down leading to a deficiency of oxygen in the rhizoshere. Such soils have pH above 8.2 and a deficiency of Ca and Zn and excess of B at some places coupled with the poor physical conditions of the soil are the main reasons for low productivity under sodic conditions. The plants faces a deficiency of calcium because calcium carbonate is slightly soluble in water hence gets precipitated in the rhizoshere. In some sodic soils a hard impervious pan of calcium carbonate is formed which starts some where in the upper one meter and may be of different thickness. This further leads to reduced hydraulic conductivity of soils. Normally soils are saline-sodic and rarely sodic soils are met.

A level of 32 ESP and/or pH of 9.2 observed to lead to nearly 50% reduction in cane yields thus levels much lower than this only would give economic yields. Fibre content of the cane increases whereas juice content decreases at high pH in soils. This is coupled with increased sodium and a decrease in potassium in the juice at the same time. Thus, apart from lower cane yields sugar yields are also reduced by saline-sodic conditions with jaggery making becoming not only difficult but are of very poor quality at high levels. Co 7717 is good for sodic soils followed by CoS 767 whereas CoJ64 is highly sensitive and hence should not be grown.

Effect of salinity on sugarcane plants and how do the plants and crop appear

- Salinity affects germination and later growth is brought about by the difficulty faced by the setts and roots in absorption of water from saline soil solutions.
- Salinity slows down and decrease germination of sugarcane setts. The period from bud sprouting to development of at least 2 fully expanded leaves is the most sensitive period to salinity.
- Accumulation of excess Na^+ and Cl^- ions brings about yellowing followed by necrosis of leaf margins, which starts from the tip region and proceeds downwards and inwards. These symptoms arise first on the oldest leaf to proceed upward towards the younger ones. Thus the old leaves senesce earlier thereby decreasing photosynthetic area and the rates of growth.
- Salt accumulation in various plant parts caused a deficiency of potassium in the growing regions. Potassium is not deficient in the young growing parts of the shoots and roots. It is retranslocated from the older leaves in exchange for sodium to the younger parts of the plants.
- Reduced growth with stunted plant appearance, poor germination and tillering gives the sugarcane fields a poor and patchy look (because salinity levels are never uniform in the fields).
- Salt stress affects the tiller production more than the water stress and thus reduced sugarcane production under saline conditions primarily results from reduction in NMCs at harvest. A level of about 7.5 dSm^{-1} ECe of the soil leads to 50% reduction in cane yields.
- First monsoon rains would bring a shinning appearance to a filthy sugarcane crop growing under salt stress – reason for this was traced to the fact that soluble carbohydrates which accumulate in the growing shoot regions under salt stress come down within two hours of desalinization. Salt stress not only reduces rates of photosynthesis but affects their utilization in growth. Their use in growth is visible in terms of leaf elongation rates which picks up and is as good as that of the normal growing plants within 2-3 hours of desalinization.

- A moderate level of salinity normally reduces the level of sucrose in juice which results from lower level of transport of sugars from the leaves to the internodes. However, it is not that all the varieties would show decreased sucrose concentrations in juice because sucrose percent in juice depends upon the relative rates of transport of sugars to the internodes and their rates of elongation.
- Excess of soluble salts in the juice not only makes the jaggery making a difficult from sugarcane juice but also results in poor quality jaggery. High levels of salinity increase the fibre content of canes as well.

Poor Quality Water

The fresh water is about 2.5 percent of the total global waters and the salt water is about 97.5 percent. Human use of fresh water has increased more than 35 fold over the past three centuries. The inland saline water has now great potential for the use in irrigation with the application of the adaptable water use technologies as a non conventional water resource.

The adaptability of irrigation with saline water is decided by: (1) crop salt tolerance limit (2) nature of soil (3) quality of saline water (4) intensity of rainfall (5) leaching characteristics (6) availability of fresh water (7) method of application of irrigation water (8) climate of the area (9) soil-water-crop-environment and human resource management practices and (10) saline water irrigation economics.

Trends in Saline Water Use

The suitability for safe use of saline water for irrigation has been realized the world over under a number of factors viz., crop salt tolerance, cultural practices, climate, favourable soil profile, salt index of fertilizer, topography to permit effective leaching, drainage, prevention of salt accumulation, irrigation water management skills and environmental protection measures. The different countries have proposed various water classification schemes and different saline water management strategies (cyclic or blending) in light of the local sources of saline waters and fresh waters which constitute different levels of salinity/ sodicity, specific ion toxicity, local climate, soil and crop practices. Irrigation in the world, however, needs to be adequately understand under their respective saline environments the specific significance of the water quality, phenomena of the build-up of soil salinity, salinity effect on soils and crops, management of salinity problems, drainage, salinity control by leaching, land development for salinity control, crop tolerance to salinity, cultural practices, soil amendment, traditional to changing methods of advanced irrigation and appropriate means of blending water supplies.

Ground water resources play a major role in irrigation and other water supplies. Nearly 48% of the irrigation is provided by ground water and 52% by surface water. According to CGWB, the ground water levels have dropped 5-15 m in many areas of India as a result of over exploitation of fresh water.

Ground water quality zones include good water (ECiw < 2, SAR < 10), saline water (ECiw >4, SAR < 10), high SAR saline water (ECiw > 2, SAR <10) and alkali water (ECiw variable, RSC > 2.5). Though large spatial variations are encountered at small intervals about 32 to 84% of the well waters in different states of India have been rated to be of poor quality. High salinity ground waters largely occur in arid parts of the north-western states of India like Rajasthan, Gujarat, Haryana and parts of Punjab. Associated with salinity, groundwater in some pockets contains toxic levels of B, F, NO_3, Se and Si etc. The alkali waters are found prominently in the semiarid zones of Indian states where the annual average rainfall varies between 500-700 mm. The Bureau of Indian Standards (BIS) has classified quality of irrigation water vide BIS: 11624(1996) on the basis of ECiw into four classes: (1) Low salinity water ECiw below 1.5 dS/m. (2) Medium salinity water ECiw 1.5 to 3 dS/m (3) High salinity water ECiw 3 to 6 dS/m and (4) very high salinity water ECiw above 6 dS/m.

Saline Water Problem

The harmful effects of saline water irrigation are mainly associated with accumulation of salts in the soil profile and are manifested through reduced availability of water to plants, poor to delayed germination and slow growth rate. Osmosis is a normal process with the fresh water irrigation. But, if the irrigate water is saline the plant has to work harder to absorb water from the soil. Excessive salts in the soil induce early wilting and the effects are almost similar to those of drought. Some of the visual symptoms of saline water irrigation are that the plants look stunted and leaves are smaller but thicker and have often-dark green colour as compared to plants growing in a salt free soil irrigated with good quality (Bernstein 1964, Van Hoorn 1971, Minhas 1998). If the irrigation water is highly saline the process of osmosis can become reversed. Where the solution outside the plant roots is higher in salt concentration than that of the root cells water will move from the roots into the surrounding solution. The plant loses moisture and thus suffers stress. The symptoms of high salt damage are similar to those from high moisture stress damage. If saline water is sprayed directly on leaves it can cause salt scorch even at lower salinities. The saline water of ECiw more than 4 dS/m will cause salt toxicity in most of the crops in areas with annual rainfall less than 250 mm.

Sodic Water Problem

The alkali or sodic water also constitutes a significant proportion of groundwater in arid and semiarid areas. Relative proportion of calcium and magnesium salts is much smaller as compared to sodium salt which constitutes more than 70 percent of the total cations. The alkali/sodic waters usually have sodium bicarbonate as predominant salt 38 and in certain cases the calcium salts may be nearly absent. The prolonged use of these waters in irrigation immobilizes soluble calcium and magnesium in the soil by precipitating them carbonates. Consequently, the concentration of sodium in the soil solution vis-à-vis on the exchange complex increases and leads to the development of alkali or sodic soil conditions, and that adversely affects the physical properties of soils. The harmful effects of alkali/sodic water irrigation are mainly associated with increased exchangeable sodium percentage (ESP) and reduced infiltration. Long term use of water leads to breakdown of soil structure due to swelling and dispersion of clay particles. Fine texture soils remain disposed and puddle when wet and then hard when dry. It does not attain proper soil moisture condition for activation. A thin crust formed at the surface of soil acts as a barrier to penetrating irrigation water to the soil and to the emergence of seedling (Minhas 1998, CSSRI 1988).

Water Management

The water management is a crucial component in saline water use strategy for irrigated agriculture. To maintain a viable and permanent irrigated agriculture it is imperative to: (1) protect water quality, (2) adopt adequate leaching and drainage measures to prevent excessive soil salinization and salt loading of surface and ground waters, (3) practice irrigation processes in graded land to increase efficiency and uniformity of water applications, to decrease salt loading and to utilize benefit of shallow water table conditions, (4) intercept, isolate and reuse drainage water for irrigation, and (5) adopt scientific surface and subsurface harvesting technology and skimming well designs in an area of fresh water floating over saline aquifers. Following technologies have to be adopted to harvest good sugarcane crop using poor quality irrigation water.

Leaching Requirement
Surface Irrigation Methods
Sprinkler Irrigation Methods
Drip Irrigation Methods
Pitcher Irrigation Methods
Conjunctive Use of Saline and Fresh Water
Blending and Cyclic Use of Saline Water
Drainage Measures in Saline Waterlogged Areas

Managagement of Sugarcane under Saline Condition

- Salinity reduces germination as well as tillering therefore, 25% more seed cane for planting would compensate for reduced NMCs at harvest.
- Planting sugarcane in furrows compared to traditional flat planting in the subtropics results in better crop. As salt accumulation takes place at the ridges roots would not come in contact of excessive accumulation of salts.
- Irrigation with smaller quantities of water even if saline at shorter intervals gives better yields as salts continue to remain primarily on the ridges thus protecting the rhizoshere to become more and more concentrated with the passage of time after irrigation.
- Planting poly bag raised settlings in good well manured soil would escape the most sensitive phase in the life of sugarcane crop.
- If possible use good quality canal water between irrigation with poor quality water before monsoon rains for better crop.
- Use of organic manures @ 4-6 tons/acre would help in raising a good crop. As microbial population/activity gets reduced under salt affected conditions organic manures help to overcome these effects. Use of Dhaincha as a green manure crop every alternate year would keep the land fertile.
- Use of 25% more N, P and S would also prove to be useful.
- Use of rice crop alternating with sugarcane would be a successful crop rotation as this would help in leaching of salts to some extent and protects the crop from build up of soil borne diseases.
- Growing salinity resistant varieties such as Co 7717, Co 89003 and Co 97016 would results in better yields. Salt affected areas of Rohtak and Sonepat successfully growing Co 7717 and Rohtak Sugar Mill has been paying the rates of an early maturing variety in order to survive.

Managagement of Sugarcane under Sodic Condition

- In order to improve physical conditions of such soils and make the deficient nutrients more available use of gypsum in required quantity is suggested based on soil test. As calcium of gypsum displaces sodium from the exchange sites, physical conditions of the soil improve coupled with increased availability of calcium. A decrease in pH improves zinc availability to the plant.
- Total zinc is not less in sodic soils but rather its availability is the real problem and only 4% of it contributes towards plant growth.
- Use of FYM or any other organic manure along with gypsum and zinc sulphate @ 10Kg/ha is the best combination for sodic soils. It improves the microbial activity (which is lower in sodic soils) thereby greater production of chelating substances facilitates zinc uptake by the plant roots.
- Plant sugarcane in furrows if you have a problem of sodic waters (water with high residual sodium carbonate or sodium adsorption ratio). Use gypsum based on water quality report. Pass water over gypsum stored in the haudi before applying to the fields.
- High RSC waters slowly make the fields sodic by bringing about chemical and thereby physical changes in the soil structure.
- If water stands in sodic soils upon irrigation, use of poly bag technology to raise nursery and plant them when they have at least two fully expanded leaves.
- Apply small quantity of water at shorter intervals of time to keep the root zone at relatively low levels of salts and prevent the build up of anaerobic conditions in the root zone over longer periods of time.

Thus, the major agronomic management includes, leaching practices to remove excess salts from the root zone, use of chemical amendments, application of higher rates of fertilizers to mitigate salinity effects, growing of salt-tolerant plant species, and improvement in genotypes of commonly grown field crops. Despite all these efforts, problems of soil degradation still persist in vast tracts of irrigated areas because farmers generally lack knowledge of important aspects of proper management of saline soils and irrigation waters of different quality.

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Salinity Management with Special Reference to Indian Mustard

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Introduction

Oilseed crops occupy a place of prime importance in Indian economy and the impressive gains made, with respect to increase in productivity still does not match the edible oil requirements of our country. Indian mustard [Brassica juncea (L.) Czernj & Cosson] is most widely grown amongst different crops in rapeseed and mustard group. This crop is mostly confined to arid and semi arid regions of the country, characterized by saline underground water, which, on irrigation causes severe constraints on almost all the growth and developmental traits of the plants ultimately limiting crop yields. Average yield of this crop is 872 kg/ha against the realizable potential yield of 1326 kg/ha. Further in salt affected areas, the average yield is reduced to 580 kg/ha; in India, about 6.73 m hectares of area is affected by salinity/sodicity. Therefore, an increased home production of oilseed crops by bringing reclaimed or partially degraded salt affected soils under its cultivation could greatly reduce import bill. The production, under such situations, can only be achieved by exploiting genetic potential of a particular crop. The conventional methods of improving plant salt tolerance generally employ selection for seed yield and there are few examples of producing salt tolerant varieties following these approaches at CSSRI. Inducing mutations by radiation will help generate and identify new mutants with higher salt tolerance than the existing varieties. However, breeding efforts could be more profitable if physiological approaches and the more modern molecular tools are employed for developing salt tolerant varieties.

Some of the important physiological characters associated with salt tolerance have been studied in this crop. Identification of lines with desired characters would serve as parental material in breeding program. Further, identifying and pyramiding genes contributing to abiotic stress tolerance, and the use of marker-assisted methods and induced mutations will help accelerate improvement. Sustained breeding efforts at the institute following conventional methods have already resulted in the development and release of two salt tolerant high yielding varieties CS 52 and CS 54 of Indian mustard (Brassica juncea). Another line CS 234-2 has been identified for release for salt tolerance and late sown irrigated conditions. Many other lines are at various stages in the All India coordinated varietal trial for release for salt affected areas of the country.

Studies on the mechanisms of salt tolerance on Brassica juncea, revolved around their effects on the processes of growth, photosynthesis and ion accumulation at different growth and developmental stages. Generally, it was observed that once a seedling emerges under field situations under salt affected soils, it continues to grow to maturity with minimum loss in yield. Large numbers of genotypes are being screened to identify tolerant material at seedling emergence stage and also at whole plant level. A rapid screening methodology has already been developed to evaluate large number of genotypes in solution culture under laboratory conditions. Besides tolerance at seedling emergence stage, better performance of Brassica juncea genotypes under salinity stress was associated with higher shoot and root fresh and dry weight at seedling stage, minimum percentage reduction in grain yield under salinity, maximum mean susceptibility index values, more number of pods/plant at higher salinity levels, lower accumulation of Na in shoot and higher in root and lower shoot Na/K ratio. These better performing genotypes are used as breeding material in developing salt tolerant genotypes with higher seed yield. Various physiological factors contributing to the salt tolerance of Indian mustard have been discussed in detail below.

Germination and Seedling Emergence

In India, rapeseed-mustard is one of the important oilseed crops grown mainly for edible oil in about 6.0 m ha of lands. The productivity of the crop is very poor, compared to world's average, as about 2.0 m ha out of 6.0 m ha total area under its cultivation comes under semi-arid region, which is affected with varying degree of soil salinity. In states like western UP, Haryana and Rajasthan, this crop is irrigated with brackish water, in the absence of good quality water, at one or two important crop growth stages. Germination of seeds and emergence of seedlings in saline soils in almost all crops is considered to be very sensitive and critical stage, which ultimately influences crop productivity through decreased plant stands. Accordingly, germination, emergence of seedlings and its good growth are therefore, pre-requisite attributes for increasing mustard production in semi-arid saline soils. There is distinct possibility for the improvement of these traits in Brassica juncea as large genetic variation with regards to these traits exists. All crops, which are directly seeded in saline and alkaline field, are considered to be sensitive at germination stage. Rapeseed and mustard is considered as relatively sensitive at germination, whereas, it gives positive response at later growth stages unless it was a critical level of salinity (Rai, M, 1977). Amongst different species, Huang and Redmann (1995) described Brassica kaber (wild mustard) as more salt tolerant compared to B. napus during germination and early seedling growth. It was also shown that the germination of Brassica species was more salt sensitive to NaCl than to mixed sulphate salts. There is meager information available on salt tolerance of Indian mustard at germination and seedling emergence stages. Different genotypes of Indian mustard were shown to differ in their tolerance to soil salinity at seed germination and seedling growth (Sharma and Gill 1995, Sinha *et al.*, 2003) and also at whole plant level (Sharma and Gill 1994). Performance of 12 genotypes of Indian mustard was studied for their salinity tolerance at germination and seedling emergence stage besides their threshold values under salinity stress (Sharma, 2003). Pooled data of 12 genotypes revealed less than 100% seedling emergence even in control conditions. Under increasing salinity, seedling emergence declined from 85.83% at EC 5.75 dS m^{-1} to 7.92% at EC 15.5 dS m^{-1}. Application of piece wise linear response function (van Genuchten and Hoffman, 1984) to the pooled data of seedling emergence of 12 mustard genotypes showed 50% seedling emergence (S50) at EC 10.15 dS m^{-1} whereas complete cessation of seedling emergence (S0) was computed to be at EC 17.62 dS m^{-1}. The regression equation for seedling emergence under different salinity levels was calculated as Y= 6.6877 (X) + 117.881, where Y and X represents seed yield and salinity levels respectively. Variation in the response of different genotypes was also recorded at a particular salinity level. The mean seedling emergence over different salinity levels varied from 55% in CS 245 to 70% in CS 322. At salinity level of 12 dS m^{-1}, seedling emergence varied from 48.3% in CS 383 to18.3% in Varuna and 21.6% in CS 245.

The differential response of different genotypes under control as well as different salinity levels may be ascribed to different physiological reasons like proper maturity of seed and variation in internal elemental composition of the seed due to their position in the inflorescence of the plant. In Brassica juncea, decline in K along with increase in Na was reported (Sharma and Kumar, 1999) in developing seedlings upto 150 mM NaCl treatment after which it either stabilized or declined, probably due to the direct competition between K and Na at sites of uptake at the plasmalemma. Variability in different genotypes was observed for ionic accumulation at seedling stage. Variation in Na/K accumulation was shown in five different genotypes of Indian mustard at seedling stage. At EC 12 dS/m, genotypes ST 51 and ST 63 accumulated almost double the Na/K contents compared to CS 330, CS 609 abd CS 610.

Screening Methodology for Seedling Emergence

Under field salinity conditions, it was observed that once a seedling emerges, it continues to grow with relatively lesser reductions in growth and yield. Accordingly, it is imperative to know the salt tolerance potential of different Indian mustard genotypes for seedling emergence by some rapid screening methodology under laboratory conditions. For this, different genotypes were evaluated under solution culture in laboratory, sand and soil culture in pots to know their inter-relationships. Genotype CS 245-2 recorded 100% germination upto 18 dS m^{-1} whereas BS 50 showed similar germination upto 10 dS m^{-1}. Mean germination percentage declined upon exposure of seeds to salinity stress in the growing medium; it ranged from 98% at 6 dS m^{-1} to only 32% at EC 26 dS m^{-1}. At EC 26 dS m^{-1}, minimum decline in germination percentage was noticed compared to control in genotypes CS 245-2 (24%) and CS 614-4-1-4 (44%). Higher rate of germination under stress represents earliness in completion of germination, which is a desirable trait while its lower value exhibits sensitiveness to stress. Amongst different genotypes, CS 614-4-1-4 (41 day-1) and CS 245-2 (39 day-1) showed more tolerance with higher rate of germination.

Generally, all the germinating seeds may not necessarily emerge out especially in salinity stress situations. Accordingly, seedling emergence percentage will always be lesser than the seed germination percentage in any genotype. In solution culture, the maximum mean emergence percentage was observed around 8th day, whereas in sand and soil culture, maximum emergence percentage was recorded at 10th and 15th day respectively. Salinity also suppressed seedling emergence. Seedling emergence in some of the genotypes in solution culture even at EC 26 dS m^{-1}, whereas similar emergence was seen only upto 22 and 17 dS m^{-1} under sand and soil culture experiments, respectively. Amongst different genotypes, genotype BS 50 was the most sensitive in three types of growth medium. Variability in different genotypes with respect to their behaviour under salinity stress may be attributed to the differences in uptake of toxic ions along with the absorption of water by the seeds. Seedling emergence under solution culture and sand culture declined only due to the ionic stress caused by salinity of the soil solution, whereas in soil culture, osmotic effects play an associative role along with ionic effects. Accordingly, the higher decline in seedling emergence under soil culture may be associated to aggravation in ionic accumulation caused by the increasing osmotic stress along with matric stress. Seedling emergence under soil culture was also observed to decline through post germination salt injuries to hypocotyls at the time of their protruding through soil.

Application of piece-wise linear response model to the pooled data of seven genotypes in different types of growing medium showed that threshold salinity level was highest in solution culture experiments (Ct = 14.15). It declined to 7.84 in sand culture and further to 5.96 in soil culture experiments. Similarly, the salinity level at which 50% reduction in seedling emergence occurred was also highest in solution culture (C50 = 21.06) which declined to 15.96 in sand culture and to 12.31 in soil culture experiments. Along with the decline in Ct and C50 upon shifting from solution to sand and soil culture, the slope values increased from 7.25 in solution culture to 9.30 in soil culture experiments. The regression equation for the pooled data in three types of growing medium was computed to be Y = -3.8789 X + 111.417 (r^2 = 0.69). Further, the regression equations for seedling emergence under different salinity levels in solution culture only was Y = - 2.1712 (X) +

104.1922 (r^2 = 0.38) while in sand culture, it was Y = - 4.2505 (X) + 114.4129 (r^2 = 0.87) and in soil culture the equation was Y = - 4.6805 (X) + 106.7743 (r^2 = 0.86), where X= salinity level and Y= seedling emergence.

Salinity levels in which the results for seedling emergence under solution or sand culture are typical representative of the results under soil culture were calculated. These values were computed where the two types of growing media recorded around 50% of seedling emergence (C50). Significant positive correlation (r=0.81) was observed between seedling emergence at ECiw 22 dS m^{-1} in solution culture with ECe 12.8 dS m^{-1} in soil culture. Similar correlation between seedling emergence at ECiw 26 dS m^{-1} in solution culture with ECe 12.8 dS m^{-1} in soil culture was recorded to be r = 0.92. Hence, the screening of different mustard genotypes for salinity tolerance can be done quickly under laboratory conditions in solution culture at ECiw 26 dS $m^{-1,}$ which correlates significantly (r=0.92) with ECe 12.8 dS m^{-1} salinity level in soil culture conditions. Thus large number of genotypes can be tested for salinity tolerance in short period of time.

Compartmentalization of Toxic Ions in Different Plant Parts

After emergence, the seedlings continued to grow with time. The toxic ions are accumulated along with transpirational stream and the plant tries to compartmentalize these in different plant parts to minimize their effects on various metabolic processes associated with growth of the plant. In a detailed study, on a better performing bold seeded cv. CS 609 and a national check Varuna, fresh and dry weight of seedlings declined at 4 days after salinity imposition to 30 days old crop. Varuna recorded higher leaf, main stem and root fresh and dry weight compared to CS 609 under both salinity levels. Varuna accumulated higher Na content in leaf and main stem while roots accumulated higher Na in CS 609 and reverse was true for K accumulation. At this stage, as the leaves are the major growing and expanding regions in the plant, it also becomes the seat for major accumulation of different ions along the transpirational stream and very little accumulation was observed in other plant parts. Amongst different plant parts, leaves accumulated almost double the Na content than main stem and root in cv. Varuna. Highest Na content was accumulated in second leaf followed by first leaf, root and main stem. Similar trend was observed for K accumulation with second leaf accumulating maximum K content.

