An Overview of the Water Resources and Water Management Issues Related to Irrigated Agriculture

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Water, a unique resource on the planet earth, is essential for sustaining all forms of life, food production, economic development, and for general well being of the life on the planet. The importance of water could be gauged from the fact that while looking for life on other planets, presence of water is first examined as an indicator of the presence of life on the planet. Although our earth is called the 'Blue Planet' as 70% of the earth is covered by water, yet only 2.5% of the world's water is fresh, while 97.5% is saline being oceans. Of this small percentage of freshwater, only 0.3% is available in rivers, lakes and reservoirs, 30% is ground water, while the rest is stored in distant glaciers, ice sheets, mountainous areas and places that we can hardly access. Civilizations have been developed along the rivers. Yet, it would not be an exaggeration of the fact that civilizations doomed not because the water was not available but because the water was misused resulting in unsustainable use of the resource. Current example is the Aral Sea Basin, where large-scale mismanagement of water has played havoc on agriculture, environment and the life.

Historical

Water has always been scarce and people by habit have been mismanaging the resource resulting in wastage and severe pollution of the water bodies. If it had not been so then - Rahim ji would not have said "*Rahiman pani rakhiye, bin Pani sab soon, Pani gaye na ubre, moti, manush chun*". Lord Krishna as revealed through the Episode on '*Kaliya Mardan*' tried to sensitize the people on pollution of surface water bodies. Our elders, even today, ask their children to throw some coins in the river/water resource as a copper coin would help to purify the water as well as sensitize the child towards upkeep of the precious resource. The practice has become a mere ritual today because people throw any coin that is available in their pockets and not a copper coin, which is a water purifying metal.

In India per capita surface water availability in 2001 was 1902 m^3 and is projected to reduce to 1401 and 1191 m^3 in 2025 and 2050, respectively. As per current international norms, if per-capita water availability is less than 1700 m^3 per year then the region is categorized as water stressed and if it is less than 1000 m^3 per capita per year then the region is classified as water scarce. At or below 500 m^3 it is severe water scarcity affecting general well being. Hence, there is a need for proper planning, development and management of the greatest asset of the country, the water for raising the standards of living of the millions of people, particularly in the rural areas.

Surface Water Resources of India

From the point of view of surface water resources, India has been divided into 20 river basins. These comprise of 12 major basins each having a catchment area exceeding 20,000 sq km and 8 composite river basins combining suitably together all the other remaining medium and small river systems. The total water potential of these basins is estimated at 187.9 M ha m. A break up of this resource reveals that 105 million ha m is the runoff from rainfall that flows into rivers and streams including reservoir and tanks. Additional water is received from snow melt (10 M ha m), flow from outside India (20 M ha m), from ground water (37 M ha m) and from irrigated areas (11 M ha m) making a total of about 183 million ha m. The largest potential of water is available in Ganga/Brahmaputra/Barak and others making a total of 117 M ha m followed by Godavari and by west flowing rivers from Tapi to Tadri each having an average annual potential of more than 10 M ha m.

Due to extreme variability in precipitation, which disallows assured storage of all the water, due to non-availability of storage space in hills and plains, evaporation losses and water going to the sea and outside India, it is anticipated that utilizable surface water resources would be 69 M ha m which will be utilized by the year 2025. It is assessed that on full development, 76 M ha area would be irrigated through surface water resources.

Ground Water Resources of India

Ground water is also an important source of water that accounts for about 80% of domestic water requirement and more than 45% of the total irrigation in the country. Replenishable ground water resource is mostly derived from the precipitation. Out of 400 M ha m, 215 M ha m of rain water percolates into the ground out of which only 50 M ha m joins the ground water or is available for exploitation. While a part of this water would regenerate into streams, there would be net addition of water through streams and irrigation which is presently estimated at 26 M ha m. Deep percolation adds another 11 M ha m. The state wise ground water potential as recently estimated by Central Ground Water Board (now Authority) is 43.2 M ha m. Basin wise estimates reveal that the Ganga basin has the maximum ground water potential and accounts for more than 38% of the total groundwater potential. It is followed by Brahmani and Baitarni at 5.9 M ha m. After deducting the provision for domestic and industrial purposes, the potential available for irrigation is 36.03 million ha m. The utilizable ground water for irrigation is thus assessed at 32.47 M ha m. It is likely to increase to 35 M ha m in 2025. About 5-6 M ha m of water goes into storage, which results in rising water table and is lost through evaporation. Amongst the states, Uttar Pradesh, which mostly lies in the Ganga basin, has the highest potential. Himachal Pradesh on the other hand has the least potential amongst the states. In terms of area, the irrigation potential of the ground water has been revised and placed at 64.05 M ha.

Current and Projected Water Requirement

India's population is increasing at a relatively fast rate. At a high growth scenario, population is likely to stabilize at 1581 million in 2050. To feed such a large population, green revolution played a very significant role as the food grains production increased from around 50 MT in the fifties to about 203 MT in the year 1999-2000. Although it hovered around that value for some years, it has again got the momentum and is likely to touch 234 MT during 2009-10. Even then water resource allocation to irrigation has to be made to continue to get high production and productivity. On the other hand, increasing demand of the other sectors cannot be ignored, more so because of their paying capacity. As such agriculture has to depend upon poor quality waters in times to come. The likely demand of water for various sectors at a low and high growth scenario as projected in the National Planning Documents is reproduced in Table 1.1.

Problems of Water Resources in India

Although it is highlighted that India has to support 17% of the world population with less than 4% of the water resource, yet it could be said that water inadequacy may not be of as much concern as its management due to several problems encountered in the use of the resource. Some of the problems are enumerated in the following sections.

Spatial and temporal distribution: On an average over space and time, average annual rainfall over the Indian sub-continent has been estimated at 1200 mm. The annual precipitation including snowfall is estimated at 400 M ha m (4000 km^3). The highest rainfall of about 11,690 mm is recorded at Mousinram near Cherrapunji in Meghalaya in the northeast. In this region as much as 1040 mm of rainfall could occur in a single day. At the other extreme are places like Jaisalmer, in the west, which receive barely an annual average rainfall of 150 mm. Distribution with respect to different rainfall zones reveal that more than 50 % of the resource is generated in the zone with rainfall ranging from 1000-2500 mm (Table 1.2). The area receiving less than 1000 mm of rainfall constituting about 48% of the geographical area contributes only 24.6% of the water resource. About 300 M ha m of this resource is generated during June to September while another 100 M ha m is during the rest of the year. Another characteristic of the rainfall is that in many areas of the country, it is only a few heavy storms, which account for most of the annual rainfall. Absence of heavy storms would generally mean reduced rainfall.

The consequence of the spatial and temporal distribution is reflected in the per capita availability of water in different basins. For example, even now, per capita availability of water is 13636 cubic m in the Brahmaputra-Barak basin while it is only 298 m^3 in the Sabarmati basin.