The pattern of accumulation of different ions changed with the growth stage mainly due to shift in growing and expanding regions of the plant. Further at 55 days after salinity (85 d old crop), when the plants had attained their full vegetative growth, non-significant differences were observed w.r.t. fresh and dry weight of different plant parts in the two genotypes. However, significant differences were observed with regard to their Na accumulation in two genotypes. Varuna accumulated higher Na content in different plant parts compared to CS 609. On an average, leaves accumulated higher Na followed by main stem, primary and secondary branches. Similar trend was observed for K content with leaves retaining maximum. In CS 609, there was seven times higher accumulation of Na in oldest leaf (basal) compared to top youngest leaf. Here, the plant tries to keep the active photosynthesizing tissue free from toxic ions by their compartmentation and better regulation in different tissues. Amongst different leaves, the oldest leaf have minimum K content, but the leaves from 3-8 position maintained almost similar status. Further, leaves and main stem accumulated higher Ca content in CS 609 than Varuna, whereas it was reverse in case of primary and secondary branches.

Effects on Photosynthesis

Plant growth is affected by salinity stress, which is a consequence of several physiological processes including photosynthesis. Earlier, the limitation of photosynthesis under salinity was attributed to stomatal closure upon exposure of plants to salinity. This lead to reduced leaf diffusive conductance and decline in internal CO2 concentration. Other studies ascribed it to non-stomatal effects like changes in ionic accumulation, water status and different biochemical factors. Accumulation of different ions by the plants under salinity may contribute to osmotic adjustment of the vacuolar water, however accumulation over time leads to reduction in the rates of photosynthesis possibly due to injury to the ion photosynthetic machinery. Parallel responses of transpiration and photosynthesis to salinity have also been shown and have been associated with unchanged Ci. The process of photosynthesis as affected by short and long term exposure of Indian mustard plants to salinity is discussed here.

As explained above, the lowest basal leaf on mustard stem accumulate seven times higher sodium content compared to topmost youngest leaf and also the reverse gradient exist for potassium accumulation. The effects of variation in ion accumulation on photosynthesis and transpiration was studied in cv. Kranti by imposing saline irrigation water of 150 and 250 mM NaCl in Hoagland solution at flowering stage (60DAS). Short-term effects were studied at 2, 24 and 120 hrs of salinity imposition.

Though the water stress symptoms were observed immediately after the salinity imposition, yet the effects on transpiration rate (E), stomatal conductance (gs), assimilation rate (Pn) and internal CO2 were not observed even after 2 h of salinity treatment. The deteriorating effects of salinity were observed at 24 h of saline irrigation wrt above mentioned parameters. The effect remained stable even after 120 hrs in 150 mM treatment, however, it continues to decline further from 0.83 to 0.52 in 250 mM treatment and probably the plant is still not able to adjust in such a higher salinity. Similar trend was recorded for changes in stomatal conductance. Further, the decline in assimilation rate was also observed at 24 hrs after salinity imposition with an average decline of about 40-50% compared to control. Further, it declined drastically to 0.95 after 120 hrs of 250 mM treatment. Even under high salinity, the plant tried to maintain its photosynthetic activity as the effects varied greatly with respect to different leaves. The assimilation rate declined drastically in lower leaves approximately up to position 5 from base where about 60-80% of the effect was observed. The upper leaves were still maintaining higher assimilation rate under salinity compared to lower leaves.

In another experiment, the long term effects of salinity on the above mentioned parameters were studied in different varieties viz. Varuna, CS 330, CS 609, ST 63 and CS 33. These varieties differ with respect to 1000 seed weight and grain yield under salinity. The plants were irrigated with saline water of EC 12 and 15 dS/m (NaCl, $CaCl_2$ and Na_2SO_4) for 45 days. The plants generally adjusts to long term salinity application as evidenced by their lower transpiration rates (36 and 41%), stomatal conductance (45 and 59%) and in turn their effects on lowering the assimilation rates by 25 and 35% in leaves under 12 and 15 dS/m salinity respectively, compared to control. This results in reduced photosynthesis leading to reduction in grain yield under salinity. The transpiration rate is positively correlated to stomatal conductance both in short (r=0.922) and long term (r=0.906) effects of salinity. Further, the assimilation rate is also positively related to transpiration (r= 0.721 and 0.726) and conductance (r=0.70 and 0.706) both under short and long term effects of salinity respectively.

Effect of Supplemental Calcium on Growth and Ion Uptake

While studying the effect of supplemental Ca2+ under salt stress on germination of four Brassica species, *B. campestris, B. carinata, B. juncea and B. napus*, Ashraf and Naqvi (1992) showed increase in percentage germination of B. napus and B. juncea by addition of 11.25 mM CaCl2 to the saline irrigation water containing 225 mM NaCl. Addition of Ca+2 in the saline medium (150 mM NaCl) showed non –significant effects on shoot biomass and seed yield of B. carinata and B. campestris. By contrast, shoot dry matter of B. napus and B. juncea increased significantly with the increased addition of Ca+2 in the saline solution, but their seed yield remained unaffected. Further, the declining Ca+2 concentrations in the salinity treatments reduced percent oil content in B. carinata, B. juncea, and B. campestris. In B. campestris, increasing Na/Ca ratios in the saline medium did not show any effect on Na, Cl, and Ca concentration in the shoots and Na, Cl, and K concentration in the roots. Only shoot K and root Ca decreased consistently. In the highly salt-sensitive species, B. napus, the shoot Na was reduced by the addition of Ca+2 in the saline solutions, whereas increase in Cl and Ca uptake was noticed with the addition of Ca+2. Root K+ concentrations declined with increase in Na/Ca. In B. juncea, which was similar to B. napus in biomass production, high Ca+2 concentration in the saline solution reduced shoot Na and root Cl and increase K uptake. Shoot Na/Ca and Na/K ratios were increased in B. napus and B. juncea at the highest Na/Ca ratio of the growth medium. Huang and Redman (1995) also observed increase in germination percentage of canola and wild Brassica by the supplemental calcium.

Salt Tolerance at Whole Plant Level

Summarizng the results of tolerance at whole plant level, plant height, number of branches, pods number/plant and pod length decreased with increase in salinity in all the varieties. Plant dry matter decreased under salinity and most of the genotypes suffered 50% reduction in dry matter at EC 10.5 dS/m. Grain yield also followed the same trend. Early flowering is also noticed under salinity, showing escaping mechanism under salinity stress. Grain/husk ratio was reduced at higher salinity and the better performing genotypes maintained higher ratio compared to other genotypes. Seed weight decreased with increasing salinity in all the genotypes. Sodium content increased with age in leaves and also in husk. Pod husk contained almost double the sodium content than in leaves at maturity. The better performing genotypes retained lesser sodium in leaves. Higher yield in tolerant genotypes was also attributed to more number of primary and secondary branches besides the number of pods, accompanied by lesser sodium accumulation in shoot keeping a favorable ionic balance.

Genetic Studies under Salt Stress

Genetic variability is the key to any crop improvement programme and the extent to which the desirable characters are heritable is also important. For improving yield and yield component characters, information on their genetic variability and their interrelationships in different characters is necessary. Partitioning the genotypic correlation coefficients of yield components into direct and indirect effects may help to estimate the actual contribution of an attribute and its influence through other characters. Sixty genotypes were evaluated for their adaptation under semi arid saline soil conditions (Sinha, 1991). High variability was recorded for secondary branches /plant, pods/plant, 1000 seed weight, seed yield/plant and seed yield/pod. Further low variability was recorded for seeds/pod and primary branches per plant. Seeds /plant were least affected by salinity. Variability studies in 30 genotypes of Indian mustard indicated higher estimates of GCV, PCV, heritability and genetic advance for number of primary branches and siliquae plant-1 on normal soil; and for seedling emergence, number of siliquae on main shoot, number of secondary branches plant-1 and seed yield on saline soil. Number of siliquae per plant on normal soil; and seedling emergence and plant height on saline soil had significant positive association with seed yield. Seedling emergence and plant height exhibited maximum direct, positive effects on seed yield on saline soil.

Further, genetic parameters for variability were also studied under sodic stress conditions in 19 genotypes of Indian mustard (Sinha *et al.*, 2002). The GCV, PCV, heritability and genetic advance as percent of mean were high for 1000 seed weight on normal soil and for plant height, secondary branches per plant, number of pods per main shoot length and seed yield per plant on sodic conditions. Correlation analysis revealed that seed yield per plant has positive and significant associations for primary branches per plant and main shoot length on normal soil; and for plant height, secondary branches per plant and number of pods per main shoot length in sodic stress conditions. The path analysis showed that secondary branches per plant had maximum direct effect on seed yield under sodic stress conditions. These studies point out that the framing of selection criteria could be based on number of primary branches per plant, main shoot length and 1000 seed weight for normal conditions and secondary branches per plant, number of pods per main shoot length and seed yield per plant under sodic stress conditions.

Salt Tolerant Varieties

Amongst different Brassica species, Indian mustard (raya) showed higher tolerance to salinity/ alkalinity stresses compared to Gobhi sarson, Karan rai, yellow and brown sarson. Different genotypes of Indian mustard also showed differential tolerance to saline and alkali stresses. The sustained breeding efforts at the institute for the development of high yielding salt tolerant genotype of Indian mustard have led to the development and release of two salt tolerant genotypes CS 52 and CS 54. Another genotype CS 234-2 has been identified fro release for salt tolerance and late sown irrigated conditions.

The salt tolerant varieties CS 52 and CS 54 yield 20% higher in salt affected soils compared to the high yielding released varieties of Indian mustard at the national level. However, their maturity takes a week more compared to the well known high yielding released varieties of Indian mustard i.e. Varuna, Kranti and Pusa Bold. These varieties are also more tolerant to insects and pests' attack compared to other released varieties of Indian mustard. The two varieties accumulate and compartmentalize the toxic ions in the root part, hence restricting the accumulation of toxic ions in leaves and stem. Further, the toxic ions, which moves into the upper part gets accumulated in lower leaves, which shed ultimately reducing the effects of toxic ions on the plant. These processes help the plant to survive better under salt stress conditions.

These can grow economically in saline soils up to a soil salinity level of ECe 9 dS m^{-1} and in alkali soils up to pH 9.5. Within the salt tolerant limits of this variety, CS 52 and CS 54 yield more than 15 quintals per hectare. By growing in saline soils and even irrigating with saline waters, more than 37% oil content has been determined.

Molecular Approaches

As mentioned above, high yielding salt tolerant genotypes have been developed at CSSRI by following conventional breeding approaches, exploiting the variability already present in the system. Variability can be generated further by mutations. Though the success of producing salt tolerant varieties through mutagenic approach is limited, this process can't be ignored at all. Large number of mutants have been developed which have shown sensitiveness to salinity and have become important tool for studying mechanism of salt tolerance. Further, the process of developing salt tolerant varieties can be quickened by employing physiological and more modern biotechnological approaches. Generally two major approaches are followed, either producing transgenics with desired genes or by following marker assisted selection approach.

Salt induced gene activation has been demonstrated for genes belonging to all the functional groups. Whereas, only a limited number of genes have been tested in transgenic plants for their effect on stress tolerance. Primarily these genes encode enzymes involved in osmoprotectant synthesis, molecular chaperons and detoxifying enzymes involved in oxidative stress responses. Increased osmoprotectant synthesis has been manipulated in plants by over expression of enzymes leading to increased ononitol production in tobacco (Sheveleva *et al.*, 1997), trehalose synthesis in rice (Garg *et al.*, 2002.), glycine betaine in tobacco (Holmstrom *et al.*, 2000), amino acid proline in tobacco (Kishor *et al.*, 1995). In each case incremental improvements in salt tolerance were measured under laboratory conditions that correlated with increased constitutive accumulation of the manipulated solutes. Further, the induction of the tonoplast Na+/H+ antiporter NHX1 gene by both salinity and ABA has been shown in Arabidopsis by Shi and Zhu (2002). In the transgenic plants, over expressing AtNHX1 higher salt tolerance was exhibited at 200 mM NaCl salinity stress compared to wild type plants (Apse *et al.*, 1999). This gene was also introduced into transgenic tomato plants that fall into otherwise sensitive category. Over expressing AtNHX1 in tomato enhances its salt tolerance as these plants produced fruits up to salinity stress level of 200 mM NaCl and its yield was compared to normal (Zhang and Blumwald, 2001). Further Zhang *et al.* (2001) have also demonstrated the production of salt tolerant transgenic canola (Brassica napus) plants by over expressing AtNHX1 gene. However, the applicability of this approach for all plant species has been questioned by Flowers *et al.*, 2004. Marker assisted selection approaches may give an insight into the desired QTL's responsible for salt tolerance and their further exploitation for improving genotypes for salt tolerance and high yield.

At CSSRI, the parental polymorphism is being studied with SSR markers. Around 295 SSR markers have been screened on salt tolerant and sensitive genotypes. Amongst these, 139 SSR markers showed amplification and polymorphism was recorded in only 21 SSR markers. Further studies are in progress.

Conclusions and Prospects

Large amount of variability is present amongst and within species and genotypes of Indian mustard for salt tolerance. The variability present within a genotype at a particular salinity level needs to be exploited to select parental genotypes for inclusion in the breeding program to develop salt tolerant genotypes of Indian mustard. Identification of critical sensitive stages to salinity in Indian mustard have practical implications for managing poor quality waters as irrigation waters of higher salinity could be used more profitably in the later stages of crop growth and waters below the threshold salinity level can be used for irrigation during the initial stages of growth. To explore further, genetic variation for salt tolerance at specific growth stages needs to be adequately exploited.

The conventional breeding approaches are not able to exploit the gene pool present within each species. Salt Tolerance is interplay of a number of separate physiological processes like low transport of Na to shoot, vigour of a cultivar, ability of a plant to sequester ions in older rather than younger leaves and the tolerance of tissue to salt. The testable hypothesis is by recombination of genes from appropriate donors for all component traits could lead to a genotype with good performance under salinity. There is need to mark individual genotypes for a particular physiological character and then pyramiding of all such physiological characters in a genotype to develop salt tolerant genotypes with high yield and desired quality. Crossing program like recurrent selection, which maximizes recombination by single seed descent, then selection for lower Na transport before agronomic characters is required. There is also need to search for nutrient efficient cultivars for help in better survival and performance of genotypes under adverse conditions.

Being a quantitative trait, salinity tolerance has been generally resistant to improvements by conventional plant breeding. Since quantitative traits influence maximal plant productivity, introducing a trait that improves salinity tolerance may actually lower the potential yield under normal conditions. Thus, the need to balance productivity with salinity tolerance has become a contested point of discussion that is likely to be resolved in favour of relative yield only. Transcriptional regulation is an area with potential for coordinate regulation of genes relevant to tolerance, but will require identification of factors limiting the sustained response so that their expression may be manipulated in a tissue targeted manner.

In the present times, physiologists must pay attention to the studies involving marker-characterized segregating populations and marker specific near-isogenic lines instead of varieties. Accordingly, QTL analysis should be given due importance to understand improvement in plant growth and behaviour in a range of environments.

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Cactus – Potential Crop for Saline and Arid Environment

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Introduction

Cactus (*Opuntia ficus indica*) has been commercially exploited as fruit, vegetable, forage, energy, medicinal and dye yielding crop in the arid and semi arid areas of the world. Mexico is the largest producer of the cactus and is a global player in export of cactus to North America and Europe. The other countries where cactus is known as a cultivated crop and commercially exploited include Brazil, Argentina, South Africa, Israel, USA, Italy and many other Latin American countries. The cultivation of cactus as a commercial crop is little known in Indian sub continent. Only the wild cactus is found growing in wasteland, as hedge around agricultural fields to protect crops from wild life and as a decorative plant in parks and home gardens. Due to its highest water use efficiency per unit dry matter production (because of CAM mode of photosynthesis), the plant has ample scope for introduction and cultivation in rainfed and dry areas of India where 67% of the poor rural population is settled. Cactus has special significance in drought prone area of the country where if planted will help in augmenting food and fodder requirement and thus halting cattle migration to other areas. In addition to its remarkable value as cattle and human food, it has a potential for soil and water conservation when planted on slopes in the hilly terrace in the rainfed areas of the country. With these qualities in view, several attempts were made in the past to introduce this plant in India. However, national initiative on promotion of edible cactus in dry areas of the country is lacking.

Cactus Classification

Kingdom - Plantae (plants)
Phylum - Tracheophyta (vascular plants
Division - Magnoliophyta = Anthophyta] (angioperms)
Class - Dicotyledonae = Magnoliopsida (dicots)
Subclass - Caryophyllidae
Order - Caryophyllales
Family - Cactaceae (cacti)
Genus - About 100 genera and 1000-2000 species divided into three tribes

Tribe

Pereskieae - They have woody stems, leaves are persistent or semideciduous, areoles are spiny and woolly at the leaf axils, flowers are pendulous, and the fruit is fleshy.

Opunitieae - Fleshy, branched plants, areoles may or may not have spines but always have fine hairs (glochids), leaves are flat or cylindrical, spines are usually straight, the fruit is a seedy berry.

Cactoidea - about 100 genera (most cacti are in this tribe). (Fig.1)

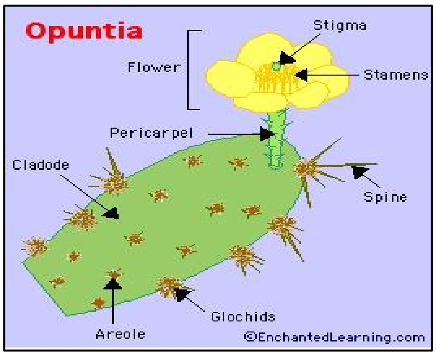

Fig.1. Opuntia Morphology

Chemical composition

Opuntia spp. Cladodes have high contents in water (90 %), ash (20 % DM), Ca (1.4 % DM), soluble carbohydrates and vitamin A. They have low contents in crude protein (CP. ~ 4 % DM), crude fiber (CF ~ 10 % DM), and phosphorus (P ~ 0.2 % DM).

Hoffman and Walker (table 1) have analyzed Opuntia species for nutrient contents as early as 1912. These early investigations indicate already that spiny and spineless cactus have practically the same chemical composition and are of equal value for feeding purposes.

Table.1. Chemical composition (% DM) of O. engelmannii and O. lindermeri (Hoffman and Walker, 1912).

Water	85	Phosphoric acid	0.33
Crude protein	1.4-4.4	Potassium	3.04
Nitrogen free extract	7.85	Magnesium	1.6
Fat	1.55	Calcium	2.84-13.85
Crude fiber	8.65		

Nutritional Value

The use of Opuntia as a source of food for humans, domestic animals and wildlife has been very important in the arid and semi-arid regions of northern Mexico for centuries. Although it has been considered poor in terms of nutrients and fibre, it constitutes the main source of water in traditional production systems, particularly during the dry winter-spring season. Opuntia is a key ingredient to supplement the diet of domestic animals due to its:

* *Water content*. Opuntia is one of the main water sources for animals in the semi-arid north. However, the total amount of water stored depends upon species and varieties (Table 2). Water content is strongly influenced by environmental conditions.

* *Dry matter content*. Several factors strongly influence DM, both endogenous (species, geno-type and cultivar) and environmental, such as soil, climate and season.

* *Bromatological analysis*. There are significant differences among reported data on tissue analysis, associated with variation in species, physiological factors, soil fertility, climate, etc.

* *Minerals*. There are few reports on studies aimed to quantify mineral content of opuntia. The main mineral components in opuntia ashes are calcium, potassium, magnesium and sodium, usually found as salts and silica. Iron and aluminium are found in traces.

* *Digestibility*. The rate of feed intake by the animal is influenced by species, variety and season, cladode age and their corresponding interactions.The digestibility values as fibre, 40%; crude fat, 72%; protein, 44%; and nitrogen-free extract (NFE), 78%, while the influence on opuntia digestibility of yeast supplemented with two sources of nitrogen. When yeast is added to Opuntia, digestibility was 61.6%; if ammonium sulphate was combined with yeast, digestibility increased to 93.9%. Adding yeast and urea, digestibility reached 76.8%.

Table.2**.** Nutritional values of *Opuntia* species on a DM basis.

Species	**DM**	**OM**	**CP**	**Fat**	**Fibre**	**Ash**	**NFE**
Nopalea spp.	10.69	73.79	8.92	1.51	17.21	26.21	50.7
O. robusta	10.38	81.41	4.43	1.73	17.63	18.59	57.61
O. ficus-indica	13.36	81.55	3.66	1.76	9.18	18.45	69.95
O. spp.	10.01	----	5.71	3.01	8.11	12.01	55.01
O. ficus-indica	8.01	----	6.81	1.01	----	8.88	81.25
O. ficus-indica	7.96	----	4.04	1.43	8.94	19.92	65.67
O. imbricata	10.41	----	5.01	1.81	7.81	17.30	68.11

Key: DM = dry matter. OM = organic matter. CP = crude protein. NFE = nitrogen-free extract

Relevance for Rainfed Areas in India

Planting of trees and bushes like cactus on all kinds of wastelands, on field boundaries, road and railway track sides etc. in all drought prone areas of the country has tremendous potential to generate livelihood opportunities. The low cost of cactus establishment and production as well as its tolerance to drought make it well suited to become a viable future industry in rainfed India. There is a need to import promising cactus material from Mexico, Brazil, South Africa, Italy and Argentina for evaluation in India. There is also a need to develop a network programme for evaluation and promotion of cactus in dry land areas of the country. It is also required to organize one international workshop on cactus in India to sensitize scientists, developmental agencies and policy managers about cultivation and use potential of edible cactus.

Water Use Efficiency

A useful benefit:cost index for gas exchange by plants is the ratio of CO fixed by photosynthesis to water lost by transpiration, which is referred to as the water-use efficiency (WUE). For the gas exchange data presented in Fig. 2, net CO_2 uptake integrated over the 24-hour period is 1.14 mol/m^2/day and the water loss is 51.3 mol/m^2/day. Thus the WUE is 0.022 mol CO_2 fixed per mol H_2O lost for this CAM plant.