Table 1.1. Annual water requirement for various uses

Item of use	1997-98	2010			2025			2050		
		Low	High	%	Low	High	%	Low	High	%
Irrigation	524	543	557	78	561	611	72	628	807	68
Domestic	30	42	43	6	55	62	7	90	111	9
Industries	30	37	37	5	66	67	8	81	81	7
Power	9	18	19	3	31	33	4	63	70	6
Inland navigation	-	7	7	1	10	10	1	15	15	1
Environment/Ecology	0	5	5	1	10	10	1	20	20	2
Evaporation losses	36	42	42	6	50	50	6	76	76	7
Total	629	694	710	100	784	843	100	973	1180	100

Table 1.2. Distribution of geographical area in different rainfall zones in India

Rainfall zone (mm)	Geographical area (m ha)	Rainwater availability (m ha m)
100-500	52.07	15.62
500-750	40.26	25.16
750-1000	65.86	57.63
1000-2500	137.24	205.86
> 2500	32.57	95.73
Total	328.00	400.00

Conflicting Objectives of Water Resources Development: Major and medium projects are multipurpose projects with hydropower generation, flood control and irrigation. Thus the operational strategy for one objective may not match the need for the other objective. For example, operational strategy for irrigation would be quite different as water would be needed over the seasons, hydropower generation may require steady release of water to meet relatively steady demand as well as to take care of any eventuality of dry periods. Similarly, storage for irrigation and hydropower would overweigh concerns for the flood control. Therefore, operational aspects of multi-purpose projects need to be optimized to meet most objectives in most effective manner. Concern to maintain water quality, river regime, maintenance of river ecosystem or other public necessities is should also be given due importance in the release of water.

Increasing Competition between Sectors: Increasing population, change in eating habits, life style changes and increasing emphasis on travel/tourism and environment, the demand scenario of water is expected to change drastically. Agriculture, which is currently consuming 83% of the developed water resource, would be the looser and would have to sacrifice fresh water for the interests of other sectors of economy. Although, overall quantity of water allocated to agriculture would increase yet it would be less than the demand. Therefore, agriculture needs to look at other sources particularly the so-called wastewaters released after first use by other sectors. Researches on the use of such waters have already begun with right earnest.

Pollution of Surface and Ground Water Resources: We are all witness to extreme pollution levels of surface water bodies and more so of the rivers, which turn into drains during non-monsoon season, as effluents from large number of municipal and industrial establishments are discharged untreated into the rivers. The ground water pollution is even more serious which goes unnoticed and remains hidden from the public view. Non-point source (agriculture use of excessive fertilizers, insecticides and pesticides) and point sources (disposal of industrial and domestic sewage) have resulted in increase contaminant concentrations exceeding the limits prescribed by World Health Organization (WHO). Direct disposal of effluents in the bore wells in unorganized colonies and industries is even more serious matter. It may be mentioned that it should be possible to take remedial measures to remove pollution of surface water bodies but it would be difficult, almost bordering on the impossible, to reverse the process once the ground water aquifers gets contaminated.

Irrigation and Crop Productivity: Rainfall is the most significant climate factor that affects the crop growth and production from the rain fed areas in the country. A good example is the interaction between annual food grain production in India and the summer monsoon rainfall. The fall in production is observed during the years of deficit rainfall. The difference in total annual food grain production of the country was about 20 percent between the poor monsoon of 1974 and the succeeding good monsoon of 1975. The high production achieved during 2009-10 is attributed to well distributed and good rainfall received during the year. The rainfall uncertainty is more in the rain fed region as the rainfall is quite erratic with large spatial and temporal variations. The coefficient of variation increases with decreasing rainfall. While it is about 20% in dry sub-humid regions, it is as high as 61% in the arid regions. Besides water, other bio-physical and socio-economic constraints limit the productivity of crops and livestock. Progress in making inroads for higher productivity in rain fed agriculture has been quite slow although rain fed areas constitutes bulk of our agricultural land. The productivity of rain fed agriculture being less than half of the productivity of irrigated lands (Table 1.3), it is clear that irrigation can result in substantial improvements in the productivity of rain fed crops.

Table 1.3. Yields of principal crops under irrigated and non-irrigated conditions

Crop	Irrigated (kg/ha)	Non-irrigated (kg/ha)	Per cent increase over non-irrigated
Rice	1880.3	1220.4	54.1
Sorghum	1242.6	606.9	104.7
Pearl millet	1170.2	596.2	96.2
Maize	2040.5	1339.2	52.4
Ragi	1966.8	995.9	97.5
Wheat	2068.1	1100.1	88.0
Barley	1836.6	1127.2	62.9
Gram	830.0	548.5	51.3
Groundnut	1244.2	844.4	47.3
Sugarcane	70687.5	43161.2	63.8
Rapeseed & mustard	893.6	573.2	55.9
Cotton	440.3	195.1	125.7
Jute	1952.6	1502.8	29.9

Average of 1985-86 to 1991-92 over different states; Source: Central Water Commission (1995)

The issue of major concern, however, is the fact that even the productivity of irrigated agriculture is not as high as anticipated in the project proposals or as spectacular as in other countries. There is no national level assessment of the overall irrigation efficiencies. The irrigation efficiency in surface irrigation systems might be in the range of 35-40% while it could be 65-70% for ground water. The overall low productivity of Indian irrigated agriculture could be attributed to inefficiencies of the system.

Lag in utilization of irrigation potential is also a cause of concern. The irrigation potential utilized is around 90% of the developed irrigation potential. It has locked in huge investment made in developing the irrigation potential. A modest estimate would reveal locking up of Rs. 12500 billion due to non-utilization of the irrigation potential created.

Paradox of Rising and Falling Water Table: Most irrigation projects in India are operating at low efficiencies. Clearly, 60-65% of the irrigation water is lost either during conveyance or in the fields. This has led to rising water table in irrigation commands, particularly in areas underlain with poor quality ground waters. This has resulted in increased problems of water logging and soil salinization.

It is estimated that around 6.73 M ha of agriculturally productive lands have turned barren because of these twin problems. Besides, large areas that might be producing below the potential productivity have not been estimated so far.

Because of the inadequacy and unreliability of canal waters, farmers have resorted to intensive irrigation through ground water development. Over-exploitation of ground water is causing water table to decline by 0.2-1.0 m per annum in Punjab, Haryana, Western Uttar Pradesh and many other states. Besides higher investments on installation of submersible pumps, such a scenario would lead to increased consumption of power that would not only affect the energy scenario but would also increase the cost of production. In the state of Haryana, if this trend continues, the reversal of ground water gradient might lead to poor quality ground water moving into the good quality aquifers, causing a severe set-back to the farming community and the state. Besides, one third of the total geographic area or about 108 M ha area inhabited by 263 million people is drought prone. This 26% of the population has a marked tendency to intensively exploit ground water particularly during drought years. In coastal areas overexploitation of ground water is causing problem of seawater intrusion.

Water - the Cause of the Conflicts: War or no war, large conflicts arising over water could be a reality. There are at least 300 conflicts zones where water could be the cause of the conflict. Nile River has catchment spread over 10 countries. Nearer home, India has several such conflict zones with Pakistan, Bangladesh and Nepal. World war over water foreseen by policy planners might or might not occur but fierce fight for water within states in India has already begun with no end in sight. Conflicts between Tamil Nadu-Karnataka-Andhra Pradesh and Punjab-Haryana-Rajasthan are too well known.

Can We Meet the Challenges of Water Resources?