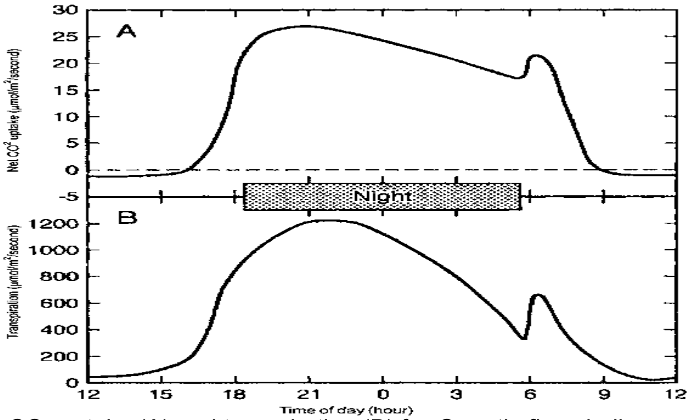

Fig.2. Net CO_2 uptake (A) and transpiration (B) for *Opuntia ficus-indica* over a 24-hour period
(Source: Nobel, 1988, 1995)

This WUE is about triple that found for highly productive C_4 plants (such as maize or sugar cane) under similar environmental conditions. C_4 plants have daytime net CO uptake initially into four-carbon organic acids, and 5-fold higher than for highly productive C_3 plants (such as alfalfa, cotton, or wheat), which also have daytime net CO_2 uptake but whose initial photosynthetic product is a three-carbon compound (Nobel, 1995). The much higher WUE for CAM plants relates to the reduced difference in water vapour concentration between the plant and the atmosphere during the period of substantial stomatal opening. In particular, the water vapour content in leaves and stems is within 1% of the saturation value in air at the tissue temperature ,tissue temperatures tend to be much lower at night, and the water vapour saturation value of air increases nearly exponentially with temperature. For instance, the water vapour content for saturated air is 0.52 mol/m^3 at 10°C, 0.96 mol/m^3 at 20°C, and 1.69 mol/m^3 at 30°C. If the water vapour content of the air is 0.38 mol/m^3 (40% relative humidity at 20°C), then the drop in water vapour concentration from the plant to the atmosphere, which represents the driving force for water loss from a plant, is the difference between 0.52 and 0.38, or 0.14 mol/m^3 at 10°C; 0.96 - 0.38, or 0.58 mol/m^3 at 20°C; and 1.69 - 0.38, or 1.31 mol/m^3 at 30°C. For the same degree of stomatal opening, the driving force for water loss then is 0.58/0.14, or 4.1-fold higher at 20°C than at 10°C, and 1.31/0.58 or 2.3-fold higher at 30°C than at 20°C. Because tissue temperatures typically average at least 10°C lower at night than during the daytime in many locations, CAM plants tend to lose only 20 to 35% as much water as do C3 or C4 plants for a given degree of stomatal opening. This is a key feature in their utility as forage crops in arid and semi-arid regions.

Water Requirement

Opuntia uses water more efficiently than conventional fodder crops, as illustrated in Table 3.

Table.3. Opuntia water use efficiency (WUE) under rainfed and irrigated conditions

Crop	Water use efficiency (WUE)	
	kg H_2O/kg DM	mg DM/g H_2O
Opuntia	15-43	23-65
Agave	93	10.7
Atriplex nummularia	304	3.3
Pear millet	400	2.5
Barley	500	2.0
Sorghum	666	1.6
Wheat	750	1.3
Alfalfa	1000	1.0
Rangeland	2000	0.5

Introduction in India

It is reported that cactus was introduced into India by the British somewhere during 1940s to raise insects for production of natural red dyes. It is also reported that those plantations vanished because of insects and diseases and other problems of management and prolonged waterlogging. The plant was introduced by the researchers at Central Arid Zone Research Institute, Jodhpur in late 70s, but it is reported that the introduced varieties did not fruit under Jodhpur type of climate. A scientist (Nandini Nimbkar) from Nimbkar Institute, Phalton near Puna introduced several clones of cactus from Dr. Peter Felker's collection in Texas, USA. It is reported that some of these clones fruited in dry areas of Maharashtra, but the crop did not spread to other arid and semi arid areas of the country because of lack of the coordinated network effort at national, state, regional or local level. The systematic work on cactus initiated with the efforts made by the Dr.Gurbachan Singh who worked with Peter Felker in Texas, US for four months between July to November, 1991 as FAO visiting fellow. While returning from Texas, after the training, he brought five most promising clones(considered the best in 1991) and planted at Karnal, first in pots then in microplots followed by large scale evaluation in the field. The clones introduced included 1270(forage and fruit), 1271(fruit), 1280(fruit), 1287(fruit) and 1308(vegetable). These were multiplied on a large scale, evaluated for sodicity tolerance and developed agro-techniques for their cultivation. Based upon its success in trials at Karnal, the material was distributed to several research centres/organizations located in arid and semi-arid regions of India like National Research Centre on Arid Fruits, Bikaner, Central Arid Zone Research Institute, Jodhpur, Indian Grassland and Fodder Research Institute, Jhansi for further evaluation and testing.

Evaluation for Salt Tolerance

Fruit and forage clone 1270 was planted in 20 kg capacity ceramic pots filled with soil of pH ranging from 8.1 to 10.0. The survival, growth and fruit production was drastically reduced beyond pH 9.2. Growth initiation was affected markedly by the pH levels of the medium. At pH 8.1, the growth started after 54 days of planting, whereas at pH 10.0 the sprouting took about 90 days. Though the plant survived at soil pH of 10 also, but the biomass production was almost negligible. Even the survival was reduced to less than 50 per cent at this level of pH. The five clones were also planted in the microplots filled with different pH soil varying from 8.0 to 10.2. Similar response to soil pH was observed in the microplots as was recorded in the pots.

Planting, Cultivation, Fertilization and Care

Being drought tolerant prickly pears are suited to those areas, where rainfall is scarce and unreliable and irrigation water is limited. The optimum conditions for its growth are available in summer rainfall regions having average rainfall between 300 to 600 mm. Hot sunny days and cool dry winter where temperatures do not fall below maximum 5oC are most suitable for cactus production. Cactus thrives best on sandy and sandy loam soils. However, it does well even on heavy soils with adequate drainage. Gravelly or stony lands especially at the foot hill slopes are also suitable. Cactus plantation can work as an excellent vegetative barrier to check soil and water erosion when planted on hill slopes in rainfed regions. Further, it thrives well on slightly alkaline soils rich in calcium and potassium. This indicates that any type of soil which is not suitable for other crops can be planted to cactus provided that area is not subject to prolonged waterlogging. A large part of India is, thus, suitable for its cultivation to generate alternate source of livelihood and employment.

Cactus can be planted both from seed and vegetative parts. However, the most common method of propagating cactus is by leaves that are at least one year old. The best way of planting is upright method in which one third portion of the cladode is below the ground and two-third above. Cladodes before planting should be allowed to dry under shade for 4 to 6 weeks to reduce the moisture content. Before planting, the leaves should be dipped in some common fungicide solution to check root rot caused by soil borne pathogens. Immediately after planting, 8-10 litres of water to each plant should be applied. It is better to plant on ridges to avoid flooding during rainy season. Since most of the feeding roots of cactus are very superficial, it is important that the upper 30 cm of soil is in good physical condition to promote maximum root growth. Cactus can be planted throughout the year, but the best time for its planting is September-October and February-March. Spacing depends upon the type of cultivar and the purpose for which the plantation is being raised. In general, cactus is reported to give best production when planted in rows 4 m apart keeping distance between plants 3 m. Cactus does not require additional irrigation if well distributed rainfall of about 500 to 600 mm is available. In case of sub optimal rainfall, 2 to 3 irrigations especially during fruit formation stage enhances production and checks the problem of fruit cracking and fruit drop. One supplementary irrigation is required during frost period to negate/moderate frost impact in drought prone areas.The recommended dose of fertilizer is 224 kg ha^{-1} N in every two years to maintain crude protein levels about 10% with dry matter productivities in the range if 50 t ha^{-1} yr^{-1}.

Pruning is an important practice to give proper shape to the plants, reducing competition for light, improving yields, fruit quality, fruit size and rejuvenation of the plantation. The best time for pruning is when the crop has been reaped and the plant is no longer growing actively. The thumb rule for pruning is that low hanging leaves should be removed first. The damaged and diseased leaves should also be removed. Sometimes, more than 20 fruits are borne on a single cactus cladode. In case fruits are allowed to stay for ripening, fruit size and quality are adversely affected. Pruning of fruits is important and to maintain optimum production, 10 to15 fruits may be retained on each cladode.

Multiple Uses of Cactus

Cactus is used for several purposes but the most significant uses include : as a fruit and vegetable for human consumption, forage for livestock and as a red dye. Several other minor uses of cactus are: control of diabetes, ethanol production, as live fence and for industrial use of its galactomannan mucilage. Mexico is the largest producer of fruits with more than 100,00 ha area under its cultivation. Similarly, Sicily is the largest exporter of fruits to Europe. Countries like Brazil and Argentina have several hundred thousand ha of thornless cacti grown for forage purpose. The consumption of cacti as vegetable nopalitos is limited to Mexico and USA. Bolivia, Peru, Chile and South Africa are reported the dominant countries producing the red cochineal dye.

Fruit: The most important use of cactus is to produce fresh fruits for human consumption. The size of fruits varies according to varieties and management practices. The fruit of mostly commerce grown varieties range between 110g per fruit to bout 160g per fruit. The fruit colour varies from red, orange, purple, yellow and lime green. The edible portion in a total weight of fruit is about half of the total weight of the fruit. Sugar content mainly glucose is reported to range from 12-15% with a pH of 6.5. The fruit has 2.1 to 6.3 g of seeds. In general, the hard seeds are the major limiting factor for the acceptance of the people who consume it for the first time. However, seedless varieties are also available which have much wider acceptability. That seeds are also reported to have a very good quality oil, which consists of about 60% linoleic acid. The total fruit yields from cactus varies depending upon soil, climate, variety and management practices. For example, in Kingsville, Texas, with a rainfall of about 500 mm, the fresh weight fruit production ranged from 0.5 to 55 tones per ha for the 130 clones tried. Seven clones are reported to have more than 20 t per ha fruit producton. However, in case even the best clones are grown without weed control or fertilization, the yield ranged between 1-3 t per ha. The four clones planted at CSSRI, Karnal farm yielded between 5-15 kg of fruit per plant six years after planting. The fruit production was maximum in clone 1270 and 1287.

Livestock Feed: Since cactus has a higher conversion efficiency of water to dry matter than any other kind of plants, hence is highly useful as forage for cattle, sheep and goats. Another remarkable characteristic of this plant is that it can persist during dry periods when all other forms of cultivated and naturally growing herbaceous forage have vanished. There are more than 150 districts in India which are highly drought prone, this crop has tremendous potential to augment forage production in those areas. The forage quality is reported quite comparable with several other cultivated nutritious forages. It is a highly digestible source of energy with about 70 % dry matter digestibility but normally low in protein content. The average tentative chemical composition of cactus cladodes as reported in literature is : moisture content 85-90 %, crude protein 5-12 %, phosphorus 0.08-0.18 %, calcium 4.2 %, potassium 2.3 %, magnesium 1.4%, energy 2.6 Mcal/kg, carotenoids 29 µg/per 100 g and ascorbic acid 13 mg per 100 g. The in vitro digestibility values reported are 72 % for protein, 62% for dry matter, 43% for crude fiber and 67% for organic matter. Though the cactus is low in protein but its protein content can be increased appreciably with the application of fertilizers. Several experiments have been conducted in Texas and elsewhere which indicated that protein content improved with the application of nitrogen and P fertilizers. Similarly, the vitamins and trace elements supplementation are of utmost importance when cattle are fed for longer period of time on cactus. The trials conducted in Brazil and elsewhere on non-ruminants like pigs and rabbits indicated that rabbits like Brazilian forage variety 1270 than nopalitos variety 1308. Indian experience indicates that cactus is a preferred forage species for blue bulls. The plantations at Jhansi were frequently browsed by the blue bulls and other wild life.

Both the thorny and thornless varieties of forage cactus have advantages and disadvantages. Thorny varieties are preferred as biofence. To make effective use of thorny varieties as forage for cattle, spines need to be burned off over fires or with propane torches before utilization. It has been studied in Texas that one man using an 8 L propane tank and propane torch, can burn enough cactus to feed about 100 heads of cattle per day. Even the sound of the propane torch attracts animals from as for as 700 m away where the person is burning spines of cactus. Most of the thornless Opuntia varieties are not as cold hardy as spiny varieties. Therefore, care must be taken in selection for planting stock of spineless cactus forage varieties. There will also be a need for intensive management of domestic and wild life to keep the cactus resource from being over utilized.

Vegetable: Cactus has several varieties which are used as vegetables. In Spanish, vegetable part is called nopalitos. Nopalitos are generally between 12 to 16 cm long, about 10 cm wide and 0.5 to 0.8 cm in the thickness. The most important cactus which yields nopalitos is Opuntia ficus-indica, most of the nopalitos have immature spines which need to be removed prior to being eaten. Similarly, glochids are also a problem which needs to be removed before eaten/cooking. However, clone 1308 being grown at Karnal is almost free of spines and glochids. The nutrition value of nopalitos has been reported to be comparable to lettuce and spinach.

Red Cochineal Dye Production: Cactus is also used for producing natural red cochineal dye. The dye is produced by the insects (Dactyloptus coccus) which is raised on cactus cladodes. Wild cochineal appears as white fuzzy clumps about 3-8 mm in diameter on the surfaces of cactus cladodes. On squeezing of these clumps, the red dye appears. However, wild cochineal can be a problem in commercial plantations in reducing the growth and development of the plants. In case of commercial cochineal production systems specially bred cochineal insects strains are used that have higher dye contents and are easier to remove from the cladodes. The world price of cochineal dye is reported to range from $20 per kg to more than $60 per kg of the dried product. The cochineal yield per ha has been reported to range from 100 to 200 kg of course with good management. Since cochineal dye prices show a great variation in the world market, caution must be exercised while making recommendation for large scale cultivation of cactus for cochineal dye production. There are numerous small land holding farmers are raising cactus for dye production in Mexico. It has been reported that this cultivation is quite profitable and sustainable.

Medicinal Use: The most widely acclaimed medicinal use of cactus is the control of diabetes. It has been reported that when 300 g or more of Opuntia stems were ingested, either cold, heated, boiled or blended, blood glucose levels decreased about 30-40 mg per dl in three hours. The undesirable side effects reported in the literature include increase in stool volume and abdominal fullness.

Mucilage Production for Binders and Thickening Agents: In general, about 3% of the weight of cactus is reported to be composed of a galactomannan mucilage. This mucilage is reported to increase the viscosity of solutions. These mucilages may be used as thickening agents in soups, confectioneries and plastering type agents. However, this use of Opuntia is not commercially exploited on a large scale.

International Status

The Food and Agriculture Organization (FAO), Rome is coordinating activities of cactus research and development in the world. More than 20 countries are participating in the FAO CACTUSNET. The CACTUSNET facilitates organization of meetings/workshops/ congresses on cactus to review the progress of research, development and extension activities in various countries. Dr. Enrique Arias is coordinating research and promotional activities of cactus at the FAO headquarters So far five International Cactus Congresses have been organized. The 6th International Cactus Pear and Cochineal Production Congress is scheduled to be held in Brazil in October, 2007. The proceedings of all the cactus congresses held in the past have been published and contain state of the art information on all aspects of cactus research, development, extension, post harvest value addition and marketing information. An International Journal “JPACD” is also being published by the US Professional Association of Cactus Research and Development.

Present Status of Cactus Research and Development at Karnal

To promote research and development aspects of cactus, the following activities have been initiated:

- The five clones have been planted in the herbal garden as ‘demonstration site’ for farmers, visitors to the institute and school students. Every year, a large number of visitors and students visit the herbal garden. Clone 1271 started fruiting about 16 months after planting in the herbal garden.
- To multiply germplasm for distribution to various research and development organizations a separate orchard has been established at CSSRI experimental farm, Karnal. This orchard is serving as permanent germplasm source.
- Studies for exploiting cactus potential in rainfed saline vertisols have been initiated at CSSRI, Regional Research Station, Bharauch, Gujarat.
- The four clones have been planted at Hisar (Haryana) farm of the institute for standardizing planting methods and irrigation requirement. The area represents dry land salinity. The annual rainfall at Hisar is 30-40 cm and the under ground water is saline. The experimental farm offers good scope for biosaline agriculture research.
- The performance of five clones is being evaluated with saline water irrigation treatments of 0, 8 and 16 dS/m. Effect of saline water irrigation on chemical composition of cladodes is being periodically monitored.
- All the five clones have been planted in 30 kg capacity ceramic pots for studying salt tolerance and impacts of salts on chemical composition of the cladodes and fruits.

Problems and Perspectives

Production systems practised today destroy vegetation and accelerate the desertification process, representing a serious danger to the native flora and fauna of arid regions. Therefore, it is very important to implement re-vegetation projects that include several important native species, such as Opuntia, Agave, Prosopis, Acacia, Mimosa and others. Opuntia clones, when planted in rows, fertilized and weeded, can achieve annual dry matter and fresh weight yields of 17 000 kg/ha and 170 000 kg/ha respectively, with crude protein concentrations of about 10%. When properly supplemented with protein, trace elements and critical vitamins, excellent growth and conception rates are possible. Opuntia has great potential for increasing production in average rainfall years, and to provide a critical reserve of forage for animals in severe drought years. In droughts, cactus can also provide a source of green forage and a much appreciated source of water for livestock.

Cactus Glossary

acicular - shaped like a needle. Cactus spines are often acicular.

areoles - circular clusters of spines on a cactus. Flowers bud at an areole .

cladode - a flattened stem that looks like a leaf.

cuticle - the outer layer of the epidermis, which is often waxy

floccose - covered with short hairs, like the areole of some cacti.

glochids - tufts of short, barbed spines that are found at the areoles of opuntia cacti.

glabrous - lacking hairs, usually applied to an old areole or a flower scale.

glaucous - covered with a wax-like layer, liek the cuticle of many cactus species.

globose - shaped like a globe (or sphere).

parastichy - the spiral line (invisible) of the pattern of the areoles on a cactus.

pericarpel - the tissue of the upper part of the flower stem, the receptable, and the lower part of the pistil.

spine - a sharp, pointed, modified leaf found in areoles of cacti.

stamen - the male reproductive parts of a flower. It consists of the filament and the anther.

stigma - part of the pistil, the female reproductive tissue of a flower.

succulent - a plant that has fleshy and juicy tissues, like cacti, sedums, aloes, and yuccas.

xeric - xeric environmental conditions are ones that are very dry.

xerophyte - a plant that is adapted to very dry conditions.

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Problems and Prospectus of Aquaculture in Saline Environments

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Introduction

Aquaculture is the farming of aquatic organisms, including fish, mollusks, crustaceans and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production such as regular stocking, feeding, protection from predators etc. Farming also implies individual or corporate ownership of the stock being cultivated. For statistical purposes, aquatic organisms which are harvested by an individual or corporate body which has owned them through out their rearing period contribute to aquaculture, while aquatic organisms which are exploitable by the public as common property resource with or without appropriate licenses are the harvest of fisheries. Aquaculture production has increased tremendously during past decade. Aquaculture production in total inland fish production is estimated to be about 75-80%. Two major aqua produced are carps and prawn in freshwater aquaculture and shrimps in brackish water aquaculture have contributed to the bulk as well as value of inland aquaculture sector. There are basically four types of aquaculture practices followed in India, i.e. freshwater aquaculture, brackish water aquaculture, marine culture and coldwater aquaculture.

In addition to contributing to nutritional security, the fisheries sector has also been providing world wide livelihood to tens of million of people involved in small scale fisheries and about 200 million earns income and subsistence indirectly through the processing and trade of fish. Indian fisheries sector has been providing employment to over 6 million in capture and culture fisheries, and sector has been a net foreign exchange earner. The export of fish and fisheries products from developing countries exceeds other agriculture products. About 40% of global fish production is traded across countries as compared to about 10% for meat.

Global Fish Production

In 2005, global fish production was 141.6 million tons out of which food fish constituted 107 million tons. Of the total fish production, 27% came from Inland fisheries and 73% from marine fisheries. The contribution of aquaculture to inland fish production amounted to 75% while in case of marine fish production it was 18.3%. Aquaculture production has shown an annual growth of 8.9% since 1970 as against 1.4% for capture fisheries and 2.8% meat production (Table 1). Studies indicate that an additional 30-40 million tons of food fish would be needed by the year 2020 to meet the demand of growing population, changing dietary habits and increasing income levels.

Table 1. World fisheries and aquaculture production and utilization (million tons)

Production	2000	2004	2005
Inland Capture	8.8	9.2	9.6
Inland culture	21.2	27.2	28.9
Total inland	30.0	36.4	38.5
Marine capture	86.8	85.8	84.2
Marine culture	14.3	18.3	18.9
Total marine	101.1	104.1	103.1
Total capture	95.6	95.0	93.8
Total culture	35.5	54.5	47.8
Total world fish production	131.1	140.5	141.6
Human consumption	96.9	105.6	107.2
Non-food uses	34.2	34.8	34.4

FAO (2006)

Indian Perspective of Aquaculture

Freshwater aquaculture

The tanks and ponds which are the major resource of fresh water aquaculture production accounts for 2.3 million ha while the oxbow lakes and derelict water bodies accounts for 1.3 million ha. Reservoirs which spread over an area of 3.15 million ha offer a great scope for enhancing fish production. The total length of various river systems and canal network in the country is about 1.91 lakh kilometers. Various freshwater aquaculture practices of fish culture is taken up by farmers in different regions with production ranging from 3 to 15 tons/ha and thus making significant contribution to the total fish production.

Optimum Range of Soil Parameters for Aquaculture

1. Soil texture	: clay loam
2. Soil colour	: blackish brown
3. pH	: 6.0 to 8.0
4. Water retention capacity	: 40% and above
5. Sand	: 40%
6. Silt	: 30%
7. Clay	: 30%
8. Total nitrogen	: 50 mg/100 g (0.05%) soil and above
9. Phosphate	: 6 mg/100 g soil and above
10. Organic carbon	: 0.5% and above
11. Electrical conductivity	: less than 16 dS/m

Brackish Water Aquaculture /Coastal Aquaculture

Brackish water as the term denotes is a water medium with characteristics between seawater and freshwater salinities ranging from 1 to 35 %. Coastal aquaculture production in the country on account of shrimp farming is estimated that out of about 1.23 million ha identified as potential areas for brackish water fish farming in the country about 10 % area is being farmed at present. Of this area, about 80% is under traditional farming systems and the remaining is under commercial scale extensive and semi-extensive shrimp farming taken up in the states of Andhra Pradesh, Orissa and Tamil Nadu. The traditional farming systems are located in West Bengal and Kerala. Commercial shrimp farming is more than a decade old in India. Most of the coastal lands are owned by the state and to develop aquaculture in new areas clear-cut land lease policies are needed for farming. The optimum physico-chemical parameters for three types of aquaculture are presented in table 2.

Utilization of Inland Saline Soil and Water Resources as New Option for Aquaculture

Large area under saline and alkaline soils which is less suitable and less profitable for agriculture offers additional resource for aquaculture in the country. Vast area of our country in the states of Punjab, Haryana, Rajasthan, Uttar Pradesh, Southern Maharashtra and Gujarat has saline groundwater. In order to achieve 10% growth rate and enhanced fish production from the present 6.57 million tons to 10.0 million tones by the end of XI Five Year Plan, it is highly essential to put at least 75% of the existing aquaculture resources into productive fisheries use. India is not only the second largest producer but also the third largest consumer of fish. Though our per capita consumption is only 9.0 kg which is low as compared to many developing and developed countries and world average of 11.0 kg but increasing per capita income of Indian people has made the fish a more affordable food item. The recent development of super markets having a separate section for fresh fish indicates the potential for upcoming domestic marketing.

Prospectus of Aquaculture in Inland Saline Water

The growing problem of salinity-sodicity needs to be minimized or eliminated as early as possible since it is growing at alarming rate of 10% every year. Soil salinity has become an acute problem rendering crop productivity to decline or making the soil unfit for cultivation. Prolonged non-utilization of this water on one hand is increasing the salinity status of ground saline water and on the other hand it is facilitating saline waterlogged conditions at many places. Thus the problem of soil salinity and saline ground water conditions are alarming and needs immediate attention of the executors. These challenges provide new opportunity for aquaculture in non-traditional areas of inland saline waters. Following aquaculture intervention and introduction of suitable species is the need of the hours (Table 3).

Seed Production of Giant Freshwater Prawn

Giant freshwater prawn has a bi-phasic life cycle. It requires 12 ppt brackish water for the completion of 11stage larval cycle. The source of 12 ppt brakish water for larval rearing in hatcheries is generally met with coastal seawater and rarely with synthetic seawater as it is more costly. Since seawater is cost effective in the coastal belt all hatcheries of this species exist in coastal states. However, the raw ground saline water was found unfit for the larval cycle of prawn predominantly due to the high and low level of calcium and potassium respectively. These ions were amended through a simple cost effective methodology and larval cycle was closed successfully with an over all survival of 40%. Now a days availability of seed of this species is not a problem for the north –western states of the country.

Grow-out of Giant Prawn

The giant prawn (scampi) is well known for culture in fresh water and low salinity seawater. However, the species is not cultured in inland ground saline water in the country. Recent studies have indicated that it can be successfully cultured in raw inland waters of salinity up to 5 ppt. Two phase culture trials i.e. nursery phase of 45 days and grow out phase of three months have shown that this prawn could be cultured with 60% survival rate in nursery phase and up to 77% in grow out phase with a production of 1267kg/ha. Thus these trials have opened prospects for the utilization of low salinity inland waters for the commercial farming of giant prawn. The laboratory and field experiments conducted on raw inland saline ground water of salinity range 7-10 ppt revealed that survival of giant prawn post-larvae is very poor in comparison to fresh and low salinity (<4 ppt) water. The results of indoor experiments with the amendment of potassium (Muriate of Potash) was found to enhance growth and survival to 80% in a 45 days culture trial whereas prawns reared in raw saline water of similar salinity died within 30 days. Thus prawns can be cultured in inland saline water up to 10 ppt salinity with amendment of potassium.

Table 2. Optimum physico-chemical parameters for three types of aquaculture

S.No.	Parameter		Freshwater	Brackish water	Sea water
1	Colour		Clear greenish brown water	Clear greenish brown water	Clear greenish brown water
2	Transparency (cm)		20-35	26-35	26-35
3	Clay turbidity (mg/l)		<30	<30	<30
4	Solids (mg/l)	Total	<500	<500	<500
		Suspended	30-200	25-200	25-200
5	Temperature (^{0}C)	Tropical climate	25-32	25-32	25-32
		Temperate climate	10-12	10-12	10-12
6	pH		6.7-9.5	7.0-8.7	7.0-8.5
7	Hardness (mg/l)		30-180	>50	>50
8	Alkalinity (mg/l)		50-300	>50	>50
9	Chlorides (mg/l)		31-50	>500	>500
10	Salinity (ppt)		<0.5	10-25	5-25
11	Dissolved oxygen (mg/l)		5-10	5-10	5-10
12	Free CO_2 (mg/l)		<3	<3	<3
13	Ammonia Nitrogen-	Unionized-NH_3	0-0.1	0-0.1	0-0.1
	(NH_3-N (mg/l)	Ionized-$NH+_4$	0-1.0	0-1.0	0-1.0
14	Nitrite Nitrogen-NO_2 (mg/l)		0-0.5	0-0.5	0-0.5
15	Nitrate Nitrogen-NO_3 (mg/l)		0.1-3.0	0.1-3.0	0.1-3.0
16	Total Nitrogen (mg/l)		0.5-4.5	0.5-4.5	0.5-4.5
17	Total phosphorous (mg/l)		0.05-0.4	0.05-0.5	0.05-0.5
18	Potassium (mg/l)		0.5-10	>0.5	>0.5
19	Calcium (mg/l)		75-150	>75	>75
20	Magnesium (mg/l)		20-200	200-1350	>1350
21	Sulphate (mg/l)		20-200	200-885	>885
22	Manganese (mg/l)		0.001-0.002	0.002-0.02	0.002-0.02
23	Zinc (mg/l)		0.002-0.01	0.002-0.01	0.002-0.01
24	BOD (mg/l)		<10	<15	<15
25	BOD (kg/ha/day)		<150	<100	<75
26	COD (mg/l)		<50	<70	<70
27	Hydrogen sulphide (mg/l)		<0.002	<0.003	<0.003
28	Residual Chlorine (mg/l)		<0.003	<0.003	<0.003
29	Primary productivity (mg/c/m^3/day)		1000-3000	1000-2500	1000-2500
30	Plankton (ml/100 litre)		2	1	1
31	Chlorophyll-a (ug/l)		20-275	20-250	20-250
32	Redox potential (volts)		0.40-0.52	0.40-0.52	0.40-0.52

Table 3. Candidate species suitable for fish farming in saline water

S. No.	Species character	*Lates calcarifer*	*Chanos chanos*	*Mugil cephalus*	*Etroplus suratensis*	*Peneaus monodon**	*Macrobrachium rosenbergii**
1	Salinity tolerance (ppt)	0-40	0-40	0-40	0-40	0-40	0-15
2	Feeding habit	Carnivore	Herbivore	Herbivore	Herbivore	Omnivore	Omnivore
3	Growth rate (g/yr)	500-1000	1000-3300	1000-1200	200-250	150-250	100-300
	Production (t/ha/yr)	2.0-3.0	2.0-6.0	2.5-3.0	3.0-5.0	2.0-2.4	1.5-3.0
4	Temperature tolerance (^{0}C)	4-38	8-42	3-40	4-40	4-40	4-38
5	Breeding in hatchery	Yes	No	No	Yes	Yes	Yes
6	Seed availability	natural & hatchery	natural collection	natural collection	natural & in ponds	hatchery	hatchery
7	Market price	100-120	50-60	50-100	50-100	250-350	150-250

*Six month culture period

Grow-out of Milkfish (*Chanos chanos*)

Milkfish a euryhaline brackish water finfish of coastal water has been identified as an important species for culture in low and high salinity inland ground waters of north-western India. The seed of milkfish (25-35 mm) was procured from coastal states and successfully reared in 23 ± 1 ppt salinity inland ground water. The stocking density was maintained at 17,000/ha in an earthen pond of 0.1 ha and fed on farm made feed comprising of mustard oil cake, rice polish, soybean meal and mineral mix and reared for 12 months. The juveniles attained a length of 289.27 mm and weight 253.01 gm with 90% survival with a production of 3750 kg/ha/year.

Grow-out of Grey Mullet (*Mugil cephalus*)

Grey mullet is another suitable and commercially important euryhaline finfish species suitable for rearing in raw inland ground saline water. The seed of this species was procured from the coastal states through collection from wild resources. Four month culture in 22 ± 1 ppt salinity water with a stocking density of 5750/ha has shown an average growth of 295.3 ± l7.0 mm length and 266.0 ± 49.9 gm weight with 90% survival and a net production of 1320 kg/ha.

Grow-out of Indian Major Carp and Chinese Carps

Indian major carps - catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhinus mrigala*) and chinese carps - common carp (*Cyprinus carpio*) and grass carp (*Ctenopharyngodon idella*) have been found to grow well up to 5 ppt salinity in inland saline water. Poly culture of these species has shown a production of around 3000 kg/ha/year when stocked with one season old fingerlings.

Tiger Shrimp Culture

Tiger shrimp (*Penaeus monodon*) is an important euryhaline shellfish species which has been found suitable for culture in inland saline water. The results revealed that tiger shrimp do not survive in raw inland ground saline water at salinity above 5 ppt. However, addition of potassium in the form of muriate of potash in water has been found to enhance growth and survival. Since there is no dearth of seed of this species this may bring boom in the sector.

Indian Magur Culture

Indian (desi) magur (Clarias batrachus) is another freshwater fish species which has been found suitable for culture in low saline (<5 ppt) water. Since this is an air breathing fish and fetches very high price in the market may provide better income to the farmers.

Ornamental Fish Culture

Freshwater ornamental fishes like koi carp, goldfish, mollies, platies and gouramis have been found to survive and grow well in low salinity inland water (<5 ppt). Thus these species also provide avenues for culture in inland saline water. Some ornamental fish species like koi carp, mollies, platies and blue gorami have been breeding in low salinity inland water in pond as well in indoor hatchery conditions.

Control of Pond Seepage and Secondary Salinisatiion

UV-stabilized poly qua-lining of PVC (poly vinyl chloride) material of thickness 0.5 to 0.7mm has been found highly suitable for laying in aquaculture ponds. This lining has been found to help in total control of pond seepage and nutrient loss and is safe for fish and prawn cultures. Since the disposal of high saline inland water from aquaculture ponds has been a matter of great concern from the environment point of view, ponds lined with this film could be used to serve as salt evaporation basins for the treatment of the wastewater. Thus it will solve the problem of secondary salinization and the salt produced could be utilized as a raw material by the industry.

Integrated Fish Farming in Sodic/alkaline Soil and Water Condition

The principle of integrated fish farming involves farming of fish along with livestock and/or agricultural crops. This type of farming offers great efficiency in resource utilization (such as sodic /alkaline soil and water) as waste or as by product from one system is effectively recycled. It also enables effective utilization of per unit area of land available for maximizing production. The rising cost of protein rich fish food, chemical fertilizer and the general concern for energy conservation have created awareness in the utilization of rice and other crop fields and livestock wastes for fish culture. Fish culture in combination with agriculture or livestock is a unique and lucrative venture and provides higher farm income, makes available a cheap source of protein for the rural population, increases productivity on small land holdings and increases the supply of feed for the farm livestock. The scope of integrated farming is considerably wide. Ducks are raised in ponds and pond dykes are used for horticultural and agricultural crop in addition to fish farming in ponds. Hence this system provides better production, more employment, and improves socio-economic status of farmers and rural economy. This hype of integrated farming system approach will be very much fruitful in different canal command areas. This will be very much fruitful enterprise in water logged area with the incorporation of poly culture fish species.

Identification of Thrust Areas of R & D

The progress of R & D in the field of inland saline water aquaculture needs to be speeded up so as to keep pace with the demand of the situation. Setting up of hatcheries, farming of new species, use of hyper saline water etc. needs attention. Capacity building and networking of R & D efforts are also essential. Collaborative research programmes involving local organisation, transfer of technology needs top priority.

Seed Production of Suitable Species

The availability of the seed of species that can be cultured in saline water is a serious problem particularly for small and marginal farmers. Information has to be collected on natural seed collection centres both in private and government sectors. Fisheries department of inland states shall develop suitable mechanism with private as well as government organization of coastal states to help in the procurement of seed. Inland states should set up "Seed supply centre' which can procure seed from coastal states in large quantity and then distribute them to local farmers.

Environmental Consideration

The development of saline water aquaculture will require continuous abstraction of saline ground water and its impoundment in ponds. There are possibilities of horizontal movement of saline water during the process of abstraction and ponding. Both these processes may contaminate the limited fresh water aquifers. The disposal of untreated fish pond effluents will also be a serious threat to surrounding environment. Therefore, it will be required to formulate environment management plans at the beginning itself that include safe methods of water abstraction and pond construction with no seepage loss. A multitier saline water production system commencing from fish farming to Artemia farming and finally ending up with salt production is recommended.

Technical Issues

There will be many technical issues with regard to development of inland saline aquaculture. These may be related to availability of facilities for infrastructure development, pond construction, electricity, skilled manpower, approach roads, marketing of products etc. If the salinity of water is 35 ppt or above it may be difficult to maintain the salinity of pond at permissible limits as it may go very high during summers and cause high fish mortality.

Conclusion

The world summit on sustainable development (WSSD) held at Johannesburg, South Africa (26 August-4 September, 2002) identified water sanitation, energy, health, agricultural productivity & biodiversity and ecosystem management as major areas of concern for improving the quality of life of the entire global population. It was specified that building of a truly sustainable way of life it would require the integration of action in three key areas i.e. economic growth & equity, conserving natural resources and the environment and social development. Salinisatlon of land and water resources beyond coastal zone is a serious threat to the important concerns of WSSD. Developing technologies for utilization of saline water resources in inland regions through aquaculture based activities will reduce the pressure on freshwater resources that could be spared for drinking purposes. They would also optimize the use and productivity of waste lands and water, provide an occupation to marginal and poor farmers and ensure socio-economic independence and food security to resource deprived farming communities.

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Biosaline Agriculture

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Introduction

The mission of biosaline agriculture is to develop and promote the use of suitable agricultural systems that use saline water to grow crops. Over the next 30 years we must increase food production by a fifth in developed countries and by nearly two-thirds in the developing world, just to maintain current levels of nutrition. But most land suited to agriculture is already cultivated. Therefore, most of the increase will have to come for increasing the productivity of land that is already cropped and growing novel crops on land currently considered unfit for cropping. A major weapon in the farmer's armoury of productivity-enhancing tools is irrigation. Now, we are running out of the good quality water normally used for irrigation. More than half the world's groundwater supplies are already saline and the proportion is increasing as demand for water outstrips supply. Groundwater surveys in India indicate that poor quality waters being utilized in different states are 25 to 84% of the total ground water development - more in arid and semiarid regions. It is 84% in Rajasthan, 62% in Haryana, 47% in Uttar Pradesh, 38% in Karnataka, 30% in Gujarat, 32% in Andhra Pradesh and 25% in Madhya Pradesh. Many more areas with good-quality aquifers are endangered with contamination as a consequence of excessive withdrawals of groundwater. Therefore, biosaline agriculture is the opportunity to create new, viable and sustainable agricultural systems based on the use of saline/sodic water. There is need to focus on the use of salt-tolerant plants in practical production systems. There are millions of hectares of salt-affected land and vast resources of saline water on our disposal. Bringing these into productive use will be a major step forward in efforts to boost food production as we enter the new millennium. CSSRI has made some efforts, which have been high lighted in this paper.

Afforestation/ Agroforestry on Sodic Lands Using Sodic Water

Alkali soils have a compact hard sub-surface layer or a caliche (calcite) bed (of nodulated or amorphous $CaCO_3$) in lower depths, which imposes physical impediment to root penetration/ development. Unlike soil reclamation for arable crops, where only plough layer is sought to be improved in the first instance, deep-rooted trees require reclamation of the soil to lower depths. The planting technique should further ensure efficient utilization of rainwater, and leaching of reaction products after interaction of amendments and root development in the soil profile, soil structural improvement for increased water retention to encourage rapid root penetration in the vertical rather than horizontal direction, and minimize direct sodium toxicity hazards. Keeping this view, attempts were made to develop suitable techniques (pit-auger-hole technique) for planting trees on such lands. In this technique the auger is mounted on a tractor and used for making holes of dimensions 20-25 cm diameter and 1.2-1.8 deep. This technique recognizes that in trees, owing to their deep root systems, management of the root zone by modifying the soil environment to greater soil depths using a limited quantity of amendments has a vital role. With this in mind a number of studies were conducted to establish positive benefits of this planting technique for tree plantations on alkali soils and it was concluded that original soil mixed up with 3-5 kg gypsum (50% of gypsum requirement in the auger-hole) and 8-10 kg farm yard manure (FYM) in each auger-hole is most suitable for alkali soils of high pH. Application of small dose of nitrogen in the auger-hole filling mixture and its regular application every year thereafter (25 g in monsoon and 25 g in winter) proved beneficial in non-leguminous tree species.

Series of long-term experiments were conducted to prove usefulness of 'auger-hole technique' for raising tree plantations on sodic soils. Based on the evaluation of more than 5 dozen species planted with auger hole technique through series of experimentation on sodic soils), it could be concluded that *Prosopis juliflora* was the best performer for the sodic soils of high pH (> 10) followed by *Tamarix articulata* and *Acacia nilotica*. Species such as *Eucalyptus tereticornis, Terminalia arjuna, Salvadora oleoides, Cordia rothii* and fruit trees (with improved management) such as *Carissa carandus, Emblica officinalis* and *Psidium guajava* can be grown with great success on moderate alkali soil (pH < 10), preferably at pH around 9.5 or less (Table 1).

A large proportion of salt-affected lands (particularly in Indian subcontinent) does not belong to individual farmers, but is either government land or in the custody of village *Panchayats*. Reclamation of such lands for crop production is not feasible because of common property rights. Raising suitable trees and grasses would appear to be a promising use of these lands. As mentioned earlier, the most promising tree species for highly alkali soils are *Prosopis juliflora, Acacia nilotica* and *Tamarix articulata*. Highly salt-tolerant and high biomass producing grass species include *Leptochloa fusca, Brachiaria mutica, Chloris gayana,* species of *Sporobolus* and *Panicum.* Mesquite (*P. juliflora*) and *kallar* grass (*L. fusca*) based silvi-pastoral practice has been found most promising for firewood and forage production and also for soil amelioration. This system improved the soil to such an extent that less tolerant but more palatable fodder species such as Persianclover (*Trifolium resupinatum*), Berseem (*T. alexandrinum*), Lucerene (*Medicago sativa*) and Sweet clover (*Melilolus denticulata*) could be grown under mesquite trees after 4-5 years. The grazing lands of sodic soils are very poor in forage production under open grazing, but when brought under judicious management these can be explored successfully for sustainable production. Based on series of long-term experiments it was found that *L. fusca* can be rated the most tolerant grass to highly sodic soil and waterlogged conditions as compared to other grasses. In one experiment tree species such as *Acacia nilotica*, *Eucalyputs tereticornis* and *Parkinsonia aculeata* were planted on ridges and kallar grass (*L. fusca*) was established in the trenches between ridges. This system conserved rainwater during monsoon, which in turn increased the biomass of trees and intercrops of grasses. In addition to firewood and forage production, this system was found useful in checking runoff and soil loss.

Table 1. Relative tolerance of tree species for soil sodicity.

Average pH_2 (0-1.2 m)	Fuelwood/fodder/timber species	Fruit tree species
> 10	*Prosopis juliflora, Acacia nilotica, Tamarix articulata*	Not recommended
9.6 – 10.0	*Eucalyptus tereticornis,Pithecellobium dulce, Prosopis alba, P. cineraria, Casuarina equisetifolia*[*1], *Salvadora persica, S. oleoides, Capparis decidua, Terminalis arjuna*	*Carissa earandus, Psidium guajava, Zizyphus mauritiana, Emblica officinalis*
9.1-9.5	*Cordia rothii, Albizia lebbeck, Cassia siamea, Pongamia pinnata, Sesbania sesban, Parkinsonia aculeata, Dalbergia sissoo, Kigelia pinnata, Butea monosperma*	*Punica granatum*[*2], *Phoenix dactylifera, Achrus japota*[*1], *Tamarindus indica*[*1], *Syzygium cuminii, Feronia limonia*
8.2-9.0	*Grevillia robusta, Azadirachta indica, Melia azedarach, Leucaena lencocephata, Hardwickea binnata, Moringa loiefera, Populus deltoids, Tectona grandis*	*Grewia asidatica, Aegle marmelos*[*2], *Prunus persica, Pyrus communis, Manigifera indica, Morus alba, Ficus* spp.

[*1] (frost sensitive), [*2] Does not stand water stagnation, may be raised on bunds.

Forest or fruit trees may also be raised in wider spaces (row to row 4-5 m, plant to plant 4 m) and the arable crops may be cultivated in the interspaces. In one experiment, berseem (*Trifolium alexandrinum*), wheat, onion and garlic could be grown successfully for three years with fruit trees such as *Carissa carandus, Punica granatum, Emblica officinalis, Psidium guajava, Syzygium cuminii* and *Ziziphus mauritiana*. To avoid water stagnation problem in alkali soil, the trees (both fruit and forest species) can be grown on raised bunds and water-loving crops such as rice and forage grasses (*L. fusca, Brachiaria mutica*) during rainy season and salt-tolerant wheat or berseem or Lucerne during winter may be raised in sunken beds.

Many of the medicinal and aromatic under-explored crops are in great demand for both internal requirements and export. But since these crops are non-conventional in nature, it is not always feasible to produce these on fertile land, which can be used for arable crops. The marginal lands, specifically the salt lands where profitable returns are not possible from agricultural crops, can successfully be utilized for the cultivation of these high value crops with marginal inputs. Results of several experiments clearly indicated that aromatic grasses such as palmarosa (*Cymbopogon martini*) and lemon grass (*C. flexuosus*) could successfully be grown on moderate alkali soils up to pH 9.2 while vetiver (*Vetiveria zizanoides*) which withstands both high pH and stagnation of water, could successfully be grown without significant yield reduction on highly alkali soils. Medicinal Isabgol (*Plantago ovata*) produced 1.47 to 1.58 t/ ha grain (including husk) at pH 9.2 and 1.03 to 1.12 t/ha at pH 9.6 showing its potential at moderate alkali soil. *Matricaria chamomile, Catharanthus roseus* and *Chrysanthemum indicum* were other interesting crops, which could be grown on moderate alkali soil. All these crops can be blended in suitable agroforestry systems.

Afforestation of Waterlogged Saline Soils Having Saline Underground Water

The saline soils suffer from excessive concentration of salts, high water table often leading to water logging, and occurrence of poor quality underground waters in many areas. Poor root zone aeration caused by high water table (water logging) and excess presence of salts, which operate simultaneously, impair success of plantations on such soils. The planting techniques should be such that salt concentration in the root zone remains at a low level and the plants are able to escape adverse affects of high salinity. Though a series of experiments, techniques of plantations on waterlogged saline soils were developed.

To provide better aeration and avoid excessive salinization planting on high ridges was often considered beneficial for establishing tree plantations on waterlogged saline soils. This method was compared with the sub-surface and furrow planting methods. Long-term field studies were conducted on about three dozen woody perennial species for afforestation of waterlogged saline soils in arid and semiarid regions of India. The initial electrolytic conductivity of soil (ECe) was 36-40 dS/m in the upper 30 cm and the water table was shallow, fluctuating between 1.5 m depth to the surface in different seasons of the year, and the water was brackish (average EC 30 dS/m). During this study, it was observed that the greater the surface area of the ridges, the more salts accumulated in the surface 1 m root zone of ridge planted trees. In contrast, under the sub-surface planting method, roots were encountering a milder saline transmission zone and were meeting most of their water requirement from the phreatic zone. Difficulty of conserving rainwater on the ridge tops and the presence of salts causing higher susceptibility to soil erosion were the other disadvantages encountered with ridge planting. In the sub-surface planting method the roots encountered a smaller saline transmission zone. Further, the subsurface planting method was modified and furrow planting technique was developed. In this technique, a tractor-driven furrow maker was used to create about 60 cm wide and 20 cm deep furrows. The saplings of a tree species were planted at the base of the furrows. These furrows were subsequently used for irrigating the tree saplings. Establishment of saplings with furrow method was better than sub-surface method of planting. In addition to reducing the water application costs and increasing uniformity in water application, downward and lateral fluxes of water and salts from these furrows helped to create zones of favourable low salinity below their bases, especially when low-salinity irrigation water was used. Creation of such low 'salt-niches' favoured the establishment of young tree seedlings. With the furrow planting technique, salt concentrations were kept lower in the rooting zone of trees, such that the trees were able to escape the adverse effects of high salinity. Moreover, the furrow system seems more viable than the other techniques from a practical point of view for undertaking large-scale plantation of trees.

The data on biomass production after 9 years of plantation established with saline water showed that *P. juliflora* and *Casuarina glauca* was highest (98 and 96 t ha^{-1}), followed by *Acacia nilotica* (52-67 t / ha and *A. tortilis* (41 t/ha) when planted with subsurface or furrow technique showing their potential for saline waterlogged soils. Thus, on the basis of performance of trees for 6-9 years after planting in saline waterlogged soils it was found that species like *P. juliflora, Tamarix articulata, T. traupii, Acacia farnesiana*, *Parkinsonia aculeata* and *Salvadora persica* to be most tolerant to waterlogged saline soil and could be raised successfully up to salinity levels of ECe 30-40 dS/m. Species like *A. nilotica, A. tortilis, A. pennatula, Casuarina glauca, C. obesa, C. equisetifolia, Callistemon lanceolatus*, *Eucalyptus camaldulensis, Feronia limonia, Leucaena leucocephala* and *Ziziphus mauritiana* could be grown on sites with ECe 10-20 dS/m. Other species including *Casuarina cunninghamiana, Eucalyptus tereticornis, Terminalia arjuna, Albizzia carbaea, Dalbergia sissoo, Emblica officinalis, Guazuma ulmifolia, Punica granatum, Pongama pinnata, Samanea saman, Acacia catechu, Syzygium cuminii* and *Tamorindus indica* could be grown satisfactorily only at ECe < 10 dS/m. Based on the salinity level at which satisfactory growth of species occurred, salt-tolerant agroforstry species tried in India have been grouped into highly tolerant, tolerant and moderately tolerant categories (Table 2).