When one looks at the statistics being fed through the media, one becomes quite skeptical to the future. Doubts have been raised on the socio-economic development, sustainability of irrigated agriculture and environmental quality. But let us face the facts. Water has been as scarce in the past as it was when our population was a fraction of today's population. Our forefathers were equally worried about the scarcity and pollution of surface water bodies. Yet we could survive so far. There are still many opportunities to tap our water resources. Let us look at some of these opportunities so that we can make a better choice in exploiting these resources. Some of such opportunities are discussed in following sections.

Irrigation System Improvement: Suggestions on modernization of existing Irrigation systems with better operation and maintenance, rationalization of water rates, techniques for equitable water distribution, night irrigation, dynamic regulation through decision support systems, computer use, information technology and advanced methods of communication have emerged at various forums. It is estimated that a 10% improvement in agriculture sector could compensate the 40% increase in demand of domestic and industrial sectors. Inadequacy and uncertainty is being tackled through inter-basin transfer of water. With initial hiccups being removed, inter-basin transfer is slowly becoming a reality. It has been estimated that in due course of time inter-basin transfer of water would add to 35 M ha of irrigated lands. Participatory Irrigation Management (PIM) could play a very effective role in irrigation management. Although many people think it to be the panacea for all the ills that plague the irrigation system, such an overemphasis has already burdened the concept of PIM and voices are now being heard to go for privatization of the irrigation system in participatory mode. What it really means is yet to emerge? Nonetheless, stakeholder's participation from the beginning of the project should be ensured for the success of the project.

Dew: Dew is the water vapour in the atmosphere, condensed on surface of objects exposed to nocturnal radiation. Observations of dew in India were started on a regular basis from 1968 and since then have expanded greatly. Although, dew may not add much to our water resource compared to the magnitude of other sources, yet dew accumulation is 15-30 mm in north and north east India during a period of 6 months i.e. October-March. The largest value is over Assam. About 25 to 50 percent of water deficiency in the month of January in South Punjab to Assam assessed at about 40 mm could be met with dew. The importance of dew in relatively drier areas may not be a promising option.

Green-Blue Water Integration: Green water constitutes about 50% of the total water resource. While too much emphasis is placed on the development and use of blue water, not much attention has been paid to green water. If efficiency of green water is increased, it alone would be able to generate about 230 M ha m water at the global scale. If the syndrome of green and blue water could somehow be broken, the increased efficiency of green water in itself could raise the productivity of irrigated lands.

Reuse of Drainage Water: Not long back drainage waters were treated as wastewaters. Analysis of water samples from surface drains showed that water in these drains during monsoon season is of good quality and it can be used in agriculture without affecting the land resource or the crop yields. Fortunately for the nation, farmers are quite conscious of this fact and this source is now being tapped to the hilt. It is very encouraging scene to see the farmers pumping water from the drains, borrow pits and depressions to irrigate their fields. Water so pumped is being transported for more than a kilometer. If low weight Chinese kind of pump were made available, there would be a spurt in the reuse of drainage water.

Exploitation of Saline/Sodic Waters: This issue would be discussed in a number of lectures. Therefore, discussion on this issue is not being included in this lecture. However, it may be appropriate to add that head-end to tail-end transport of water and skimming of fresh water floating on the poor quality ground water is catching up fast in western Haryana and south-west Punjab.

Multiple Use of Water: All of us have an idea that water released from one sector after first use could be beneficially used in agriculture. However, multiple use of water within agriculture sector should also be ensured to enhance water productivity. For this purpose non-consumptive and consumption activities needs to be identified. Aquaculture with agriculture could be one major activity, where value added water from aquaculture could be used to irrigate crops. Reuse of drainage water discussed before in this lecture could also be cited as an example of multiple uses.

Interlinking of Rivers: (i) Interlinking of the Mahanadi – Godavari – Krishna – Cauvery rivers and building of storages at potential sites in these basins with a view to transferring surplus water to needy areas further south; (ii) Interlinking of west flowing rivers, north of Mumbai and south of Tapi with provision of storages for supplying water for irrigation in Gujarat state and water supply to Mumbai; (iii) Interlinking Ken-Chambal rivers with provision of a water grid for Madhya Pradesh and Uttar Pradesh; and (iv) Diversion of other west flowing rivers with interlinking canal systems backed by storages to meet the requirements of Kerala and to transfer water to drought affected areas on the east. These could provide additional irrigation to about 22 M ha and generate about 30 million KW of hydropower besides providing substantial flood control in the Ganga and Brahmaputra basins. The Peninsular rivers development is expected to provide additional irrigation of about 13 M ha and about 4 million KW of hydropower. The main crux of the inter-basin transfer does not lie in identifying the surplus and deficit basins, but in quantifying the amount by which these basins will have surplus or deficit of water. This is the point where all bottlenecks are bound to appear whenever any link comes into operation. It might prove to be a Herculean task to resolve the differences as is happening currently in most of the projects where allocated water is not being released by the states.

Separation of Grey/Black Waters: Freshwater withdrawals by urban areas will rise from an estimated minimum of about 15 BCM to a projected maximum of 60 BCM. More than 80% of this water would be released back. It would be released in the form of grey and black water (Table 1.4). Grey water is the water released from washbasins, kitchens and bathrooms etc. This water is relatively of good quality and could be used to irrigate lawns/kitchen gardens. On the other hand sewage water is black water. The quantity of black water is quite large because currently grey and dark waters are being mixed up creating problems in the disposal. In many countries it is now mandatory to separate grey and black waters. The day is not far off when we would need to adopt such regulations to reutilize grey waters so that disposal related problems are minimized.

Table 1.4. Categorization of waters and their role in agriculture

Category of water	Source	Potential for use in agricultural or remarks
Blue water	Sea, lakes, rivers, canals etc.	Extensively used for irrigation. Its availability is likely to decrease with increasing competition from other sectors.
Green water	Soil moisture and water in plants	Mostly used by plants/ agricultural crops particularly forest, grass lands and rain fed agriculture.
Fossil water	Ground water	Use for domestic and agricultural uses. Its availability to agriculture would decrease with time as a result of competitive demand from other sectors.
Grey water	Wastewater from bathroom, kitchen and washbasins.	Potential for use in crop production. Suitable for kitchen gardening and irrigating lawns.
Black water	Domestic sewage/ Industrial waste	Potential for use in crop production. 21st century water resource for agriculture. Cleaner technologies required to avoid heavy metals/pathogens entering human chain.
Virtual water	Water used in producing grains/ animal product	Export-import of food grains/animal product indirectly results in export-import of water. It is going to assume importance in export-import during next few decades (Table 1.5).

Technology Upgradation in Agriculture: Researches in water management have shown a number of areas where water could be saved without detrimental effect to crops. It could be achieved through deficit irrigation as well as by crop diversification. Switchover from high water requiring crops to low water requiring crops could save a major fraction of water in agriculture. Application of resource conservation technologies such as land leveling, zero tillage, bed and furrow planting of wheat, dry or semi-dry seeding of rice could save water. Improved irrigation techniques such as drip and sprinkler can save water as well as result in higher productivity.