In waterlogged areas near canals planting cloned *Eucalyptus* on bunds (of ~ one meter height) on farmers field (in two lines in a space of 1m x 1m) proved very useful, which not only controlled rise in water table but also helped in revenue generation as after 5 years of plantation farmers could sold the trees (at the rate of Rs 350 per tree) and these could coppice further. In saline areas lining of poly-sheets on bunds helped in controlling the development of salinity.

Afforestation/ Agroforestry on calcareous Degraded Land Using Saline Water

The traditional approach for sustaining the use of saline water is to irrigate more frequently and provide for leaching requirements. Nevertheless, such practices demand for application of additional quantities of saline water and thereby also result in enhancement of salt loads of soils. These approaches were advocated for shallow rooted crop plants in arid environments mainly because the added salts could be pushed beyond the rooting zone. But in deep rooted tree plantations, the additional salts going into the soil through enhanced frequency of irrigations during their establishment may rather aggravate the problem as these are likely to persist within their expanding rooting zones and may subsequently hinder the growth of trees. Therefore, irrigation with saline waters should aim to create favourable niches for the better establishment of saplings and also eliminate the over salinity buildup. This could be achieved by irrigating only the limited area under furrows planted with tree saplings. In this technique furrows (15-20 cm deep and 50-60 cm wide) are created at 3-5 m intervals with a tractor drawn furrow maker. Auger-holes (0.2 m diameter and 1.2 m deep) are dug at the sill of these furrows spaced at 2-3 m intervals. These are re-filled with the mixture of original soil plus 8 kg of farmyard manure, 30 g super-phosphate, 15 g zinc sulphate and 15 g of iron sulphate. Six months old tree saplings are transplanted during rainy season (July-August) at sites where auger-holes are dug. The irrigation with saline water is given in furrows only. The technique is known as subsurface planting and furrow irrigation system (SPFIM). The irrigation may be provided for initial three years (4-6 times in a year) and thereafter, plantations may be irrigated once during the winter only. Salt storage in soil profile may increase during irrigation period but the added salts get distributed in soil profile as a consequence of seasonal concentration of rainfall during monsoons and some episodic events of rainfall during the following years. The inter-spaces may be utilized for growing low-irrigation requiring crops such as barley, toria (*Eruca saliva*), cluster bean, and soya (*Anethun graveolens*) during initial years. Medicinal Isabgol (*Plantago ovata*) was found doing well under partial shade. The soil is enriched with organic carbon (> 0.4% in upper 30 cm) under the promising tree species. Thus, rehabilitation of arid soils with the promising tree species using the available saline waters would not only render the abandoned soils to be productive but would also ensure conservation and improvement in environment for long range ecological security on these lands. A long-term field trial with 31 tree species was conducted over 9 years on a calcareous soil in a semiarid part (annual rainfall about 350 mm) of northwest India using furrow method of irrigation as described earlier. The saplings were irrigated with saline water (EC 8-10 dS m^{-1}) for initial three years (4-6 times in a year) and thereafter plants were irrigated once in a year during winter. Most of the tree species (except

Syzygium cuminii, Bauhinia variegata and *Crescentia alata*) showed quite high survival rate (71-100%) during first three years. Ranking in order of survival, growth and biomass yield showed that *Tamarix articulata, Acacia nilotica, Prosopis juliflora*, *Eucalyptus tereticornis, Acacia tortilis* and *Cassia siamea* were most successful species. After 7 years of planting, the highest shoot biomass was harvested (Fig. 1) from *Tamarix articulata* (71.9 t/ha) followed by *Acacia nilotica* (23.4 t/ha), *P. juliflora* (20.2 t/ha) and *Eucalyptus tereticornis* (14.8 t/ ha).

Table 2. Tolerant species for saline soils tried in India.

Very high salt-tolerant ECe > 35 dS/m
Trees and shrubs
Prosopis juliflora, Salvadora persica, S. oleoides, Tamarix ericoides, T. troupii, Salsola baryosma etc.
High salt-tolerant (ECe > 25-35 dS/m)
Trees and shrubs
Tamarix articulata, *Acacia farnesiana, Parkinsonia aculeata*
Tolerant (EC 15-25 dS/m)
Trees and shrubs
Casuarina (glauca, obesa, equiselifolia), Acacia tortilis, A. nilotica, Callistemon lanceolata, Pongamia pinnata, Eucalyptus camaldulensis, Crescentia alata, Albizia lebbeck.
Grasses & forbs
Ziziphus nummularia, species of *Chenopodium, Dichanthium, Eragrostis, Panicum, Spartina, Paspalum, Sporobolus, Brachiaria, Chloris.*
Moderately tolerant (ECe 10-15 dS/m)
Trees and shrubs
Casuarina cunninghamiana, Eucalyptus tereticornis, Acacia catcechu, A. ampliceps, A. eburnea, A. leucocephala, Terminalia arjuna, Samanea saman, Albizia procera, Borassus flabellifer, Prosopis cineraria, Azadirachta indica, Dendrocalamus strictus, Butea monosperma, Cassia siamea, Feronia limonia, Leucaena leucocephala, Tamarindus indica, Guazuma ulmifolia, Ailanthus excelsa, Dichrostachys cinerea, Balanites roxburghii, Maytenus emarginatus, Dalbergia sissoo, Salix babylonica
Grasses & forbs
Andropogon annulatus, Anthistria prostrata, Paspalum notatum, Urochloa mossiambicensis, Glycine javanica, Phaseolus lunata, Cenchrus pennisetiformis, Lasiurus sindicus, Echinochloa colonum, etc.

Fruit trees like *Feronia limonia, Ziziphus mauritiana, Carissa carandus, Emblica officinalis* and *Aegle marmelos* could be established irrigating with saline water up to EC 10 dS/m and intercrops in wider spaces between rows (5 m) such as cluster bean and barley could be raised with success applying one or two irrigations Table 3). This appears very viable agroforestry system for such soils.

Table 3.Grain and straw yield (t ha^{-1}) of cluster bean and barley with different plantations

Fruit tree	*Treatment*	*Yield of* cluster bean		Yield of barley	
		Grain	*Straw*	*Grain*	*Straw*
Karonda	T_1	0.88	1.46	3.58	3.88
	T_2	0.86	1.38	3.47	3.97
	T_3	0.81	1.27	3.45	3.71
	T_4	0.76	1.15	3.10	3.32
Anwla	T_1	0.79	1.29	4.19	3.40
	T_2	0.81	1.33	3.63	3.83
	T_3	0.76	1.24	3.24	3.34
	T_4	0.69	1.18	2.87	3.00
Bael	T_1	0.75	1.23	3.27	3.45
	T_2	0.71	1.21	3.22	3.35
	T_3	0.67	1.06	2.73	2.86
	T_4	0.63	1.02	2.52	2.64
LSD (p = 0.05)					
Factor A (species)		0.13	NS	0.12	0.17
Factor B (treatment)		0.02	0.11	0.14	0.15
Interaction (A x B)		NS	NS	0.24	0.26

Treatments T_1- T_4 depict as planted in traditional rings and irrigated with water of low salinity (EC 4-5 dS/m); planted in furrows and irrigated with water of low salinity; furrow planting and irrigated alternately with water of low and high (EC 10-12 dS/m); and furrow planting and irrigating with water of high salinity, respectively.

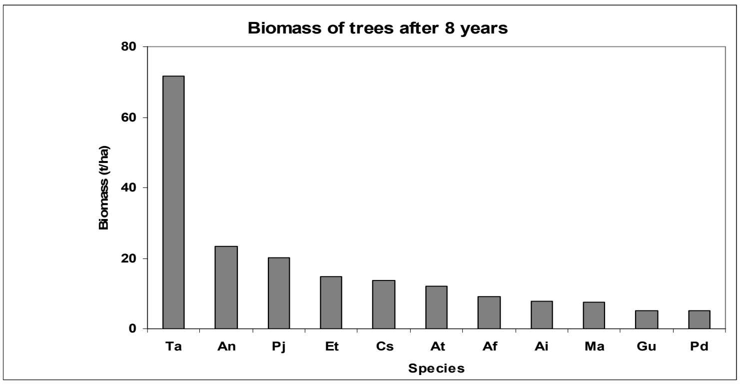

Fig. 1. Biomass of trees after 8 years of planting {Af- *Acacia.farnesiana*, An- *A. nilotica*, At - *A. tortilis*, Ai- *Azadirachta indica*, , Cs – *Cassia siamea,* Et - *E. tereticornis, Gu- Guazuma ulmifolia,* Ma - *Melia azedarach*, Pd - *Pithecelubium dulce*, Pj - *Prosopis juliflora, Ta- Tamarix articulata*}

Among forage grasses *Panicum laevifolium* and *P. maximum* were most suitable species producing annually 14-17 t/ha forage. About 25-30% of total forage was also available during lean period of summer when most of the people become nomadic along with their cattle.

In series of experiments the performance of winter annual flowers, aromatic grasses, and some medicinal plant species under saline irrigation was also evaluated on calcareous soils. It could be concluded that ornamental flowers such as *Chrysanthemum, Calendula* and *Matricaria* can successfully be cultivated irrigating with water of EC up to 5 dS/m. These species could yield 13.2, 4.7 and 3.5 t/ha, respectively fresh flowers in a season. If good quality water is available at site, a few irrigations particularly for establishment will increase the yield of flowers. The aromatic grasses such as vetiver, lemon grass and palmarosa, when irrigated with saline water (EC 8.5 dS/m) could produce on an average 90.9, 10.4 and 24.3 t/ha dry biomass, respectively. Different cultivars of vetiver could produce 72.6 to 78.7 t/ha shoot biomass and 1.12 to 1.71 t/ha root biomass. The roots are used to extract aromatic oil.

Amongst the species tested for medicinal value, the most promising was psyllium (*Plantago ovata*) with average seed yield of 1050 kg/ha with saline water (EC 8.5 dS/m) did not show any adverse impact when compared with canal water irrigation. *Aloe barbadensis* was also equally tolerant and could produce 18 t/ha fresh leaves. *Ocimum sanctum* could produce 910 kg/ha dry shoot biomass. In a separate trial dill (*Anethum graveleus*), taramira (*Eruca sativa*) and castor (*Ricinus communis*) could produce 931, 965 and 3535 kg seeds per ha, respectively when provided with three irrigation of saline water (EC 10 dS/m). *Cassia senna* and *Lepidium sativum* can also be cultivated successfully irrigating with saline water up to 8 dS/m. All these high value crops can successfully be grown as inter-crops with forest or fruit trees at least during initial years of establishment. Psyllium did not show any yield reduction with *Acacia* plantation even at later stages showing its suitability for partial shade tolerance.

Agroforestry for Salty Black Soils (Saline Vertisols)

The salty soils of black soil zone are generally either contemporary or of secondary origin. The contemporary salty soils exist in the topographic situation having poor drainage conditions. However, the soils that have become sodic due to injudicious use of irrigation water can be encountered in the irrigation command area. In a long-term experiment, after 14 years of plantation it was found that *P. juliflora* and *Azadirachta indica* were most successful species for these soils. Among grasses, *Aeluropus lagopoides, Leptochloa fusca, Brachiaria mutica, Chloris gayana, Dichanthium annulatum, Bothriochloa pertusa* and species of *Eragrostis, Sporobolus* and *Panicum* are most successful. Aromatic grasses such as *Vetiveria zizanioides* and *Cymbopagon martini* can be grown easily. *Matricaria chamomile* can withstand both high pH and ESP. In a separate fruit trial on soil of ESP 25, 40 and 60 it was found that gooseberry (*Emblica officinalis*) and B*er* (*Ziziyphus mauritiana*) are the most successful plantations for these soils. Oil-yielding bush *Salvadora persica* was grown in combination with *Leptochloa fusca, Eragrostis* spp. and *Dichanthium annulatum* forage grasses on saline vertisol in Gujarat. The soil was clay loam (clay 40%, silt 31%, sand 29%) with pH ranging from 7.2 to 8.9 and ECe from 25-70 dS/m. The underground water was 0.5-2 m from surface with EC ranging from 55-60 dS/m. These grasses could produce on an average 3.72, 1.0 and 1.8 t/ha of green forage, respectively. During fourth year the seed yield of *Salvadora persica* ranged form 1.84 to 2.65 t/ha with oil contents ranging from 576-868 kg/ha at different salinity levels. The experiments conducted in sodic Vertisols with ESP 40 growing grasses like *Leptochloa fusca, Brachiaria mutica* and *Vetiveria zizanioides* showed that all these grasses performed well and the forage biomass increased during second year. Besides producing biomass silvi-pastoral system helped in amelioration of soil in terms of reducing soil pH, EC and ESP and increasing organic matter.

Epilogue

Recently the attention is being paid towards commercial forestry, raising block plantation of commercial trees and also trees yielding bio-diesel such as *Jatropha curcas*. This approach will change the economical scenario by reducing the import of fossil fuels. As discussed in earlier sections, trees play a vital role both in lowering down water table (in waterlogged areas) and also recharging the groundwater in dry regions where water table is falling drastically. By adopting agroforestry practices, we shall be able to diversify the cropping pattern when more production will be obtained per unit of water available. Adopting biosaline agroforestry, the nomadic behaviour of large population will be checked in dry regions. This will have a tremendous social impact. CSSRI being nodal Institute on Salinity Research may play more important role in promoting biosaline agriculture. The important thrust areas for biosaline research may include:

- Survey collection, assembling and maintaining a collection of plants adapted to saline conditions.
- Evaluation of potentially useful plants for agriculture, horticulture as well as landscape programme.
- Selection and evaluation within existing forage, horticultural, floriculture, medicinal and oil-yielding crops for salt tolerance.
- Developing sustainable agronomic practices such as fertilizers and irrigation using saline water.
- To understand the physiological and biochemical mechanism of salt tolerance particularly among non-conventional crops of high economic value.
- Improvement of germplasm of potential halophytic crops applying both conventional (plant breeding) and modern approach of molecular biology (genetic engineering).
- Developing a network on information and extension of the technology developed

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Tree Plantation in Saline and Sodic Soils

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Introduction

Out of 329 million ha geographical land area of the country about 175 million ha suffers from different problems and is getting further degraded through natural or man made processes. Majority of these lands is treated as wastelands as their productivity is low due to soil based constraints like waterlogging, salinity, sodicity, lack of depth and sandy, stony or gravelly soils. As no additional land resources are available for horizontal expansion of agriculture, we need to find out viable technologies for utilization of existing land resources including the wastelands in order to meet future requirements for food, fodder and fuel. Soil salinity and alkalinity have degraded about 8.6 million ha of land in India (Singh, 1992). A large acreage in the canal-irrigated tracts of arid and semi-arid regions of the country suffers from waterlogging and salinity and the resultant loss to crop production is increasing at an alarming rate. Already a sizeable area has gone out of cultivation in almost all canal commands of the country making the landscape devoid of any vegetation except a few hardy trees and grass species like *Salvadora persica, Capparis decidua, Prosopis juliflora, Acacia nilotica, Desmostachya bipinnata, Sporobolus spp.*, *Kochia indica and Suaeda maritima.*

According to the National forest policy of India enunciated in May 1952, at least 33% of the total land area should be under forest for a balanced agrarian economy but the existing forest area is far less. The National Commission on Agriculture (1976) has also reported a wide gap between the requirement and availability of fuel wood in our country and recommended afforestation on all types of lands otherwise considered unsuitable for arable crops. Salt affected soils represent one such category of lands. Alternate use of such lands is an option of great promise in view of the growing demand for fuel wood and fodder and also for environmental considerations. For reclamation and management purposes, salt affected soils in India are broadly placed under two groups: alkali and saline. About one third of the reported salt affected soils in India are alkali and are characterized by high pH (> 8.2), large presence of carbonates and bicarbonates of sodium, exchangeable sodium percentage above 15, variable EC, low fertility and very poor physical properties; which support very little vegetation. The main causes that render saline soils unfavorable to plant growth, include excess amounts of neutral soluble salts chiefly chlorides and sulfates of sodium, magnesium and calcium causing osmotic stress, specific ion toxicity and nutritional disorders. Often high water table conditions in such soils cause impeded drainage. Coupled with this, the poor quality of ground waters are responsible for desertification of saline areas. Considering the vast scope that salt-affected soils offer for afforestation, a number of forest tree species have been evaluated for their tolerance to alkali and saline conditions.

Suitable Methods for Plantations

In order to rehabilitate salt affected soils, appropriate tree planting techniques and choices of tree species are very crucial for reducing mortality and consequently for improvement in the initial establishment of saplings. Since alkaline and saline soils differ from each other, methods of working the soils will also be different. For example, in alkali soils a hard kankar layer of calcium carbonate is generally found at a depth about 1.25 to 1.5m. This layer acts as a barrier for root penetration. The layer, therefore, has to be broken first to allow proper development of roots. However, saline soils do not require such preparation, as they do not have any such barriers. These require special techniques of afforestation so that salt contents in root zone are minimized. We must, therefore, diagnose the soils first and then choose the method accordingly.

Plantation in Sodic Soils

The ideal planting method for alkali soils should provide a favorable soil environment such as by breaking the hard kankar layer, replacement of exchangeable sodium and additional nutrition of tree species for optimum root growth. The prevailing planting methods for afforestation of alkali soils are sole pits, pit-auger hole, and ridge-trench. However, among these planting methods, results of pit- auger hole planting method have been found promising over other methods. In this planting method, augerholes of 15 cm diameter are made to pierce the hard kankar layer up to 150 -180 cm deep, with the help of a tractor-mounted auger after digging pits of 35 cm X 35 cm. Auger holes are refilled with original soil, 3 kg gypsum, 8 kg FYM, 10 g $ZnSO_4$ and small quantity of aldrin or BHC to take care of termites. Tree saplings of 6-9 months old are planted in the refilled pit-auger holes followed by irrigation with buckets. Two to three irrigations are immediately needed for establishment of saplings. This method enables the plant roots to grow at a faster rate towards deeper soil layers where sufficient moisture and nutrients are available in alkali soils. The kankar layer, which creates hindrance in the development of plant roots, is broken in the process of making holes. Yadav (1956) suggested pit planting having pits of 90 x 90 x 90 cm size. Sandhu and Abrol (1981) laid out two experiments at the research farm of the CSSRI, Karnal. In one experiment, the treatment included various dimensions of auger and pit holes. The second experiment investigated the effect of the composition of filling mixtures. Performance of two tree species viz. *Eucalyptus tereticornis* and *A. nilotica* were studied. In the first experiment, *Eucalytus* plants failed to establish in the treatment where the auger holes had been replaced with original soil because plants could apparently not tolerate highly sodic conditions. However, in the same treatment 38 % of the planted *Acacia* plants survived, indicating its adaptability to the highly adverse soil conditions. However, the plant height and growth were limited. The application of 3 and 6 kg gypsum resulted in increased survival and growth of both the species. However, 50 % and 31 % of the *Eucalyptus* plants died in the two treatments. Addition of farmyard manure along with 3 kg gypsum increased growth, and *Eucalyptus* performed better than *Acacia.* Inclusion of sand in the auger holes further improved the performance of the two species. In the second experiment, *Eucalyptus* trees grew to an average height of 4.66 m and attained a girth of about 18 cm in 16 months in treatments where the auger holes were 15 cm diam and 180 cm deep. Similarly, *Acacia* showed excellent growth in this treatment. Auger holes of 180 cm depth provided a favorable environment for root growth and penetration. A layer of concretions at 87 to 139 cm was probably responsible for restricted root penetration, and growth was somewhat checked in treatments having shallow auger holes.

Plantation in Saline Lands

For more than a decade, Central Soil Salinity Research Institute, Karnal has been conducting several long - term experiments for developing afforestation technologies on a highly saline waterlogged soils at its experimental farm, Sampla (Tomar *et al.*, 1998). In saline waterlogged situations, for successful afforestation program, selection of proper planting technique is of utmost importance. The technique should be such that the rain water is utilized to the maximum possible extent and the salt concentration in the active root zone of young plants is kept at a minimum level such that the adverse effect of high salinity of soil and ground water is minimized and the bad effect of high water table could be avoided simultaneously. To achieve this objective, three planting methods viz. sub - surface, ridge - trench, and furrow methods were tried for the initial establishment of tree saplings. In the sub - surface planting method, normal pits of 45 x 45 x 45 cm in size were prepared and since the major salt concentration remains in the surface 30 cm layer, the saplings were planted at a depth of 30 cm from the surface which was a less hostile zone of salt concentration. Earthen rings were provided around each sapling for applying irrigation water by buckets or pitchers. In case of ridge - trench method, the ridges were prepared 1.5, 3.0 and 4.5 m wide at the top, middle and bottom, respectively and had 40-cm height from the original soil surface. The saplings were planted on top of the ridges and like sub - surface planting, earthen rings were also made around each sapling planted on the ridges for applying irrigation water. Tops of the ridges were also provided with peripheral bunds to store rain water on the ridges for leaching of soluble salts whereas in furrow planting technique, a tractor driven furrow maker was used to create about 60 cm wide and 20 cm deep furrows and saplings were planted at sole of the furrows. The irrigation with good quality water was applied to tree saplings in furrows as and when required. The volume of irrigation water was kept uniform in sub - surface and ridge - trench methods. However, in case of furrow planting the volume of irrigation water applied was more because of higher volume of area filled with irrigation water. The observations such as survival percentage of plants, height and girth of plants were recorded regularly for 9 years after transplanting the seedlings. The results suggested that furrow planting improved the survival and growth of tree species as compared to other two methods due to greater desalinization of soil profile with uniform application of irrigation water. Besides reducing the water application costs, it improves uniformity in water application and helps in creating a favorable zone of low salinity below the sill of the furrow through down ward and lateral fluxes of water making salts move away from the furrow (root zone) especially when low salinity water is used. Creation of such niches favored the establishment of young seedlings of trees. However, sub - surface method showed better performance than the ridge - trench method. Salt accumulation in the root zone of trees was substantially higher in the ridges than other planting methods. Due to higher salinity in the ridges, saplings planted on the ridges generally remained at a more disadvantageous position resulting in their lower survival and poor growth. Similarly, difficulties in conserving rainwater on top of the ridges were also observed. Thus, by way of furrow planting technique, it is possible to keep salt concentration relatively low in the rooting zone of tree saplings such that they are able to escape the adverse effects of salinity. Moreover, such a system seems to be more viable from practical viewpoint of undertaking large-scale plantations of trees.