Table 1.5. Amount of water required to produce one kg of the product

Product	Amount of water (m^3)
Rice, Wheat, Maize	1-3
Beef, pork, chicken	3-16
Potato, apple and orange	0.25-0.75
Milk (1 litre)	1 (values up to 3-4 m^3 have been reported)
1 ream of A-4 size paper (80g/m^2)	5

Source: Labhsetwar (2005)

Controversy of Big and Small: In the Indian context, sustainable management of water resources with due respect to ecological, economic and ethical issues blended with technical feasibility, requires a holistic and integrated approach involving engineering, socio-economic and environmental aspects. Water resources development requires a judicious mix of large, medium and small reservoirs based on the integration of techno-economic feasibility and environmental capability along with regional demand. There seems to be no scope of any controversy in this respect since India lags far behind in meeting its demand for water. Therefore, any addition to its resource through any means big or small would contribute to the socio-economic upliftment of the people of India. It also seems that no single strategy such as reduction of losses to save water alone (Table 1.6) would work unless it is fully supported by development of additional sources of water and its multiple uses (Table 1.7). Therefore, the focus must lie both on development and management.

Table 1.6. Water saving strategies in agriculture

S. No.	Items
1	On farm land and water management that would include, land leveling, zero tillage, bed and furrow farming, precision farming, improved surface irrigation techniques and land drainage
2	Improved pressurized irrigation techniques
3	Improved agronomic practices that would include time of sowing, crop varieties, cropping systems, conjunctive use and mulching
4	Crop diversification
5	Rainwater management in agriculture including three tier system developed at CSSRI, Karnal
6	Irrigation regime in rice crop including shallow submergence, irrigation scheduling at hair cracking and dry seeding or irrigations at critical stages in other crops
7	Deficit irrigation particularly under high water table conditions
8	Pricing and legal restrictions on water use
9	Use of virtual water concept to control demand

Table 1.7. Strategies to increase the water resources

S. No.	Items
1	Use of fog and dew
2	Green and blue water syndrome
3	Watershed and flood management including rainwater harvesting
4	Increase in storage capacity
5	Inter-basin transfer of water
6	Reducing requirement through demand management and/or minimization of waste
7	Reuse/use of naturally occurring saline or domestic and industrial waste water
8	Desalination of sea water

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Extent and Nature of Salt Affected Soils and Their Distribution in India

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Salt affected soils occur in all continents and under almost all climatic conditions and physiographic regions. Their distribution, however, is relatively more extensive in the arid and semiarid regions compared to the humid regions. Salts released by weathering of silicate minerals are important original sources and are responsible for enrichment of soils and water at specific favoured locations. Soil enriched with neutral salts is termed as saline while the one with salt capable of alkaline hydrolysis as alkali or sodic. The nature and properties of these soils are also diverse such that they require specific approaches for their reclamation and management to maintain their long-term productivity. For any long-term solutions, it is, therefore, necessary to understand the nature of salt-affected soils and to classify them, keeping in view the physico-chemical characteristics, processes leading to their formation and the likely approaches for their reclamation and successful management. In India, knowledge on the extent of salt affected soils is important because they occur in association with the fertile soils of arid and semi arid regions and still more important because these regions are increasingly brought under irrigation. By acting as driver of change in land use the massive irrigation system has also induced the twin problems of waterlogging and secondary salinisation. Occurring in belts or patches, with extremely variable distribution patterns the salt-affected soils are difficult to map and monitor.

Historical Perspective

Initially, the assessment was mere qualitative but could be seen that over the time more quantitative estimates were made. In 1858 the Government of Punjab drew the attention of the then Governor-General to the seriousness of the problems of *reh* and *usar* tract. Dr. J.A. Voelcker was the first agricultural scientist appointed by Government to report on Indian Agrarian conditions. He recorded that enormous tracts especially in the plains of Northern India are affected by *reh*. Indians since ancient times had recognised and termed the soil rendered infertile due to salt toxicity as *Usar*. It was only in the middle of the nineteenth century that salinity was recognised as a potential threat to agriculture. In 1863, Mr. T.E. Brown, a Chemical Examiner, analysed salt affected soils from Punjab and ascribed the problem to the decomposition of alkaline minerals by irrigation water. "The correspondence on *reh* deterioration" published in 1864 was the first documentation on the problem and analysis of soil salinity. Subsequently a *Reh* Committee was set up in 1877 to investigate the causes of deterioration of lands by *reh* in U.P., which have developed large-scale secondary salinisation (Agarwal *et al*., 1982).

During 1930-70 the soil salinity work in India got much required impetus due to the classical works of a few veteran stalwarts. With a view to change the unproductive and unutilised land use of these menacingly increasing salt-affected soils through concerted research efforts, the Central Soil Salinity Research Institute (CSSRI) was established in 1969 at Karnal. Coinciding with the establishment of CSSRI, the period from 1969 onwards has been a turning point in the history of research on salt affected soils in India.

Source of Salt

Weathering of silicate minerals, runoff water and aeolian accession are the major sources of salt. The specific relief, geomorphic and hydrological conditions facilitate accumulation of soluble salts into micro-depressions. Periodic surface wash from immediate elevated neighborhood builds-up salt load in the concavities. Many observations in Punjab, Haryana (Bhumbla *et al*., 1973; Sharma and Bhargava, 1988a) and Uttar Pradesh (Kumar *et al*., 1996) have reported the occurrence of sodic soils in micro-depressions. Distinctively linear distribution pattern of salt affected soils in the topo-drainage sequences in Haryana (Sharma and Bhargava, 1988b) and Sharda Sahayak Command in Uttar Pradesh evidently indicate the trapping of salts in micro-depressions. Salt affected soils are broadly grouped as either saline or sodic soils (Szabolcs, 1974; Abrol and Bhumbla, 1978).

Saline Soils: Saline soils are often recognised by the presence of white salt encrustation on the surface and have predominance of chlorides and sulphates of Na, Ca and Mg in quantities sufficient to interfere with growth of most crop plant. The soils with neutral soluble salts have saturation paste pH <8.5. The electrical conductivity of saturation extract (EC_e) of saline soils >4 dS/m at 25^oC and exchangeable sodium percentage (ESP) <15. In saline soils, the excess of neutral salts limits the normal plant growth.

Sodic Soils: These soils contain excess of salts capable of alkaline hydrolysis such as sodium carbonate, sodium bicarbonate and sodium silicate; and sufficient exchangeable sodium to impart poor physical conditions to soils and thus affecting growth of most plants. These soils have saturated paste pH >8.5; exchangeable sodium percentage (ESP) >15 and different levels of EC_e.

In saline soils when chlorides and sulphates of Ca and Mg are the predominant salts, the SAR usually remains less than 15. However, predominance of Na invariably results in soil solution SAR >15. Such soils are termed saline-sodic. Many saline-sodic soils contain, in addition to soluble carbonates, the excess of neutral salts. From management point of view, the saline-sodic soils that do not contain soluble carbonates are grouped with saline soils and the others with sodic soils.

Extent and Distribution

Comprehensive information on the distribution and extent of salt affected soils in the country is important to plan and execute meaningful strategies for their utilisation. Extent and distribution of salt affected soils is usually made either using traditional methods or by modern techniques involving remote sensing and geographical information system (GIS).