Suitable Tree Species

For Sodic Lands

Normally, firewood species are grown on alkali soils. The choice, of which species should be grown, is determined by the ability of tree species to survive and withstand adverse conditions of excess of salinity. Tolerant tree species overcome high concentrations of sodicity by different regulatory mechanisms. There are very few wild plant species, which are able to grow on highly sodic soils. Recently, a field trial was planted during 1995 at Sivri farm, near Luchnow to see the relative performance of some tree species viz. *Acacia nilotica, Azadirachta indica, Cassia siamea, Casuarina equisetifolia, Eucalytus tereticornis, Pithecellobium dulce, Pongamia pinnata, Prosopis alba, Prosopis juliflora* and *Terminalia* on alkali soils (Tomar and Kumar, 1999). Almost all the species showed good performance. Similar results have been reported by many other workers. Khan & Yadav (1962), Yadav and Pathak (1967) and Dagar(1995) observed that forest species under different natural flora varied in their tolerance in different states of India. Leather (1897) reported on the basis of preliminary experiments that *Acacia nilotica, Azadirachta indica, Albizzia procera* and *Prosopis juliflora* showed better performance when planted in 0.5 m deep pits filled with good soil. *P. juliflora* and *A. nilotica* showed higher tolerance than *Azadirecta indica, Butea monosperma, Dalbergia sissoo, Pongamia pinnata* and *Terminalia arjuna. Eucaliptus tereticonis* could be grown when the soil pH remained lower than 9.0 and soluble salt content was 0.3 % (Kaushik *et al.*, 1969). On the basis of experiments conducted on highly alkali soil at Gudda Farm, Gill *et al.* (1984) and Gill (1985) reported that *A. nilotica, P. juliflora, Casuarina equisetifolia, A. lebbeck, Parkinsonia aculeata* demonstrated a higher tolerance than *A. indica, Melia azedarach, D. sissoo, Syzygium fructicosum, Populus deltoides* and *Morus indica* while *Syzygium cumini* failed to survive. *P.*

juliflora, A. nilotica and *C. equisetifolia* performed well in highly alkali soil and *E. tereticonis* grew well in the initial two years but the growth started slowing thereafter, whereas *Melia azedarach* proved inferior. Chhabra *et al.* (1987) reported in their field study that *Sesbania* species could not be grown at an ESP level of 98. *A. nilotica* was found more tolerant than *E. tereticonis* and *Parkinsonia aculeata* (Grewal, 1984). *Eucalyptus camaldulensis* and *E. tereticonis* were found more promising than *Eucalyptus citriodora* and *Eucalyptus alba.* In another study carried out by by Gill and Abrol (1986), *Prosopis, Acacia* and *Casuarina* were promising for afforestation of alkali soils and *Eucalyptus* performed well during the initial 2 years, but growth slowed thereafter, and *Melia* failed completely. Batra (1988) found *Casuarina glauca* to be more tolerant than *C. equisetifolia* and *Casuarina obesa.* Singh *et al.* (1989) reported that *P. juliflora* can be grown satisfactorily in soils of pH 9.0 to 9.6 and EC 0.6 to 1.23 dS/m even without the application of any amendment. Dagar and Singh (1992) reported that *P. juliflora* was an ideal tree for highly alkaline soil. Singh and Gill (1990) compiled information showing that *P. juliflora,, A. nilotica* and *C. equisetifolia* were more tolerant than *T. articulata, T. arjuna, A. lebbeck, P. pinnata, Sesbania sesban, E. tereticonis* and other sensitive tree species such as *D. sissoo, Morus alba, Grevillia robusta, A. indica, Tectona grandis* and *P. deltoides.* Dagar *et al.*(2001) in a comprehansive study for 7 years on highly alkali soil with pH>10 at Saraswati Range Forest site evaluated about 30 tree species (Table 1) after planting them in two auger depths (Shallow not piercing Kanker pan and deep auger piercing Kanker pan) and concluded that for such high pH soils though many species had good survival but *P. juliflora, A.nilotica, T.articulata,* and *E.teriticornis* are the only most suitable species which had some kind of growth and biomass. The biomass of 7 years old *T. articulata* was 97.3 t/ha in deep augers and 31.7 t/ha in shallow augers (Table 2). *A. nilotica* produced 69.8 t/ha in deep augers and 39.1 t/ha in shallow augers, and *P. juliflora* produced 51.3 and 220.1 t/ha in deep and shallow augers, respectively. For alkali black cotton soils (vertisols) besids *Prosopis juliflora* as a native check, *Azadirachta indica* and *Eucalyptus tereticornis* have been found most suitable species (Minhas, 2001).

Table 1. Survival, height and diameter at stump height (DSH) of forest trees on highly alkali soil after 7 years of planting.

Tree species	Survival (%)		Height (m)		DSH (cm)	
	D *	S **	D	S	D	S
Prosopis juliflora	97	85	3.98	2.59	8.3	5.3
Acacia nilotica	82	77	3.66	2.31	8.6	6.4
Tamarix articulata	89	74	3.24	2.56	7.3	5.4
Eucal. Tereticornis	90	76	4.13	3.41	6.0	5.1
Dalbergia sissoo	86	84	1.99	1.87	6.1	5.3
Pithecellobium dulce	87	70	1.70	1.62	5.4	4.2
Terminalia arjuna	92	87	1.51	1.45	5.1	4.8
Kigelia pinnata	93	5	1.43	1.10	5.2	5.0
Cordia rothi	79	876	1.04	0.92	4.0	3.2
Parkinsonia aculeata	80	77	2.36	1.89	4.1	3.3
Anthoc. Cadamba	81	68	0.72	0.68	4.2	3.7
Acacia leucophloea	59	45	2.24	1.77	4.8	4.7
Tamarindus indica	27	15	1.30	1.29	4.1	3.6
Cas. Equisetifolia	0	0	0	0	0	0
Pongamia pinnata	0	0	0	0	0	0
Albizia lebbek	0	0	0	0	0	0
Cassia siamea	0	0	0	0	0	0
Butea monosperma	0	0	0	0	0	0
Leuc. Leucocephala	0	0	0	0	0	0
Bombax ceiba	0	0	0	0	0	0
Bambusa arundinacea	0	0	0	0	0	0
LSD (P = 0.05)						
Auger depth	9		0.48		0.36	
Tree species	14		0.46		1.11	
Interaction	20		0.65		NS	

D * = Deep auger depth, S ** = Shallow auger depth, NS = Not significant

For Saline Lands

Like suitable planting technique, saline soils also require the proper selection of tree species for making the programme successful. As the main problem of these soils are high water table, high salinity, impeded drainage and poor soil aeration, only those tree species should be raised which can tolerate these stresses simultaneously. It has been experienced that the tree species which transpire less water are more suitable for such soils than those transpire high amount of water. In general, the plantations of fuel wood are better for saline waterlogged soils than timber wood species. Only recently, however, attention is being paid to accommodate the species of industrial importance for highly saline degraded areas. Some oil yielding species like *Salicornia bigelovii* and *Salvadora persica* are gaining importance for highly saline waterlogged soils or when irrigated with sea water. These species have been cultivated with success on black cotton saline soils irrigating with high saline water. More than 40 native and exotic tree species of arid and semi - arid areas were evaluated at research farm, Sampla by Tomar *et al.* (1998). Based upon periodical observations for survival, height and girth of experimental plants, woody species like *Acacia farnesiana, Parkinsonia aculeata, Prosopis juliflora* and *Tamarix spp.* have been rated most tolerant to waterlogged salinity and could be grown satisfactorily on soils with salinity levels up to 50 dS / m in their root transmission zone. Tree species like *Acacia nilotica, A. torilis, Casuarina glauca, C. obesa* and *C. equisetifolia* could grow on sites with ECe varying from 10 - 25 dS / m. It was concluded that the waterlogged saline conditions most affected the survival and growth of tree species used for afforestation because the salt accumulation near the rooting zone was directly attributed to ground water fluctuations and the underground water was also saline. Performance of some important tree species after 9 years of growth has been compared when these were grown with different methods of plantation. The data on biomass Table 3) of *P. juliflora* and *C. glauca* 13987 was the highest (98 and 96 t/ha) followed by *A. nilotica* (52 - 67 t/ha) and *A. tortilis* (41 t/ha) when planted with sub surface or furrow techniques proving that these are the suitable species for saline waterlogged soils. Amongst evaluation of *Eucalyptus species,* Marcar *et al.* (1990) also reported greater tolerance of *Eucalyptus camaldulensis* in waterlogged saline soils.

Table 2 : Biomass of different tree species (Mg ha $^{-1}$) after 7 years of planting on alkali soil

Tree species	Deep augerholes	Shallow augerholes
Tamarix articulata	97.3	31.7
Acacia nilotica	69.8	39.1
Prosopis juliflora	51.3	22.1
Eucalyptus tereticornis	14.4	5.20
Pithecellobium dulce	3.96	2.14
Terminalia arjuna	2.68	1.76
Dalbergia sissoo	1.75	1.18
Cordia rothii	1.48	0.62
Kigelia pinnata	1.17	0.49
Parkinsonia aculeata	1.15	0.90
LSD (p = 0.05)		
Tree species	5.94	
Auger depths	1.17	
Interaction	3.70	

Table 3. Biomass estimation of trees after 9 years of planting on saline soils

Tree species	Method of planting	Range of soil salinity at 0 - 120 cm depth (dS $^{-1}$)	Range of water table Salinity (dS $^{-1}$)	Estimated Bio-mass (Mg ha^{-1})
Acacia nilotica	Subsurface	10.6 - 25.3	27 - 33	52
	Furrow	11.1 - 21.0	17 - 27	67
A. tortilis	Subsurface	6.8 - 28.1	12 -33	41
	Ridge	19.7 - 29.1	12 - 33	6
Eucalyptus camaldulensis	Furrow	10.0 - 17.9	10 - 35	28
Prosopis juliflora	Subsurface	10.3 - 24.0	32 - 36	98
	Ridge	23.5 - 57.5	32 - 36	65
Casuarina equisetifolia	Furrow	5.6 - 20.7	10 - 31	28
C. glauca 13987	Furrow	6.5 - 33.9	12 - 19	96
C.obesa 27	Furrow	9.0 - 19.5	12 - 19	38
Leucaena leucocephala	Subsurface	6.9 - 23.9	10 - 25	30
Tamarix sp.	Furrow	8.2 - 21.3	10 - 32	12

Ameliorative Effect of Plantation

The useful effects of plantation on soils are well known. With the establishment of trees, the plantation influence the properties of salt affected soils in many ways by the physical, chemical and biological improvements. The roots of tolerant trees penetrate in the soil and improve the permeability which facilitates leaching of salts. The trees also have the potential for exclusion of salts through absorption. However, the amelioration of salt affected soils due to tree plantation depend upon the type of soil primarily.

Sodic Soils

The beneficial effect of tree plantation on alkali soils have been reported by many workers. Yadav and Singh (1970) reported that plantation of *Prosopis juliflora* decreased the pH and soluble salts and increased organic matter in surface 15 cm soil near Aligarh. Similar type of observations were reported by (Gill *et al.,* 1987) on the basis of their 5 year old study conducted in highly alkali soil at Gudha farm of CSSRI, Karnal. Ameliorative effects of 20 years old plantations appeared in the order of *Prosopis juliflora* > *Acacia nilotica* > *Terminalia arjuna* > *Albizzia lebbeck* > Eucalyptus tereticornis (Singh *et al.,* 1989). Dagar *et al.,* (2001) reported changes in soil properties due to promising tree species at the age of 7 year old experiment. The maximum reduction in ESP and pH was observed under the trees of *Tamarix articulata* and it was followed by *Prosopis juliflora* and *Acacia nilotica*. Increase in organic C in the surface 0.15 m layer under *Tamarix articulata* was 0.23 %, under *Prosopis juliflora Prosopis juliflora* 0.26 % and under *Acacia nilotica* 0.10 %.

Saline Waterlogged Soils

The beneficial effect of tree plantation on soil structure and infiltration etc. is well documented in the litrature. The tree plantation for lowering of watertable in saline waterlogged areas has been quoted as one of the major benefit. The lowering effects of a range of *Eucalyptus spp*. on watertable in Australia are well documented (Heuperman, 1991). Tomar *et al.,* (1994) on the basis of a 7 year old study conducted in saline waterlogged soils, reported that watertable for most of the time remained deeper with an average of 5 cm under the tree canopy as barren land sites apparently due to the higher evapotranspiration during the active growth phase of plantation. However, such a process may enhance salt accumulation beneath the plantations and the high salt accumulations at this juncture may eventually kill the trees. The relevant observations taken after 8 years of planting suggested that most of the salts coming up from watertable were concentrating in the region of 1.6 - 1.2 m soil depth from where most of the water uptake by tree roots was likely to occur where as in the upper soil layers (0- 0.6 m depth), salts were considerably reduced under tree canopies with bare fallow land. On the whole trees resulted useful effect in soil.

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Screening and Utilization of Salt Tolerant Genotypes of Medicinal Crops under Sodic Soils Conditions

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It is estimated that by the year 2050 the global herbal trade will grow from existing 100 billion US dollars to a phenomenal 5 trillion dollars. Therefore, given the huge financial implication, scientific manpower coupled with documented Ayurvedic heritage and well-endowed bio-diversity, India has a definite advantage and potential to emerge as a pioneer in this area. In India, the domestic herbal trade involves about Rs. 4000 crores which is expanding day by day out of which Ayurvedic drug trade alone involves Rs. 3500 crores (Anonymous 2003). The domestic medicinal plants contribute to cater 80% of the raw materials used in the preparation of drugs. At present India's share in global export market of herbal plants related trade is dismally 0.5%. Therefore, to meet the internal demand and for earning foreign exchange, production of these crops is required to be increased.

In India out of 6.73 m ha area affected by agricultural salinity, about 3.77 m ha is sodic. In the states like U.P., herbal cultivation has been traditionally going on and the state is natural habitat for 14 amongst 32 nationally prioritized herbal species. In the UP state, about 1.00m ha land is afflicted by sodicity. To substitute the traditional cropping sequence in the early years of reclamation of salt affected soils with alternate and remunerative medicinal plants with minimum amendment costs, it is essential to explore, select and test salt tolerant medicinal species and their genotypes. Surveying and utilizing higher genetic tolerance limits of medicinal plants for salt affected soils will certainly be instrumental in reaping the dual benefit of higher herbal productivity at reduced economic cost.

Like terms agriculture and horticulture, '*mediculture*' has been coined for cultivation of medicinal plants in view of their rapidly increasing importance and need to systematize their cultivation and utilization. Some economically useful medicinal crops have been found to be tolerant to sodic soils (Singh, 2002). In India, about 20 medicinal species are under commercial cultivation for which a number of superior varieties have been developed (Singh *et al.* 2000). Singh (2002) has suggested that medicinal plants may be grown as sole crops in sodic soils without hard pan (layer of calcium carbonate) or with hard pan at lower depths, whereas the sole crop may not be preferred in soils with shallow hard pan because of water stagnation in rainy season. In such situations, inter-cropping with sodicity tolerant fruit/tree species will be beneficial. As regards quality aspects, the fact that herbal quality is not affected or in few cases even improved under salt stress has been established by numerous studies (Singh and Anwar, 1985; Chandra and Sharma, 1987). Our studies at CSSRI, Karnal and RRS, Lucknow mainly focused on to procure germplasm material of suitable medicinal plants, their evaluation for tolerance to sodic soils and to characterize salt tolerance w.r.t associated morpho-physiological mechanisms/markers.

Selection of Crops and Collection of their Genotypes

In view of their economic importance, past literature and tolerance criteria, four crops viz., sweet basil (*Ocimum basilicum*), dill (*Anethum graveolans*), isabgol (*Plantago ovata*) and German chamomile (*Matricaria chamomilla*) were selected for the studies. Germplasm of these crops from various places in India was collected. A total of 13, 11, 9 and 4 genotypes, respectively of sweet basil (*Ocimum basilicum*), dill (*Anethum graveolans*), isabgol (*Plantago ovata*) and German chamomile (*Matricaria chamomilla*) were collected, maintained and multiplied.

Screening and Evaluation under Sodic Soil

Isabgol (*Plantago ovata)*

A total of 9 genotypes of Isabgol were sown in sodic soil (pH2~9.2) at Shivri Farm during *rabi* 2003-04. The genotypes in the experiment were laid in a Randomized Block Design with 3 replications and plot size of 4.25m^2 following an inter row distance of 22cm. At harvest the seed yield ranged among genotypes from as low as 1.15 q ha^{-1} to as high as 14.16 q ha^{-1} in MIB153 (Table1).Data collected on days to flowering and maturity, plant height, spikes no./plant and spike length revealed that highest seed yield in Isabgol genotype MIB-153 could be due to its maximum no. of spikes and spike length. The genotypic average was found 5.88 q ha^{-1}. These initial data indicate that proper selection of varieties in isabgol can result in almost three times more seed yield in sodic soils.

Sweet Basil (*Ocimum basilicum)*

Thirteen entries of Sweet Basil were evaluated in sodic soil at Shivri Farm, Lucknow during kharif 2005. Forty five days old seedlings of these accessions were planted in a thrice replicated RBD on raised beds in sodic soil with surface soil having pH (1:2 soil water ratio) ~ 9.3, ECe ~0.82 dS m^{-1}, ESP 24.5, organic carbon 1.2 g kg^{-1} and available N, P and K of 130, 11.3 and 265 kg ha^{-1}, respectively. Inter-row and -plant spacings of 50 and 30 cm, respectively were followed. Due to genetic homogeneity, 5 accessions *viz.* CSLT-5, CSLT-9, CSLT-12, CSLT-12-1 and CSLT-13 were selected for further evaluation, where as single plant secondary selection was made in the remaining lines for their purification. In the selected accessions, fresh herbage yield varied from 6.55 t ha^{-1} in CSLT -12-1 to 11.3 t ha^{-1} in CSLT-12 (Table 2). Though herbage yield of CSLT-9 was at par with that of CSLT-13, oil yield of CSLT-13 was almost double (89.17 l ha^{-1}) than the former genotype (47.17 l ha^{-1}).This indicates that high herb yielding genotype may not result in high oil yield or *vice versa*.

Table1. Performance of Isabgol genotypes in sodic soil (pH_2 = 9.2) at Shivri Farm

Genotype	Seed yield (kg/ ha)	Days to flower	Days of maturity	Plant height (cm)	Spike/ plant	Spike length(cm)
RI-129	781	66	89	27	46	3.7
MIB-122	115	69	90	24	34	3.0
GJ-2	207	66	102	26	42	3.1
HI-5	691	64	101	27	47	3.9
RI-23	169	68	91	26	44	3.7
MIB-2	581	63	90	28	57	3.7
MIB-153	1461	61	90	29	55	4.2
RI-121	832	63	101	29	50	4.0
MIB-125	456	67	101	23	36	2.9
Average	588	65	95	26	46	3.6
C.D. 0.05	302					

Table 2. Herbage and oil yield in basil lines grown in sodic soil

Yield t/ha	Genotypes					
	CSLT 5	CSLT 9	CSLT 12	CSLT 12-1	CSLT 13	Mean
Fresh Herb (t/ha)						
Leaf	4.88	5.80	6.10	3.73	5.40	5.18
Inflorescence	4.72	5.33	5.22	2.82	5.05	4.63
Total yield	9.6	11.13	11.32	6.55	10.45	9.81
Oil (l / ha)						
Leaf	11.16	27.50	25.00	28.83	64.50	31.40
Inflorescence	12.67	19.67	20.50	12.83	24.67	18.07
Total Oil	23.83	47.17	45.50	41.66	89.17	49.47

Basil oil fetches different prices in the market depending on its chemical constituents. Genotypes according to the predominance of particular constituent(s) are categorized as chemotypes rich in those compounds. Therefore, oil extracted from herb and inflorescence of these genotypes was scanned for the profile of more than 50 chemical constituents through GC-MS technique at CIMAP, Lucknow. Chemotype CSLT5 showed the predominance of linalool (61-64 %) with almost equal traces of others 7 chemical compounds. CSLT13 which was found to have maximum oil yield exhibited richness for methyl chavicol (65-71%) followed by linalool (23-28 %). CSLT9 was also found as almost the same chemotype as CSLT13. However, 2 accessions CSLT 12 and CSLT12-1 showed little bit higher methyl chavicol than linalool with appreciable content of methyl cinnamate.

Similarly physiological analysis resulted in some good findings. Plant samples were collected at full flowering stage and studied for chemical analysis and distribution of sodium, potassium and chloride at organ level. Maximum amount of Na^+ ions was retained in root, main branch and primary branch, sparing mature leaves (fully expanded), immature leaves (expanding) and inflorescences. Therefore, root, main branch and primary branch act as potential sink for excess Na^+ ions whereas photo- synthetically active parts *i.e.* immature leaves and inflorescences showed comparatively less Na in all genotypes. This is considered a favourable tolerance mechanism (Nayak *et al,* 2007). Accessions like CSLT12, CSLT12-1 and CSLT13 exhibited more Cl^- as compared to other lines (Table 3). High Cl^- concentration in leaves may be related to the sensitivity of germplasm to Cl^-. However, fairly good compartmentation ability towards older parts for sodium makes these germplasm suitable for sodic soils.

Dill (*Anethum graveolans*)

Dill is reported to be a salt tolerant crop (Rao *et.al*, 2000). However, we report here its genotypic response under sodic soils. Eleven collections of dill were grown in sodic soils in the more precise controlled sodic microplots at CSSRI, Karnal and at natural sodic soils at Shivri Farm Lucknow to select the sodicity tolerant line and to understand different trait association relationships. Data across different locations and sodicity conditions reveals the best performance of CSS1 giving about 9 q ha^{-1} seed yield than all other tested lines.

Table 3. Content of Na^+, K^+ and Cl^- ions in *Ocimum basilicum* lines.

Name of germplasms	Content (mg/plant)					
	Herbage			Root		
	Na^+	K^+	Cl^-	Na^+	K^+	Cl^-
CSLT-5	25.27	811.15	116.12	67.27	89.56	23.83
CSLT-9	23.21	1085.20	116.11	44.99	73.97	13.45
CSLT12	31.75	1129.20	177.54	66.05	83.02	43.54
CSLT12-1	25.28	899.56	168.80	51.37	65.38	34.75
CSLT-13	36.06	911.36	164.72	66.03	49.01	34.60
C.D.(p=0.05)	2.68	38.30	9.83	7.35	9.68	8.45

Significant differences among varieties were revealed for all the traits studied in dill i.e. seed yield, inflorescence no., secondary branches plant survival and plant stature. The traits correlation coefficients were also explored under different stress regimes. At high stress only, seed yield developed significant correlation with plant height, no. of primary branches, secondary branches and inflorescence/plant. However duration to flowering did not show any correlation with any other trait studied. On overall basis across years and locations, dill line CSS1 ranked first in terms of seed yield and therefore could be a potentially useful germplasm for getting higher economic yield in sodic soils. Due to the superiority of dill collection CSS1 in sodic soils across years and locations, it has been accepted for registration as a unique germplasm for sodicity tolerance by NBPGR, New Delhi having National Identity IC563951 and Registration No. INGR No.08106.

Conclusion and Practical Utility

Proper choice of varieties in medicinal crops has potential to appreciably influence the economic product yield in sodic soils. The genotypes CSLT13, CSS-1, Vallary and MIB-153 in Sweet Basil, Dill, German chamomile and Isabgol, respectively have been identified to be suitable, high yielding and salt tolerant genotypes for getting higher productivity of these crops in sodic soils. This will contribute to growing these remunerative alternative crops in sodic soils through low cost technology. Such promising salt tolerant genotypes need to be identified and utilized for getting higher productivity of selected medicinal crops in problem soils. The donors for different mechanisms governing salt tolerance in basil as identified should be utilized and hybridized to combine different mechanisms in a single cultivar. The information on the trait association analysis and relative sensitivity of different traits to sodicity stress should be made use of while planning breeding program for reaping enhanced economic yield from salt affected areas.