Assessment by Traditional Methods

In the beginning, the distribution of salt affected soils was reported for small scattered pockets. A decade after Independence a number of soil scientists viz; Agarwal and Mehrotra (1953) and Kanwar and Bhumbla (1969) reported the distribution of salt affected soils in various parts of IGP. Basu (1950) and Zende (1968) reported the occurrence of these soils in parts of the Penninsula while Mehta *et al.*, (1969) reported for Rajasthan and Satyanarayana (1961) for Gujarat. Occurrence of salt affected soils in compact areas of the IGP and the Central Penninsula and in scattered blocks of the other parts of India was first depicted by the Committee on Natural Resources, Planning Commission (Raychaudhuri, 1966). Bhumbla showed six categories of salt affected soils viz; alkali soils, saline soils, potentially saline soils, coastal saline soils, deltaic saline soils and acid sulphate soils on a generalised small-scale 1:6 million map of India (Fig. 2.1). Murthy *et al.,* (1980) compiled and synthesised the information of benchmark profiles of salt-affected soils from all over India and classified them into associations of great-groups.

Various Assessments Based on Localised Statistics: The area under SAS in Uttar Pradesh was first assessed to be 0.84 M ha by the *Usar* Land Reclamation Committee and Agarwal (1959) put the figure at 1.28 M ha. Talati (1941) estimated the extent of damage by salty lands in Maharashtra to 33,200 ha. In addition to this, Zende (1968) reported about 34,000 ha as khar land due to ingress of seawater. In Karnataka, salt affected soils were encountered in the districts of Dharwar, Bijapur, Belgaum, Bellary, Raichur, Chitradurg and Gulbarga that do not fall under canal irrigation. In Andhra Pradesh, the salt affected soils were estimated to occupy roughly 1.0 per cent of the total area (Dept. Agric. Andhra Pradesh, 1972). Detailed soil survey of Nagarjuna sagar irrigation project revealed the occurrence of salt affected soils under Kattalai High Level Channel. According to Ahmed *et al.*, (1967) 23,000 ha of land in the 12 districts of Tamil Nadu suffered from extreme conditions of soil salinity. The districts of Morena, Bhind, West and East Nimar, Dhar, Gwalior and Shivpuri in Madhya Pradesh have been found to contain salt affected soils. Mehta *et al.*, (1969) reported saline-alkali soils of Rajasthan. Nearly, 0.16 M ha of the Rajasthan canal command forming old bed of the Ghaggar River was affected by salinity. Large scale damage was reported in Gujarat around the estuaries of the Narmada, the Tapti, the Mahi and the Sabarmati rivers. Satyanarayana (1961) reported salty lands of Rann of Kutch. Similarly a good account of the affected districts from states like Bihar, West Bengal and Kerala was also available. Due to fragmented and miniscule coverage these statistics as such, proved inadequate and incomprehensible to compute or project the extent of salt-affected soils on all India basis.

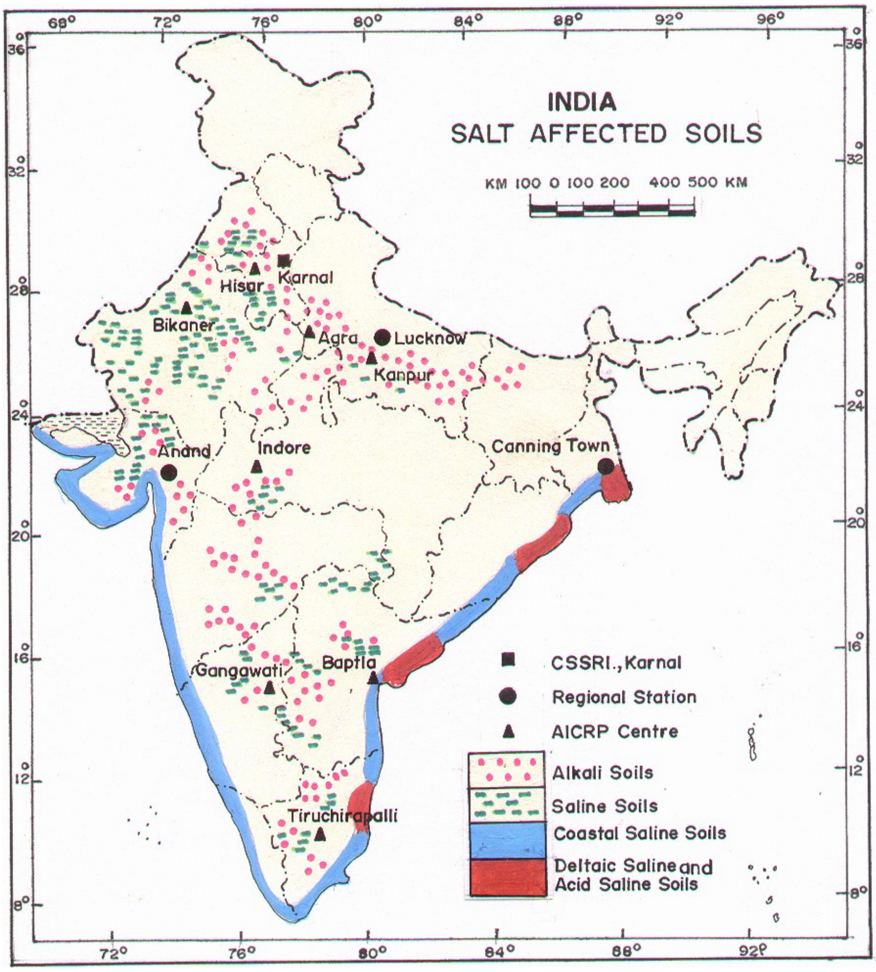

Fig. 2.1. Distribution of salt affected soils of India

Compilations by the Individuals Based on Field Observations: The absence of systematic surveys and a reconnaissance map showing the distribution and extent of salt affected soils, prompted several individuals to report on their extent (Table 2.1). The computed figures, ranged between 3.3 - 26.1 M ha. The wide variations in the statistics reflect upon the degree of concern and perception authors have for the problem. Hypothesis driven expectations of an outcome arisen by guesswork or by inspiration might have influenced them to hold some observations relevant and some irrelevant, select some data and reject the other, accept one methodology and discard the other. The divergent nature of the statistics created a very simplistic impression of the problem in the mind of general reader.

Extent Given by Different Agencies: A committee constituted by the Soil and Water Conservation Division (S & WCD) of the Ministry of Agriculture in 1993, obtained statistics on salt-affected soils from several Central and State Departments and Agencies like S & WCD; Society for Promotion of Wasteland Development (SPWD); National Remote Sensing Agency (NRSA); National Bureau of Soil Survey and Land Use Planning (NBSS & LUP); National Commission on Agriculture (NCA); National Wasteland Development Board (NWDB); Working Group of Ministry of Water Resources and various State Departments of Agriculture. The reported statistics on the extent differed from 1.5 to 7.17 M ha (Table 2.2).