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Cultivation of Medicinal and Aromatic Plants with Poor Quality Water

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Introduction

The primitive man has been using biota since his emergence to this planet. From the earlier times, tribal priests and medicine men (witch doctors) used various plants, minerals and animal organs to cure various ailments. The medicinal use of plants figured in ancient manuscripts such as the Rig-Vedas, the Bible, the Iliad, the Odyssey and the History of Herodotus. The information on drugs and drug plants whose efficiency in medicine has been established is also available in various authentic pharmacopoeias such as *Indian Pharmaceutical Codex*, *United State Pharmacopoeia*, *British Pharmaceutical Codex* and *National Formulary* which are constantly being revised and kept up-to-date. In the last few decades, however, there has been probably more interest in drugs obtained from plant sources than at any time in history. It has been because of the success with the antibiotics, and other plant drugs controlling serious diseases such as cancerous tumors and HIV, used as contraceptives, hypertensive-agents, in treatment of rheumatoid arthritis, and other ailments. Therefore, now the cultivation of aromatic and medicinal plants has gained more importance than earlier times. With increase in population and decrease in per capita available arable land it is not possible to divert more fertile arable land under cultivation of medicinal plants. Therefore, cultivation of aromatic & medicinal plants on degraded lands irrigating with poor quality water is very useful preposition. Some of the attempts made in CSSRI have been reported in this paper.

Cultivation of Medicinal & Aromatic Plants

To find suitable salt-tolerant aromatic and medicinal plants some experiments were initiated at CSSRI, Karnal and Bir Forest, Hisar involving several species. The medicinal uses of some of these are mentioned in Table 1 as described in publications of CSIR (1992).

In one experiment six species *Azadirachta indica*, *Jatropha curcas*, *J. gossypifolia*, (C*ordia rothii*, *Salvadora persica* and *Adhatoda vasica* were cultivated in calcareous sandy loam soil with 8.5% clay, 18.6% silt and 72.9% sand. The water holding capacity of soil was 37.6% and pH of upper 0-30 cm layer was 8.6, ECe 4.9 dS m^{-1} and $CaCO_3$ contents 9.5%. The plants were grown in furrows. Three irrigation treatments were imposed viz: irrigation with high salinity water (EC of water during first year ranged between 30-20 dS m^{-1} while during second year it came down to 14-16 dS m^{-1}); irrigation with low salinity water (EC ranged from 8-5 dSm^{-1}); and alternate irrigation with above two waters. Results after three years of experimentation at Hisar (Dagar *et al.*, 2006) showed that all these plants performed well under all treatments of saline irrigation. Plant height, stump diameter and biomass reduced slightly with increase in salinity of irrigation water (Table 2).

Castor (*Ricinus communis*) produced 0.9, 0.6 and 0.4 t ha^{-1} seeds when irrigated with low, alternate and high salinity waters, respectively. The air-dried per plant biomass was 15.5 kg, 4.6 kg and 2.5 kg, respectively. In a separate experiment, dill (*Anethum graveolens*) could produce 1.08, 1.22 and 1.28 t ha^{-1} grains when irrigated once, twice and thrice, respectively with water of 14 dS m^{-1} at the same site.

Some other aromatic and medicinal plants also performed well (Tomar and Minhas, 2004 a, b) with saline irrigation of EC 12 dSm^{-1} (Table 3, 4).

Among medicinal plants, performance of Isabgol (*Plantago ovata*) with saline irrigation was most promising (Tomar *et al.*, 2005). It was studied further in detail. The study comprising of 12 treatments with 3 irrigation waters viz.W_1 - irrigation with water of low salinity (ECiw 4-5 dS m^{-1}), W_2 - irrigation with water of high salinity (ECiw 12 dS m^{-1}), W_3 - alternate irrigation with above two waters and 4 irrigation scheduling viz. I_1 – Irrigation at CRI stage, I_2 –I_1 + 1 more irrigation at tillering, I_3- I_1 + 2 more irrigations at tillering and flowering, and I_4 –I_1+ 3 more irrigations at tillering, flowering & milking, was conducted to evaluate the effect of saline irrigation in different irrigation frequencies. The experimental observations in respect of plant growth and unhusked grain yield were recorded at the harvesting stage which are given in Table 5. The relevant results indicate that there was no significant difference in plant growth of isabgol and its yields due to saline irrigation having salinity up to 12 dS m^{-1}. The yield potential of the crop under high saline water equaled to 12.69 q/ha where as significant difference was observed within irrigation scheduling and it can be grown successfully with 3 saline irrigation including irrigation at sowing. The results also indicate that the interaction between irrigation water and irrigation scheduling was non-significant.

Table1. Important medicinal and other uses of plants tested for their performance in saline conditions.

Plant Species / family	Important medicinal & other uses
Aegle marmelos (Bael) Acanthaceae	Leaf used as febrifuge, in eye-diseases & ulcers, dropsy; root ingredient of ayurvedic *dasmoola*, fruit gives a cooling drink, given in diarrhoea and for dyspepsia; seed oil (34%) has antibacterial properties.
Aloe barbadensis syn. *A. vera* (Indian aloe, Ganwarpatha) Agavaceae, Liliaceae	Leaf juice is cathartic, used in liver and spleen ailments, piles & rectal fissures, rheumatic problems & joint pains; dried juice in constipation; pulp is given for menstrual irregularity, flower stalk pickled.
Anethum graveolens syn. *A. sowa* (Dill, Sowa), Apiaceae	Cremocarps (seeds) used as carminative & stomachic; essential oil given to children for flatulence. Dill oil used as soap perfume.
Azadirachta indica (Neem) Meliaceae	Bark in skin troubles; leaves antiseptic; seed oil for skin affections, used in soaps.
Capparis decidua (Kair Kurrel) Capparidaceae	Fruit useful in biliousness & cardiac troubles; bark used in cough & asthma; fruit pickled.
Cassia senna (Senna) Caesalpiniaceae	Entire plant (mainly leaves) used for constipation, liver-stimulant, tonic, in spleen enlargement, anaemia, typhoid, cholera, jaundice, gout, rheumatism, tumours, dysentery, eye-infection and to remove pimples.
Catharanthus roseus (Periwinkle, sadabahar) Apocynaceae	All parts possess several alkaloids used in treatment of various types of cancer; possess antibacterial activity; leaf infusion in menorrhagia; juice applied for wasp-stings.
Cordia rothii. Boraginaceae	Bark astringent, used in gargles; fruit edible, yield glue, pickled.
Cymbopagon flexuosus (Lemon grass) Poaceae	Yields essential oil (0.25-0.50%) used in perfumery, soaps, cosmetics, as mosquito-repellent, antimicrobiol & sedative properties.
C. martinii (Palmarosa) Poaceae	Yields essential oil used for cosmetics, perfumery & soaps; useful in lumbago, stiff joints, skin diseases and baldness.
Emblica officinalis (Gooseberry, Aonla) Euphorbiaceae	Fruit is one of the richest source of vitamin C and is constituent of drugs such as *chyavanprasa*; *septelin*, useful in chronic infection of ear, nose & throat; *triphala* for enlarged liver, stomach ailments and piles
Euphorbia antisyphalitica Euphorbiaceae	Medicinal and potential petro-crop.
Glycyrrhiza glabra (Liquorice, Mulhatti) Papilionaceae	Rhizomes and roots used as tonic and for allaying cough, catarrhal affections and in confectionery
Jatropha curcas (Purging nut, Jamalghota) Euphorbiaceae	Juice relieves toothache, applied in piles; root & leaf decoction in diarrhoea; seed oil (30-40%) in lubricants, soap & candle making and also in skin diseases.
Lepidium sativum Chandrashura) Brassicaceae	Leaves in scorbutic diseases; roots used in syphilis; seeds are galactagouge, diuretic, tonic, oil used for soap making
Matricaria chamomilla (German chamomile, babuna) Asteraceae	Possess antispasmodic, expectorant, carminative, anthelmintic, diuretic & sedative properties; an infusion is used for eczema, inflammations & piles. Oil is used in perfumery & shampoo powders.
Ocimum sanctum (Tulsi) Lamiaceae	Leaves stimulant, antiperiodic, used in bronchitis,catarrh, yield an essential oil; seed useful in genito-urinary disorders
Plantago ovata (Psyllium, Isabgol) Plantaginaceae	Dried husk & seeds in chronic constipation, dysentery, diarrhoea & inflammatory conditions of genito-urinary tract. Seed mucilage also used in cosmetics & preparation of chocolates.
Ricinus communis (Castor, Arind) Euphorbiaceae	Leaf poultice applied to boils & sores; root decoction given in lumbago; seed oil used as cathartic & lubrication and in paint & varnish industry.
Salvadora persica (Jaal) Salvadoraceae	Leaf decoction in asthma & poultice in painful tumours & piles; seed fat (40-50%) is good source of lauric acid & used in soap & candle making; also used in rheumatism & suppositories.
Simmondsia chinensis (Jojoba, hohoba) Simmondsiaceae	Seed yields a liquid wax (45-60%). oil used in preparation of lubricants, disinfectants, candles, base for creams & ointments, soaps, face-creams and in pharmaceuticals & leather industry.
Vetiveria zizanioides (Vetiver) Poaceae	Grass is used in liver disorders, as refrigerant, stimulant & stomachic. Root yields a fragrant aromatic oil (up to 2%) used in perfumes, cosmetics & soaps and possesses antimicrobial properties.

Table 2. Growth performance of some under-explored species at different stages of growth under three irrigation treatments of saline water

Species	Growth period (years)	Fresh biomass (kg/plant)			LSD (p=0.05)
		T_1	T_2	T_3	
Azadirachta indica	1.5	2.2	3.4	5.8	0.23
	2.5	8.9	9.3	9.8	
	3.5	25.6	32.2	35.7	1.48
	4.5	43.1	51.3	76.0	3.64
Salvadora persica	1.5	1.0	1.3	2.7	0.13
	2.5	15.1	16.5	20.2	1.01
	3.5	88.7	92.3	94.4	0.74
	4.5	92.6	98.1	110.0	5.50
Jatropha curcas	1.5	1.8	5.2	8.8	0.35
	2.5	4.0	6.4	10.0	0.47
	3.5	4.1	7.2	12.5	0.47
Jatropha gossipifolia	1	0.7	1.0	1.3	0.23
	2	2.2	2.8	3.6	0.26
Adhatoda vasica	1.5	0.4	0.8	2.2	0.13
	2.5	2.7	3.4	4.6	0.13
Ricinus communis	1.5	1.5	3.2	5.4	0.13
Catharanthus roseus	1.5	0.3	0.5	0.7	0.04
Aloe barbadensis	1.5	5.7	6.1	5.2	NS

T_1 = Irrigation with water of high salinity, T_3 = Irrigation with water of low salinity, T_2 = Irrigation alternately > two waters,

Table 3. Yield and growth of some aromatic plants with saline water irrigation

Crops	SW	CW	CW/SW	Mean	LSD(p=0.05)
Palmarosa (for two years)					
Fresh weight (t/ha)	66.3	92.8	79.7	79.6	12.5
Dry weight (t/ha)	24.3	34.0	29.1	29.1	4.8
Lemon grass (for two years)					
Fresh weight (t/ha)	50.7	69.4	54.5	58.2	7.7
Dry weight (t/ha)	14.0	19.2	15.1	16.1	2.1
Vetiver (for two years)					
Dry shoot biomass (t/ha)					
NC 66403	7.26	9.47	9.38	8.70	V- NS
NC 66404	7.87	10.44	9.91	9.41	
Mean	7.62	9.99	9.65	9.09	
Dry root biomass (t/ha)					
NC 66403	1.12	1.28	1.22	1.21	V 0.35
NC 66404	1.33	0.86	1.34	1.18	IW NS
Hybrid 8	1.71	2.08	2.45	2.08	Vx IW 0.61
Mean	1.39	1.41	1.67	1.49	
Celery (for one year only)					
Grain (t/ha)	0.47	0.67	0.54	0.56	NS
Biomass (t/ha)	3.02	3.28	3.16	3.15	NS

* V refers varieties of Vetiver ** IW refers quality of irrigation waters

Table 4. Yield and growth of some medicinal plants with saline irrigation

Crops/ Year	SW	CW	CW/SW	Mean	LSD(5%)
Isabgol (Unhusked grain yield q/ha (mean of 3 years))					
Weight (q/ha)	10.1	10.6	10.9	10.6	NS
Periwinkle					
Flower (q/ha)	1.2	11.5	1.8	4.8	6.9
Dry wt.of shoot (q/ha)	0.6	8.9	1.0	3.5	6.4
Tulsi (Ocimum sanctum)					
Dry wt.of shoot (q/ha)	9.1	10.6	9.3	9.7	NS
Aloe Fresh t/ha	16.9	19.0	18.1	18.0	NS

Table 5. Yield of isabgol (q/ha) with different quality of saline water irrigation and frequencies

Saline water / Irrig. freq.	I_1	I_2	I_3	I_4	Mean
BAW	9.81	11.62	12.04	11.87	11.33
SW	9.56	13.52	13.77	13.92	12.69
Alternate	12.35	12.75	13.37	14.18	13.16
Mean	10.57	12.63	13.06	13.32	12.39
LSD (p=0.0 5)	Irrigation waters: NS	Schedule: 1.99	Iw x Sch.: NS		

Table 6. Impact of different irrigation schedules on fresh yield (t ha^{-1}) of lemon grass when irrigated with water of different salinity (Total of 4 cuttings)

Salinity of irrigation water	Irrigation scheduling (IW/CPE)							
	0.2		0.4		0.6		0.8	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
Low	10.83	10.88	11.06	12.80	12.95	13.10	13.18	15.38
Low/High	8.01	7.28	8.26	9.00	9.39	10.55	10.83	12.23
High	3.39	5.23	6.99	7.25	8.13	8.88	8.11	11.95

As Lemon grass was also quite promising, therefore another experiment was conducted using saline irrigation. The experiment comprised of three main treatments of saline water viz. water of high salinity (EC 8 dS m^{-1}), low salinity (EC 4 dS m^{-1}) and alternate with low and high salinity; and four sub-treatments of irrigation scheduling at IW/CPF ratios of 0.2, 0.4, 0.6 and 0.8, respectively. The results clearly showed that irrigation with high salinity adversely affected the yield, while higher scheduling increased the yield (Table 6).

Other medicinal plants such as *Cassia senna, Lepidium sativum, Glycyrrhiza glabra*, and *Withania somnifera* also performed well when irrigated with saline water up to EC 10 dS/m. Many species of medicinal important are found growing natural on calcareous soils of Hisar at experimental site. Some of these are associated with forest trees which were established with saline irrigation for initial three years. These include *Azadirachta indica, Balanites aegyptiaca, Capparis deciduas, Clerodendron phlomidis, Lycium barbarum, Maytenus emerginata, Ricinus communis* and *Ziziphus nummularia* among trees and bushes and *Abutilon indicum, Achyranthes aspera, Adhatoda vasica, Ageratum conyzoides, Amaranthus spinosa, Asparagus racemosus, Boerhaavia diffusa, Calatropis procera, Cardiosperma halicacabum, Cassia tora, C. occidentalis, Citrullus colocynthis, Cocculus hirsutus, Datura metel, Digera muricata, Eclipta alba, Euphorbia thymifolia, Evolvulus alsinoides, Heliotropium indicum, Momordica dioica, Peristrophe bicalyculata, Physalis minima, Pupallia lappacea, Rhynchosia minima, Sida cordifolia, S. rhombifolia, Solanum nigrum, S. xanthocarpum, Tribulus terrestris, Tridax procumbens, Vernonia cinerea* and *Withania somnifera* among herbaceous species.

Thus, it can be concluded that there is tremendous scope of cultivation of medicinal and aromatic plants in saline environment. This will not only save the most fertile lands for food production but will also help in utilizing the degraded lands and saline waters for improving the rural economy.

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Biodrainage

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Irrigation

Large investments have been made world over during the last 50 years for the expansion of irrigation facilities. During this period, the net irrigation potential has increased from 95 million hectare (mha) to 260 mha in the world and 22.5 mha to 57 mha in India (Anonymous, 2003). Large volume of water for irrigation is generally imported in arid and semi-arid regions from sources (dams constructed on rivers) located outside the areas through elaborate canal systems. Water losses caused in the conveyance and distribution systems as well as in the fields during application of irrigation water percolates down to the ground water reservoir. Consequently, the ground water table starts rising. The rate of rise depends on the quantity of water percolating down and the ground water outflow from the region. If the rise in ground water table is not checked, it will be followed by waterlogging and secondary salinization of soils (Anonymous, 2003).

Waterlogging

The stagnation or pooling of water on the land surface for significant duration is known as surface waterlogging. It is a common problem during monsoon season, especially in topographical depressions. The developmental activities like the construction of roads and railway lines, etc., enhance the surface waterlogging due to obstruction in the natural drainage. Degree of water stagnation and the periods for which water stagnates on the land surface further increases with the introduction of canal irrigation system in an area. Surface waterlogging is followed by rise in ground water table causing sub-surface waterlogging. An area having ground water table within 3.0 m below the ground level is known as the waterlogged area. It is 60 mha in the world (Heuperman *et al.* 2002) and 2.46 mha in India (MOWR 1991).

Secondary Salinization

In semi-arid and arid regions, the soluble salts are often present in substantial quantities in the soil profile. Once the ground water table rises within 2-3 m, the ground water contributes substantially to evaporation resulting in gradual accumulation of harmful soluble salts in the root-zone. This process is termed as secondary salinization of soils. The phenomenon of secondary salinization is more pronounced in areas having brackish ground water. The salt-affected area in irrigated regions is about 20 mha in the world (Heuperman *et al.* 2002) and 3.30 mha in India (MOWR 1991).

Adverse Effects of Waterlogging and Salinity

Studies were conducted in the command areas of Western Jamuna Canal System and Bhakra Canal System of Haryana, Sharda Sahayak Irrigation Project in Uttar Pradesh, Indira Gandhi Irrigation Project in Rajasthan and Kakarpur Right Bank Canal in Gujarat. These studied have shown alarming consequences of waterlogging and soil salinity at the farm, regional and national levels. According to these studies, the important crops would gradually disappear from the affected areas (Joshi *et al.* 1995). Failing to take any measures, irrigation benefits will be negated and there will be displacement of labour from agriculture sector, widening income disparities, decline in sustainability of secondary and tertiary sectors, decline in agricultural production, effect on gross domestic production, and decline in export potential of important crops and increase in import bill (Anonymous 1998). The Sumerian Empire flourished about 4000 years ago in Mesopotamia, in the plains of the rivers Tigris and Euphrates, on the basis of a highly developed irrigation system. Later rise in ground water table and large scale salinization rendered the farmlands unproductive and this contributed to the collapse of the Empire and the whole population was forced to abandon the region (Jacobsen and Adams 1958).

Conventional Techniques for Combating Waterlogging and Salinity

Thornburn and George (1999) reported that the evaporation from the soil takes place up to a depth of 4 m. Therefore, we must plan to keep this 4 m soil depth free from waterlogging to minimize the process of secondary salinization of soils. The conventional techniques for the reclamation of waterlogged areas are the engineering based sub-surface horizontal drainage and sub-surface vertical drainage techniques. About 30 million hectare (mha) of land has been provided with sub-surface drainage systems in the world (Heuperman *et al.* 2002). The conventional engineering based drainage techniques, when properly designed, installed, maintained and operated, are efficient in combating the problems of waterlogging and salinity in irrigated lands.

Demerits of Conventional Techniques

The conventional techniques are relatively expensive to install, operate and maintain and require disposal of drainage effluent (Heuperman *et al.* 2002). The disposal of drainage effluent has become an important issue around the world. Commonly drainage effluent has been disposed of into rivers. This practice is progressively becoming problematic as the drainage effluent contains drained nutrients, salts and residues of agro-chemicals and affects the health of reservoirs, rivers and inland seas into which it is discharged. The salinity of most inland seas is known to increase over time because of the continuing inflow of saline drainage water. In California's Imperial Valley, drainage water from irrigated lands is discharged into Salton Sea resulting in an increase in its salinity. Discharge of drainage water from irrigated lands in San Joaquin Valley in California into Kesterton Reservoir has resulted in problems of Selenium toxicity in the biota (Cervinka *et al.* 1999). The Aral Sea Basin, the Indus basin in Pakistan, various river systems in India and the Murray-Darling Basin Catchment in Australia are suffering the consequences of river water pollution as a result of the discharge of polluted drainage effluent from irrigated lands (Heuperman *et al.* 2002). Due to environmental problems caused by conventional engineering based drainage techniques, the very high annual rate of installation of sub-surface drainage of the 1980s (300000 ha/year) has fallen to about 150000 ha/year during the 1990s (Lesaffre and Zimmer 1995).

Biodrainage – An Alternate Option

The limitations and shortcomings of the conventional engineering based drainage techniques call for alternative approaches to keep the agriculture sustainable over the long term. Alternative techniques must be effective, affordable, socially acceptable, environment friendly and which do not cause degradation of natural land and water resources. Biodrainage might be such an option. It may be defined as "*pumping of excess soil water by deep-rooted plants using their bio-energy*".

Plants absorb ground water through their roots. The absorbed water is translocated to different parts of plants and finally more than 98% of the absorbed water is transpired into the atmosphere. This combined process of absorption, translocation and transpiration of excess ground water into the atmosphere by the deep-rooted vegetation is termed as biodrainage. Biodrainage technique is relatively new, although the use of vegetation to dry out soil profile has been known for a long time. The first documented use of the term biodrainage can be attributed to Gafni (1994). Prior to that date Heuperman (1992) used the term bio-pumping to describe the use of trees for water table control. Biodrainage technique involves plantation of suitable species of vegetation capable of extracting substantial amount of water from the root zone and transpiring to lower the ground water table. This technique is now being recognized as a low cost, sustainable, economical and environment friendly technique for prevention and remediation of the problem of waterlogging and soil salinization in many countries, including India.

Merits of Biodrainage

The merits of biodrainage over the conventional engineering based sub-surface drainage systems are as given below:

- Relatively less costly to raise and maintain biodrainage plantations.
- No operational cost, as the plants use their bio-energy in draining out the excess ground water in to atmosphere.
- Increase in worth with age instead of depreciation.
- No need of any drainage outfall and disposal of drainage effluent.
- No environmental problem, as the plants drain out filtered fresh water in to the atmosphere.
- In- situ solution of the problem of waterlogging.
- Preventive as well as curative system of long life.
- Combined drainage- cum – disposal system.
- Contributes to increase in tree cover.
- Moderates the temperature of the surrounding by transpiration
- Helps in carbon sequestration.
- Mitigates the problem of climate change.
- Purifies the atmosphere by absorbing CO_2 and releasing O_2.
- Acts as wind break and shelter belts in agroforestry system.
- Provides higher income to the farmer due to the production of food, fodder, fuel wood and small timber.
- Provides assured people's participation as the biodrainage plantations on farmer's field belong to the individual farmers.

Tree Species for Biodrainage

Eucalyptus species are most suitable for biodrainage due to the following reasons:

- Eucalyptus, a native to Australia, has already reached in more than 110 countries due to its very high adaptability to different edaphic and climatic conditions, fast growth, strong coppicing power, straight bole and wide range of uses (FAO,1979 and Tewari,1992).
- Eucalyptus is known for luxurious consumption of water under excess moisture conditions and less consumption of water under moisture stress conditions (Thomas *et al.*,1972, Ghosh *et al.*,1978, Dabral and Raturi,1983, Chaturvedi,1983, Chaturvedi *et al.*,1984, Rawat *et al.*,1984 and Shiva and Bandyopadhyay,1985).
- Eucalyptus is known for its high water use efficiency (Dabral,1970; Chaturvedi,1983 and Chaturvedi *et al.*,1984).

Biodrainage Studies in Australia

Prior to European settlement, ground water tables in Australia were in long-term equilibrium. In agriculture regions, settlers cleared most of the native vegetation and replaced it with annual crops and pasture species, which allow a larger proportion of rainfall to remain unused by plants and to enter the ground water (George *et al.*,1997, Walker *et al.*,1999). As a result, ground water tables have risen; bringing dissolved accumulated salts to the surface (Anonymous,1996). Patterns and rates of ground water change vary widely but most bores show a rising trend, except where they have already reached the surface or during periods of low rainfall. Common rates of rise are 10 to 30 cm/year (Ferdowsian *et al.*,2001).

In Australia, it is now well accepted that the widespread clearing of forests has left a long-term legacy of salinization. The prime cause of this is that trees use more water than pasture so that their removal results in higher rates of recharge to ground water. Over long periods, the rising water tables eventually reach the surface zone, bringing with them salt, which (formerly) had been locked up deep in the sub-layers. In certain cases, this process has been accelerated by irrigation. For instance, around Shepparton, Victoria, irrigation has led to about 2,00,000 ha of land being salt affected due to shallow and saline ground water (Vertessy *et al.*,2000).

One of the earliest documented observations of water table drawdown beneath a block plantation of Eucalyptus was recorded by Heuperman *et al*. (1984). This Eucalyptus plantation was raised in August 1976 over an area of 2.4 ha at Kyabram in northern Victoria (Australia). A water table drawdown of 2-4 m was measured in this seven-years old (November 1982) Eucalyptus plantation surrounded by irrigated land with a shallow (2–3 m) water table. Measurements of water table were again taken in July 1995 on this (20 years old) Eucalyptus plantation and it was concluded that the water table has been lowered significantly (3-4 m) beneath the plantation relative to the water table in the adjacent irrigated pastures but the spatial extent of this water table lowering in the irrigated pastures was limited to 40 m from the plantation boundary, primarily due to low soil hydraulic conductivities at the site (Heuperman,1995).

Another area was planted at Kyabram in 1985 with *Eucalyptus grandis* (rose gum) at varying spacing with a density of 40 to 1110 trees/ ha. In the first 4 years after planting no difference was found between water table depths under the different tree densities. After 4 years of planting, the impact of trees on water table was started. There was a significant linear relation in water table level for increased spacing; the decline decreased with increasing tree spacing interval (Heuperman,1999). Another study was carried out at two sites located in Goulburn Valley in northern Australia. Site - 1 had two tree lines (63 m apart) of 20 years old *Eucalyptus globulus* (blue gum), *Melaleuca stypheliodes* (prickly paper bark) and *M. ericifolia* (swamp paper bark) on light soil. Site - 2 had one tree line of 23 years old *E. globules* (blue gum) and *E. viminalis* (manna gum) on heavy soil. The trees at site - 2 were much larger and of a healthier appearance than those of site - 1. It was concluded that single-row planting on light textured permeable soils had no measurable impact on water table levels. In heavy soils this effect was pronounced, although limited to a small strip under the trees (Travis and Heuperman,1994).

In another case study, nested piezometer transects were installed at right angles to irrigation sections at two sites in northern Victoria, Australia between August 1997 and March 2000. One site was planted with *E. camaldulensis* and *Casuarina glauca* in 1992 on a light prior stream levee soil (Boort site). The other site comprised *E. camaldulensis* and *E. sargenti,* planted in 1984 on a heavy clay floodplains soil in a relatively saline environment (Appin site). The study concluded that at the Boort site (with a shallow transmissive unit at 1.5 - 2.5 m below surface) three rows of trees were sufficient to intercept seepage during periods of peak seasonal evaporative demand, however during the early and late part of the irrigation season a larger plantation width would be required. At the Appin site (where the dominant seepage flow path was through relatively deep aquifer) seepage might had reached plantation via upwards gradients induced by water table drawdown by the trees in the low hydraulic conductivity clay top-soil (Holland, 2001).

Heuperman (1999) reported that in Eucalyptus plantation raised in August 1976 on heavy soil over an area of 2.4 ha at Kyabram in northern Victoria (Australia), the salinity inside and outside of this plantation was similar in November 1982, the year up to which this plantation was irrigated. But the salinity measured in this plantation in 1993 had clearly shown accumulation of salts in the top of the water table and the capillary fringe above the water table. Travis and Heuperman (1994) reported that in tree lines experiment in irrigated pastures of Goulburn valley, the soil profile underneath the tree line on heavy soil (site - 2) showed a clear water table drawdown in combination with salt accumulation. But the soil profile underneath the tree line on light soil (site - 1) could neither show drawdown of water table nor accumulation of salt. Silberstein *et al.* (1999) modelled the effect of soil moisture and solute conditions on long term tree growth and water use. They concluded that the largest water table impact of the tree plantation occurred about ten years after establishment, after which the water table began to rise and salt started to accumulate. According to George (2000), the question of salt accumulation under growing trees in an area requires major work, both at the theoretical and the field level. There is a concurrence among scientists that because trees usually exclude sodium and chloride ions from the transpiration stream, that these become concentrated in the soil. Limited evidence supports the contentions that the resulting salt accumulation then acts to inhibit growth of the trees. Further work can and should concentrate on quantifying this effect and determining the site requirements to either avoid this or to somehow ‘leach’ the material from the soil.

Biodrainage Studies in Pakistan

Chaudhry *et al.* (2000) described a study conducted on 18.2 ha canal irrigated area of which about 4 ha was planted with Eucalyptus at a density of 1340 plants per ha and in rest of the area crops of cotton, rice and sugarcane were raised. The study reported that water table under tree plantation (ranged between 1.4 m and 2.7 m) was deeper as compared to under irrigated cropping area (ranged between 1.1 and 2.1 m).

Biodrainage Studies in India

According to Kapoor (2001), soon after first filling, large areas along the main canal in the Indira Gandhi Nahar Project (IGNP) Rajasthan (India) became waterlogged. Surface water was apparent at 127 locations along the main canal and covered 900 ha. Plantations of *Eucalyptus camaldulensis*, *Acacia nilotica* and *Dalbergia sissoo* etc. were established along the canal. After six years, the waterlogging disappeared and the ground water table beneath plantation fell by 14 m. He concluded that when plantations are grown on sufficient large areas, the drawdown effect on groundwater is not confined to areas immediately under the plantations but extends to distances of 500 m beyond the edge of the plantation.

Biodrainage Studies in Haryana (India)

Haryana, with a geographical area of 4.42 mha, is predominantly an agricultural state where net irrigated area increased from 1.13 mha in 1967-68 to 2.95 mha in 2004-05. This increase in irrigated area has resulted in its increased food grain production from 3.97 million tonnes in 1967-68 to 13.05 million tonnes in 2004-05 (Anonymous 2008). But introduction of canal irrigation in this state has caused rise in ground water table in its about 50% area and waterlogging and salinity in its about 0.44 mha resulting in reduced crops yield and abandonment of fertile agricultural lands (Anonymous, 1998).

Biodrainage studies were carried out at three research plots, viz., Dhob-Bhali (Ram *et al.*, 2007), Sunderpur and Puthi in Haryana state. The Dhob-Bhali and Sunderpur research plots are located in Rohtak district and the Puthi research plot is in Hisar district of this state. All the 3 research plots are in the command area of Western Jamuna Canal System. Their climate is semi-arid and the soil is alluvial sandy loam with calcareous concretions. The ground water is fresh in Sunderpur research plot but brackish in other 2 research plots. The ground water table was very shallow (within 1.5 m below the ground level) in Puthi research plot, shallow (at 4 m below the ground level) in Dhob-Bhali research plot and deep (> 10 m below the ground level) in Sunderpur research plot. The Eucalyptus plantations was very young (3 years old) at Puthi research plot and mature (18 to 20 years old) at Dhob-Bhali and Sunderpur research plots.

The results of biodrainage study carried out at Dhob-Bhali research plot having 18 years old and 350 m apart two plantations of *Eucalyptus tereticornis* are as given below:

1. Throughout the study of 2 years, the ground water table underneath the plantations remained lower than the ground water table in the adjacent fields without plantation.
2. The average ground water table in the plantations was 4.95 m and the average ground water table in the control located in the adjacent fields was 4.04 m and hence, the drawdown of ground water table was 0.91 m.
3. The ground water table in the plantations was lowered up to a maximum depth of 5.63 m below the ground level.
4. The spatial extent of lowering of ground water table in the adjacent fields was up to a distance of more than 730 m from the edge of a plantation.
5. The drawdown in the ground water table developed due to the effect of a plantation was similar to the cone of depression of a pumping well.
6. The drawdown in the ground water table developed due to the joint effect of two plantations was similar to the combined cone of depression of two pumping wells.
7. The drawdown curve of ground water table underneath the fields located between two plantations was curvilinear due to overlapping of drawdown curves of two plantations.
8. There was no correlation between soil salinity and the ground water table levels.
9. The fluctuations in ground water table caused fluctuations in ground water table salinity underneath the plantation as well as in the adjacent fields.
10. There was no net increase in ground water table salinity underneath the plantation.
11. The zone of capillary fringe above the ground water table was 2.20 m within the depths of 2.50 and 4.70 m.
12. The sinker roots reached the zone of capillary fringe up to a depth of 4.40 m clearly indicating that the Eucalyptus trees were absorbing capillary water of the ground water table.

The results of biodrainage study carried out at Sunderpur research plot having 20 years old strip plantations of *Eucalyptus tereticornis* on both sides of a canal are as given below:

1. The ground water table underneath the strip plantations remained lower than the ground water table in the adjacent fields without plantation.
2. The ground water table in the strip plantations was lowered up to a maximum depth of 11.95 m below the ground level.
3. The spatial extent of lowering of ground water table in the adjacent fields was up to a distance of more than 120 m from the outer edges of strip plantations.

4. The ground water table salinity underneath the strip plantations was lower than the ground water table salinity in the adjacent fields without plantation.
5. The Eucalyptus roots penetrated in the soil profile up to a depth of 10 m.
6. The Eucalyptus trees were absorbing capillary water of the ground water table as their roots reached in the zone of capillary fringe above the ground water table.

The results of biodrainage study carried out at Puthi research plot having 4 strip plantations of clonal *Eucalyptus tereticornis* raised by ridge planting method along the 66 m apart field bunds in north-south direction and each strip plantations having two rows of plants at a spacing of 1 m x 1 m are as given below:

1. The ground water table underneath the strip-plantations remained lower than the ground water table in the adjacent fields and the drawdown in ground water table during a period of 3 years was 0.85 m.
2. The rate of transpiration, measured with sap-flow meter, was 50 litres/ day/ plant which was equal to 438 mm/ annum against the mean annual rainfall of 212 mm.
3. The benefit-cost ratio of first rotation of strip-plantations was 3:1 against 1.3:1 of agricultural crops in Haryana and it would be >100:1 for next 3 to 4 rotations due to negligible cost of maintenance of coppiced Eucalyptus.
4. The wheat yield in the inter-space of strip-plantations was 3.34 times the yield in adjacent waterlogged areas without plantation.

Recommendations

Based on the results of biodrainage studies carried out in Haryana state, the following recommendations were made for canal irrigated areas of semi-arid regions having alluvial sandy-loam soil:

1. Properly designed parallel strip plantations of clonal Eucalyptus tereticornis should be raised for the uniform reclamation of waterlogged areas having ground water table within 3 m below ground level.
2. Properly designed parallel strip plantations of E. tereticornis must also be raised on potentially waterlogged areas (specifically having ground water table within 3-6 m below ground level) to prevent their conversion into waterlogged areas.

Application

The application of above recommendations has already been started in Haryana state as is evident from the following paragraphs:

- Haryana Forest Department has already incorporated a component of “Reclamation of Waterlogged Areas” in its state funded on-going “Clonal Agroforestry” scheme. Under this component, parallel strip plantations of clonal *E. tereticornis* have been raised during the current financial year (2008-09) by the use of ridge planting method on 2000 ha farmers’ agricultural waterlogged areas having ground water table within 3 m below the ground level in 5 districts of Haryana state.
- Ministry of Water Resources, Govt. of India, has sanctioned a pilot project of biodrainage (submitted through Command Area Development Authority, Haryana) for the reclamation of 1000 ha waterlogged areas. This project is being implemented by the Haryana Forest Department on farmers’ agricultural waterlogged fields in Jhajjar district of Haryana state.
- Haryana Forest Department has also submitted biodrainage projects to the Ministry of Water Resources, Govt. of India, for the reclamation of 20,000 ha waterlogged areas. After approval, these projects will be implemented from the financial year 2009-10 onwards.
- Haryana Forest Department is also aware of the probability of conversion of the potentially waterlogged areas (specifically the areas having ground water table within 3-6 m below ground level) into waterlogged areas. Therefore, as a preventive measure, the Haryana Forest Department is raising biodrainage plantations of *E. tereticornis* of seed origin by the use of pit planting method on these potentially waterlogged areas.

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Socio-Economic Analysis of Reclamation Technologies adopted for Crop Production on Salt Affected Soils and Poor Quality Groundwater

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During the last four decades a large irrigation network has been designed and developed in India to meet the growing demand for agricultural products. Undoubtedly, irrigation development is largely responsible for intensification of agriculture that provided a different direction to the agricultural economy. The performances of canal irrigation, both gains and losses, have been viewed differently in various agro-climatic regions. The positive effects include the contribution of irrigation to agricultural production, employment, quality of life, drinking water, navigation, fisheries, microclimate, tourism, etc. The negative aspects are submergence of land, deforestation, emergence of soil sodicity and salinity, waterlogging, rise in watertable, problems of weeds, health hazards etc. The existing irrigation management and policies have created serous problems in some of the irrigated areas in terms of waterlogging and soil salinity, which lead to loss of production and significant reduction in the factor productivity. Similarly, excessive use of land and water resources inflicted significant pressure on the natural resources. Soil degradation and over application of irrigation water are the more prominent environmental issues. Therefore, the resource us efficiency of the important input resources used in the irrigated production systems assumes prominence not only for economic efficiency but also from the view point of environmental externalities.

The financial appraisal of reclaiming sodic and saline soil is aimed to find out whether the project is economically reasonable and able to provide justified return on the investment made on it. The financial feasibility involves detail analysis of cost-benefit analysis. For benefit-cost analysis, we have to estimate capital requirement for plantation, annual operational and maintenance cost and benefits generated by the project. In these projects, the initial investment is made once for reclaiming problematic land whereas the returns obtained from the project in terms of crop yield, is spread over several years in future. As a matter of fact, the cost-benefit analysis is a decision-making tool for investment choice with respect of total costs and total benefits of the technology. It helps in comparing the cost and benefit of alternative technologies and also profitability of the enterprises. Nevertheless, all the costs and benefits are difficult to quantify in financial terms in case of the forestry projects because a new technology may have positive and/ or negative side effects on the life quality of society and accordingly required to be accounted for the assessment. When side effects of a technology are accounted both direct and indirect benefits and costs, it is called social cost-benefit analysis. Generally, for the financial feasibility we consider only quantifiable direct benefits and costs for the simplicity of understanding.

There are many tools and measures to evaluate the feasibility of the land reclamation technologies. Few of the important Cost-Benefit Analysis measures are described here which are used widely to find out the financial and commercial viability of the technologies.

Pay Back Period (PBP)

The Pay Back Period measures the numbers of years it will take for the net undiscounted benefits to repay the investment. If the pay out period is longer than some arbitrary limit, say five years, the project is rejected. If shorter, it is accepted. Thus, the pay back is the time period for an investment to generate sufficient incremental cash to recover its initial capital outlay in full. The following formula is used to calculate the pay back period, if the cash flows are uniform.

$$P = \frac{I}{E}$$

Where P = Number of years required for pay back the investment,

I = Initial capital investment, and

E = Annual net benefits.

If the cash flow is not uniform per year the payback period is determined by calculating the cumulative proceeds in successive years until the total is equal to the original outlay. It is computed to supplement the other measures used to judge the desirability of the projects. The shorter pay back period provides the greater profitability of the project.

The pay out period criterion is justified for the individual's point of view in the short run but for aggregate purposes such as a nation as a whole, some times it misleads the results. The crucial draw back of this measure is that it rejects all projects whose benefits take long time to materialize and favours only good short-term prospects. There is no reason to believe that all quick yielding projects are superior projects.

Simple Rate of Return (SRR)

The simple rate of return of a project is used to compare with the rate that has been determined to cut off criterion or the minimum rate of return. The following formula is used to calculate the SSR of a project.

$$r = \frac{E - D}{I}$$

Where r = Simple rate of return on the investment made for the project,

E = Annual net benefits expected from the project,

D = Annual average depreciation on the fixed assets, and

I = Initial capital investment on the project.

Net Present Worth (NPW)

If some one offers a choice between receiving Rs 100 today or receiving Rs 100 after five years, the decision would be clear to get the money immediately and deposit in a Bank account and earn 12% interest which would give Rs 176 in five years. If you are willing to take risks and invest it in a business, you may earn much more. This is an illustration of time value of money or the cost of waiting. Money received today is always worth much more than the same money received in the future. The same is true for the economy also. Resources available to the country this year can be invested to produce goods and services over the next several years. If these resources were available five years later, the economy would lose the benefit of that output for the next five years. Thus in project appraisals it is necessary to account for the cost of waiting. Benefits and costs accruing earlier are valued more than the benefits and costs accruing later. Just as one can not meaningfully add kilograms of sugar and meters of cloth one cannot meaningfully add costs or benefits of 1991 to costs or benefits of 2001. The process of weighing cash flows according to the year in which they occur is called discounting. The percentage difference between the value of one hundred rupees now and its value a year later from now is called the discount rate. Further costs and benefits are expressed and compared in terms of present value or present worth. Let us assume that we invest Rs 200 at an interest rate of 10% per year. After 2 years it will yields Rs 200 (1+1/10)2 = 242. Now looking from the other angle, if we want to have Rs 242 in hand two years from now, how much must be deposited today? The answer is Rs 242 / (1+1/10) 2 = Rs 200. Thus Rs 200 is the present value of Rs 242 which will be available after 2 years at 10% discount rate. If we assume that Rs 242 is only available after 3 years, then the present value at 10% discount rate will be 242 / (1+0.10)3 = Rs 181.81, which is less than the present value Rs 200 in 2 years time. Let us now assume that the discount rate as 5%. Then the present value of Rs 242 in two years would be 242 / (1.05)2 = Rs 220 which is greater than the present value at 10% discount rate.

- These simple calculations prove the three important features of present value.
- The present value is always less than the nominal value that occurs in the future.
- The longer the delay, the less is the present value.
- The highest the interest rate, the lower the present values.

This means that waiting has a cost and the longer you wait the larger the cost. The third point proves that if money and other assets are more productive, as reflected in the higher discount rate, the waiting is costlier. This raises the question as to which interest rate should be used in project appraisal. Generally the discount rate should reflect the cost of capital to the investor. In the estimation of NPW, the return achieved at different future dates is made commensurable by assigning to them equivalent present values. This is an expression of net revenues from the crop production discounted to a common time point for ensuring costs and returns comparability, which occur at different periods of time. The NPW can be calculated by taking the difference between present worth of benefits and present worth of cost. The positive values of NPW reflect viability of the project whereas negative NPW indicates economic loss in the project. Once future benefits and costs have been expressed in terms of present values, we add them to find out the NPW of the project. The general formula used for estimation of NWP is:

$$NPW = \sum_{t=1}^{n} \frac{Bt - Ct}{(1 + i)t}$$

Where Bt = Benefit received each year,

C = Cost incurred each year,

t = Time in years (with present difference as 0),

n = Number in years of the project duration, and

i = Rate of interest for discounting the cost or benefit.

Present Worth of Benefit-Cost Ratio (BCR)

Benefit-Cost Ratio is the most popular criterion in social project appraisals. It is calculated by dividing the total discounted benefits by total discounted costs. The project is accepted if the BCR is above 1. The projects with the highest ratios are given higher ranking. It is the ratio of present worth of benefit and present worth of cost expected at different points of time for a particular project. The ratio more than 1 reflect economic viability of the project whereas less than 1 indicating loss in taking up the project. The BCR can be calculated with the help of the following formula.

$$BCR = \frac{\sum_{t-1}^{n} \frac{Bt - Ct}{(1-i)t}}{\sum_{t-1}^{n} \frac{Bt - Ct}{(1-i)t}}$$

The Benefit-Cost Ratio is a ratio of PVB to PVC of a technology under assessment. In other words, it is return to one rupee invested on the project. Therefore, at the economic feasibility level of the project the BCR should be more than unity.

Internal Rate of Return (IRR)

The Internal Rate of Return is used to find out the rate of return, which a project is likely to earn over its useful life. This measure is practically used for all economic and financial analyses of projects by the international financing agencies. When the internal rate of return is used in economic analysis, it is called internal economic rate of return (ERR) whereas on the financial analysis it is called internal rate of return (IRR). The IRR is the discount rate at which the NPW is equal to zero. In calculating the NPW, we independently chose a discount rate based on the opportunity cost of capital and then found the differences between discounted benefits and costs. The IRR calculation reverses the procedure as we use for NPW. Instead of selecting the discount rate, we set the NPW at zero and try to solve for the discount rate which finally gives results. Since higher discount rates reduce the present value of future cash flows, the higher the discount rate, the lower the NPW. The process of finding the IRR involves trial and error method. An arbitrary discount rate is used to find NPW. If the result is positive a higher rate is used to find the NPW, if negative a lower rate is used and the process is repeated until the NPW is reduced to zero. At this discount rate, Benefit-Cost Ratio is equal to one. The IRR is compared with the minimum acceptable rate of return and if it is either higher than or equal to the minimum acceptable rate of return, then the technology is assessed to be superior/desirable. Suppose, the IRR is 18% this means that a discount rate of 18% the project just breaks even, i.e., it will earn back all the capital and operating costs extended upon it and pay 18% for the use of money in the mean time.

The Internal Rate of Return or discounted cash flow rate of return is the marginal efficiency of capital or discounted cash flow of the investment on a project. It is the rate at which the discounted cash flows are equal to the investment outlay of the enterprises. So IRR is that rate of interest which applies to expenditures incurred at different times for finding compounded sums equal to revenues compounded at the same time. The rate of discount, which makes net present worth of the investment exactly equal to zero, is known as internal rate of return of a project. Thus IRR is that rate of discount which makes present value of benefits zero.

The IRR is a trial and error solution in which we choose a discount rate at random. The investment is considered to be desirable if the IRR is higher than the cost of capital in a project. If NPW >0, we choose a higher discount rate (accept the project viability) and NPW<0, we choose lower discount rate (reject the proposal). The rate of discount at which the NPW is equal to 0 is the actual IRR and at this stage the procedure is completed. The IRR can be expressed in algebraic form as:

$$IRR = \sum_{t=1}^{n} \frac{Bt - Ct}{(1+i)t} = 0$$

In the estimation of IRR, the first step is to discount the cash flow at the cost of capital. If the NPW is negative, we know the project cannot pay such a high rate of interest. It means that we have chosen a high discount rate. Now, choose a discount rate (lower rate) which will give a positive NPW. If in the first step, NPW is positive we should choose a new discount rate (higher), which will decrease the NPW and make it negative. The real IRR lies between these two rates, and we can successively narrow down the limits. The easier and widely adopted method employed for estimation of true IRR is the interpolation formula. The interpolation formula is as follows.

$$\text{IRR} = \text{Lower discount rate} + \text{Difference between the two discount rates} \times \frac{\text{NPW at lower discount rate}}{\text{Difference between NPW's at the two discount rates}}$$

It is very important to note that interpolation should not be carried out between a wider spread of discount rates (not more than five per cent). Since interpolation is a higher linear algebraic technique and the changes in IRR, NPW do not follow this pattern. In reality, the IRR rectified by actual verification and by narrowing down the limits between the two discount rates.