Table 2.1. Countrywide estimates on salt affected soils compiled by individuals

Source	Salt affected soils in India (M ha)
Raychaudhuri, 1966	6.0
Abrol and Bhumbla, 1971	7.0
Massoud, 1974	23.2
Ponnamperuma and Bandyopadhyay, 1980	26.1
Bhumbla and Khare, 1984	7.2
Vohra, 1987	13.0
Bhargava, 1989	10.0
Singh, 1992	9.8
Abrol, 1994	10.9
Sehgal and Abrol, 1994	10.1
Singh, 1994	8.6
Chauhan, 1996	7.2
Sewa Ram, 1996	3.3
Singh and Bandyopadhya, 1996	8.6

Table 2.2. Extent of salt affected soils in India as reported by different agencies (M ha)

NCA	S&WCD	SPWD	NRSA	NWDB	NBSS&LUP
7.17	7.00	7.17	3.90	1.5	6.20

It emerges from the discussions that such estimates by individuals or groups are likely to differ significantly. Scientific surveys by experts, precisely marking and measuring spatial distribution of salt affected soils are essential for obtaining nationwide reliable and standard data.

Geographical Extent and Distribution

The first systematic attempt to map salt affected soils of entire country in the year 1996 by NRSA in association with other National and State level organisations like CSSRI, Karnal, NBSS & LUP, Nagpur, AIS & LUS, Delhi and State Government Agencies was made using total of 125 false colour composite (FCC) prints of the Landsat TM satellite at 1:250000 scale. The methodology consist 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. The salt affected soils were classified according to norms for pH, electrical conductivity and exchangeable sodium percentage. The salt affected soils accounts for 6.73 M ha equivalent to 2.1 per cent of the geographical area of the country (Table 2.3). It shows that maximum salt affected area (including saline and sodic) 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. Maximum area affected by sodicity occurs in the state of Uttar Pradesh followed by Gujarat, Tamil Nadu and Maharashtra. Out of the total 6.73 million ha, 2.96 M ha are saline and the rest 3.77 M ha are sodic.

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Table 2.3. Extent (ha) of salt affected soils in India

State	Saline soils	Sodic soils	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
Total (million ha)			6.73

(Source: NRSA and Associates, 1996)

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Diagnostic Characteristics of Saline and Alkali Soils

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India is endowed with abundant natural resources such as land, water, vegetation and climate to meet food requirements of burgeoning human and livestock populations. Overexploitation of these precious resources during the last four decades has set in the processes of degradation in soil, water, climate and biological resources. Unscientific and over use of soil resources led to physical, chemical and biological degradation causing irreversible loss to soil quality. The intensive agriculture which ushered in green revolution is now becoming a serious threat to sustainable agriculture due to deteriorating soil quality. The total degraded area of the world is presently reported to occupy about two third of the potentially cultivable land while annual loss of arable land is reported as 5-7 M ha. The magnitude of soil loss through degradation is in several cases much higher than the additional area brought under cultivation. The problem is alarming in the developing countries suffering with stiff increase in population, unemployment and poverty. To mitigate such problem, marginal lands such as saline and alkali soil with moderate productivity are focused and brought under cultivation to supplement deficit food grain production.

The occurrence of salt affected soils in the country is recorded from ancient times. These are more prominent in the arid and semi arid regions, though sizeable coastal area in the humid conditions is also affected primarily due to ingression of sea water. The evidence of soil salinity (locally known as *Kallar*) was first noticed in 1855 at Munak village presently located in Haryana, close to the Western Yamuna canal. The analytical data published by the Royal Mineralogical Laboratory in England showed preponderance of excessive accumulation of salts in the soil which was aggravated by the lack of adequate irrigation management and insufficient internal drainage. Similar instances were reported by indigo farmers of the Aligarh district in Uttar Pradesh asking for exemption of revenue due to crop damage and land loss. Keeping in view the grave situation stretching from Punjab to Uttar Pradesh in Gangetic Plain, the "*Reh* Committee" was constituted in 1877 to investigate the causes of such land degradation and suggest remedial measures to combat the situation. The first systematic survey of salt affected soils was initiated by Leather (1914) identifying soil alkalinity and salinity problems in the Gangetic alluvium located at Etah district in Uttar Pradesh. He published his first report on the reclamation of *Reh* or *Usar* soils of Uttar Pradesh in 1893 and also continued his studies for three decades that created 12 benchmark sites for land reclamation. Later, Agarwal *et al.* (1957) revealed the absence of drainage as primary factor for soil salinization /alkalization in the lower Ganges canal areas of Uttar Pradesh. Besides, concerted efforts were made through various research activities during the fourth decade of 20th century and a seminar was also organized in 1940 to assess the salinity/ alkalinity status and its remedial measures. As a follow-up action, the Directorate of Punjab Land Reclamation was established in 1945 that produced two publications on reclamation. The Indian Council of Agricultural Research published a book entitled "Saline and Alkali Soils in India" in 1968. The Central Soil Salinity Research Institute (ICAR) was established in 1969 and the All India Coordinated project on "Use of Saline water in Agriculture" was initiated in 1972.

Sources of Salts

In India, the main causes of salt accumulation are:

- Capillary rise from subsoil salt beds or from shallow brackish ground water
- Indiscriminate use of irrigation water of variable qualities
- Weathering of rocks and the salts brought down from the upstream to the plains by rivers and subsequent deposition along with alluvial materials
- Ingress of sea water along the coast
- salt laden sand blown by sea winds
- Lack of natural leaching due to topographic situation, especially in arid and semiarid regions
- Poor quality ground water

Definition of Problem

Salt Affected Soils

The accumulation of excess salt (neutral/alkaline) in a soil often disturbs its normal function through imbalances in physical, chemical characteristics and nutrient availability. Such soil which contains excess salts (soluble/exchangeable) that adversely affect plant growth and crop yield is called a salt affected soil. Soil characteristics viz, soluble salts content and soil reaction (pH) largely influence the changes in physical and chemical properties in a salt affected soil. These soils are known as *Kallar* or *Thur* in Punjab and Haryana, *Usar* or *Reh* in Uttar Pradesh, *Luni* in Rajasthan, *khar* or *Kshar* in Gujarat and Maharashtra, *Chhouddu* or *Uppu* in Andhra Pradesh, *Choppan* in Karnataka etc. The presence of excess neutral salt essentially influences solute transport and non-availability of some essential nutrients required for plant growth. Similarly, alkaline salts facilitate increase of pH level that indirectly causes dispersion of soil particles and hence the soil loses its physical condition. Salt related properties are usually dynamic in nature and often subject to rapid changes with respect to time. To facilitate soil management and the influence of salts, salt affected soils are broadly categorized as saline or alkali.

Saline soils: These soils are occurring as patches with white salt encrustation on the soil surface located in the lower topographic position. Due high salt content, high osmotic pressure and ion toxicity these soils do not support normal agriculture. Often, these soils are located in the irrigated region associated with waterlogging condition. The soil salinity is also developed by the presence of saline ground water used for irrigation purpose in the arid and semiarid region. In the sea coast, large areas are subjected to saline water inundation that is affecting the root zone with high to very high soil salinity. The analytical data of laboratory analysis showed the presence of neutral salts such as chlorides and sulfates of sodium, calcium and magnesium higher than the prescribed limit. The pH_s of the saturation paste normally lies below 8.2 and the electrical conductivity usually exceeds 4 dS/m at 25^{o}C. These soils normally have higher (>15) sodium adsorption ratio (SAR).

Alkali soils: In the field, these soils are usually associated with bleached color, strong blocky structure, presence of mottles of iron and manganese, concretions/nodules of calcium and magnesium, presence of an illuvial fine textures layer dominated by silt/clay at a depth below the surface, and shows moderate to strong/violent effervescence following addition of dilute hydrochloric acid and changes to pink color following application of phenolphthalein indicator. Due to high soil reaction (pH_s >8.2), these soils adversely affect plant growth and crop yield. The primary limitations are poor (dispersed) soil physical condition and inadequate internal drainage that cause imbalance of nutrient availability. The laboratory investigations showed high (>15) exchangeable sodium percentage (ESP) and dominance of soluble ions such as carbonate, bicarbonate of sodium, calcium and magnesium. Due to high sodium content these soils also showed high SAR.

Waterlogged soils: A soil is called waterlogged when the soil moisture content increases to an extent that saturates soil pores in the root zone of a crop resulting in decline of oxygen level and increase in the carbon-di-oxide content. In the field, the water table depth is considered as criteria for deciding a soil as waterlogged or not. It may vary from zero for rice, 1.5 m for arable crops and more than 2.0 m for horticultural crops and forest plantations. For all practical purposes, the working group constituted by the Ministry of Water Resources, New Delhi has suggested the following criteria for various categories of waterlogged area

Depth of water from the soil surface (m)	Suggested nomenclature
<2	Waterlogged
2-3	Potentially waterlogged
>3	Safe

In the field, waterlogged areas appears in two forms viz, surface ponding and high table condition. Surface ponding occurs due to high water stagnation on the soil surface as a result of inadequate natural surface drainage. It usually happens during monsoon season under high rainfall condition when water stagnates in the low-lying areas or the depressions underlain by impermeable fine textured or *kankar* layers. The high water table condition appears in the irrigated areas with restricted drainage condition that facilitates imbalance between the recharge to the ground water and discharge to the natural out flow. As a result a perched water table is formed that rises with the continued irrigation in crops and disturb soil condition in the root zone.

Formation and Genesis

Indo-Gangetic Plain: The largest area (about 2.5 M ha) under salt affected soils lies in the Indo-Gangetic Plain covering Uttar Pradesh, Haryana, Punjab, Bihar and West Bengal. The soils in this region are commonly sodic except a few pockets which are saline in nature. The occurrence of a zone of calcium carbonate nodules at a depth of 1 m is a common feature; in places it forms an indurated layer. Some times, a shallow calcic horizon (50 cm) is available in areas suffering from excessive erosion or accumulation of dolomitic material at shallow depth formed due to inadequate leaching. The presence of such horizon reduces root growth and has low nutrient reserve and water storage capacity. Besides, alkali soils are also found with saline and sodic ground water in the rainfall zone of 500-700 mm covering Punjab, Haryana and Uttar Pradesh. A shallow saline or sodic ground water when rises close to the surface further aggravate the saline/sodic condition.

Arid and Semiarid Region: These soils occur in the rainfall zone of 300-500 mm covering Rajasthan and Gujarat and its adjoining states. The main soluble anions are chlorides and sulfates, though bicarbonates are also found in some cases. The poor quality ground water imposes another constraint in this regard. Saline and sodic soils are also found in areas where medium to deep black soils (Vertisols) are distributed in parts of Madhya Pradesh, Rajasthan, Andhra Pradesh, Gujarat and Karnataka. Due to low rainfall, lack of good quality irrigation water and absence of adequate leaching, the reclamation of such soils is difficult. Salinization and alkalization are secondary processes initiated with the rising water table subsequent to introduction of canal irrigation on Vertisols which lack adequate internal drainage. Montmorillonitic (smectitic) clay minerals and high clay content impart unfavorable physical condition for sustained crop growth. In the deltas of the Godavari, Krishna and along the Saurashtra cost in Gujarat, saline Vertisols are prevailing with shallow ground water mostly within 1 m depth. In general, these soils contain neutral salts with traces of bicarbonates. These soils with similar characteristics as inland black soils also pose similar problem for agriculture. The operating marine and delta cycles further aggravate the salinity conditions. Saline soils are also located in the great Rann of Kachchh that constitutes vast saline marsh and contain variety of saline soils. The process of accretion is continuing and textural stratification is interspersed with layers of gypsum, calcium carbonate and iron oxide enabling a separate classification unit.

Coastal and Deltaic Region under Humid and Subhumid Condition: The deep micaceous, fine textured soils of the Gangetic delta commonly occurring in the humid subtropical climate region are variable and saline in nature, underlain with a poor quality shallow water table. These soils contain neutral salts originated from the saline substratum and saline water inundation during marine cycles and also during the origin of delta. These soils have an *ocric* epipedon, yellowish brown mottles, uniformly fine texture ranging from silty clay to clay loam, neutral to acidic pH (Bhargava and Bhattachrjee, 1982). The soils showed maximum accumulation of salts at the surface and showed dominance of chlorides and sulfates of sodium, magnesium and calcium with minor quantities of bicarbonate.

In the Malabar Coast, saline soils are found under marshy condition and are rich in humus. These soils undergo freshwater submergence as well as sea water inundation under tidal cycles. The salient features are bleached horizon, humic horizon in the substratum, gleying, reduction and bleaching in the soil matrix, high EC, acidic pH, high to very high organic matter content and a shallow saline ground water. The pyrites commonly occurs in this region and the differences in pH from 3.5 to 7.5 may be ascribed due to the presence of pyritous clay.

Genesis

Studies conducted in the sodic soils in the Indo-Gangetic Plain showed that the salts are released from the piedmont zone near Siwalik hill through alkaline hydrolysis during the weathering of aluminosilicate minerals and accumulated in micro depressions. The occurrence of smectite, chlorite and vermiculite in association with the dominant mineral illite has been reported in the Indo-Gangetic Plain. Sodic environment favors degradation of aluminosilicate minerals resulting in accumulation of amorphous silica, alumina, potassium and iron. The weathering of mica present in these soils yields finer constituents of clay which preferentially moves downwards in deflocculated form and gives rise to an illuvial B horizon. The sand fraction showed a dominance of quartz and feldspars in association with white mica, biotite and other accessory minerals. According to Kovda (1947), the main carrier of salts in the ecosystem is water - its surface flow as well as the effect of rising ground water. The accumulation is more pronounced on lower part of the slope because the salt balance of the territory is influenced strongly by surface flow and also by leaching. The accumulation of soluble salts is directly proportional to the intensity of the weathering processes and inversely proportional to the intensity of leaching (Fig.3.1). According to Szabolcs (1989), the type of climate influences the geochemical processes of salt accumulation, more intense in the arid than the humid climate. Some of the salts are formed in situ as weathering products of rocks and minerals and some are transported by water and wind, etc and accumulate in the lower horizons of soil and the surface and ground water. Besides aridity index, the seasonal dynamics of salts in soils and underground waters are also responsible to a great extent for the diverse properties and global distribution of salt affected soils in different climatic conditions (Fig.3.2). Among the rocks, basalt is the common base rock found in the alkali soil zone under tropical, subtropical and moderate climatic conditions. Similarly, the enrichment of soda-saline soils with montmorillonite or smectite (black soils) takes place due to metamorphism of clay minerals in the alkaline medium and release of silica that leaches in the ground waters.

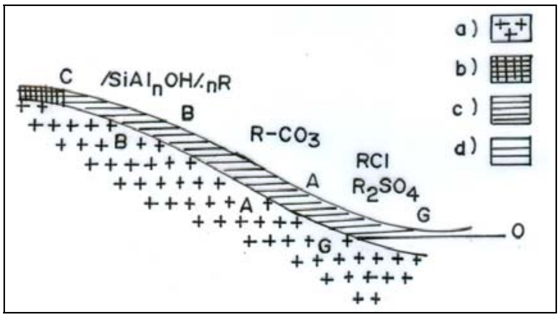

Fig. 3.1. Distribution of continental sediments: a) massive primary rock b) allitic eluviate c) eluvial overlaying layer d) level of ground water G-O = level of catchment, AA-GG = region of sulfate-chloridic, BB-AA = region of carbonate accumulation, C – BB = region of siallitic type of accumulation

(Source: Kovda 1947)

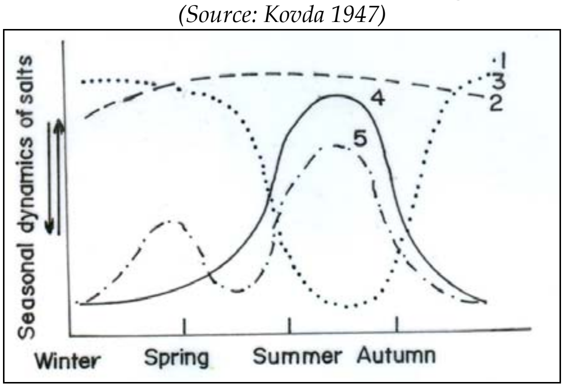

Fig. 3.2. Seasonal dynamics of salts in the soils depending on the type of climate: (1) continental tropical (2) continental subtropical (3) monsoon tropical and subtropical (4) Mediterranean and continental sub-boreal with a mild winter, (5) continental boreal and sub-boreal with a frosty winter

(Source: Kovda, 1947)

Criteria for Diagnosis and Assessment of Degree of Problem

A proper diagnosis is required for effective management and reclamation of salt affected soils. Two methods are in general used for diagnosis of salt affected soils. One is performed in the field and other is done in the laboratory. The most important observation in the field is thick salt efflorescence, barrenness and prolonged stagnation of water following irrigation or heavy rainfall. This is due to dispersed soil condition that creates unfavorable soil structure restricting leaching and permeability. Upon drying, these soils develop 1-2 cm wide cracks. Some of the prominent indicator of soil salinization/alkalization is the presence of light color of the soil profile and dark patches in the subsurface layer due to accumulation of iron and manganese mottles and the presence of kankar (calcium carbonate) layer at depth below the soil surface. In the field, the changes in the color of phenolphthalein indicator from colorless to pink on a wet soil surface is a useful indicator for diagnosis of moderate to high sodic (alkali) problem. Further, the application of dilute hydrochloric acid on a soil surface that released carbon-di-oxide as effervescence from the calcareous (calcium carbonate) soil surface is also an important indicator for existence of sodic condition in the field. .

Besides, the patchy and stunted growth of crop along with scorching and leaf burn is typical indicator of sodium toxicity while the yellowing of leaves is due to poor physical condition. In extreme cases soil remain barren with little or no vegetation. Many times alkali soils are found with varying crop growth condition depending on the degree of the problem. In such cases, these soils are categorized as slight, moderate and strongly affected soils. In some cases, natural occurrence of some salt tolerant grasses is also considered as indicators of salinity/alkalinity condition. The dark color with high clay content, wide cracks, gilgai, absence of clear horizon boundaries and intermixing of soil particles for churning processes and the presence of calcium carbonate nodules is typically indicators of a salt affected black soil.

Determination of Salinity and Sodicity Status

Two techniques, viz, morphological and physico-chemical characteristics of soils are used to assess the salinity or sodicity status of salt affected soil. During morphological investigations, field survey is conducted to know the nature, extent and distribution of the problem. The characteristics of the landscape, slope percentage, elevation, slope direction, landform, land use and other locational information are collected during the survey. Soil samples are collected from auger bores and the water samples from open dug well or tube well or deep boring. In the field, indicators of salt crust, presence of salt tolerant plants, growth and vigor of arable crops, waterlogging condition, irrigation infrastructure, depth of ground water are visualized prior to selection of an area for collecting a soil profile. A soil profile approximately 5′x 5′ x 5′ size is excavated to examine the surface and subsurface soil condition including texture, structure, color, porosity, drainage, permeability, parent material, moisture status, salinity/alkalinity, presence of pans, concretions, root development, lime nodules, cutans etc. The diagnostic layers called soil horizons are primarily identified through preliminary investigations for morphological parameters such as texture, structure, color and consistency. In most of the cases, salt affected soils are deep to very deep in the Gangetic Plain and the black soil region. In the field, soil texture is determined by feel method in which a paste is prepared with a certain amount of soils mixed with minimum quantity of water and pressed with thumbs to prepare a ribbon. The ability of the ribbon to hold finger pressure determines the composition of the soil particles and soil texture. A clayey soil sticks more to the finger than a sandy or loamy soil. Similarly, the stickiness and plasticity of the ribbon determines the consistency of a soil. The structure of a soil is defined by the arrangement of soil particles to present a size or class, type or form and grade or distinctness. The size varies from fine to coarse while grade ranges from weak to strong and type varies from platy to massive. The salt affected soils are moderately coarse textured in the alluvial region and fine to very fine textured in the black soil region. The structure varies from granular in the sandy tract of Rajasthan, to blocky, columnar or platy type depending on the composition of the parent material and the environmental condition. The alluvial soils are lighter color at the surface and darker in the subsurface layers. Where textural B horizon is present, the content of finer clay is higher than the overlying/underlying horizon. Due to illuvial operation coupled with imperfect drainage and dispersed soil condition, the precipitation of reduced forms of iron and manganese take place. As the pH of the soil rises to alkaline side, the precipitation of calcium takes place as carbonate which is sparingly soluble in water. Most often, layer of calcium carbonate is found either as concretions or nodules depending on the maturity of its development. Due to adverse physical condition these soils are hard to very hard on drying. It lacks adequate macro- and micro-pores for aeration and nutrient mobilization. In a well developed salt affected soil, clay cutans are found and detected with a hand lens. In clay cutans, the finer clay particles enter the macro- and micro- pores and hence block the passage of water and air. In the field, the intensity of pink color developed on addition of phenolphthalein indicator is used for detecting the extent of alkalinity in soil. A portable EC_e meter is used to know the salinity condition in the field. During soil profile studies, based on the diagnostic characteristics, the soil horizons are identified and demarcated. Soil samples are collected form the horizons or layers and brought to the laboratory for physico-chemical characterization. For quantitative assessment of alkalinity and salinity status, the pH of saturated soil paste and the ECe of saturation extract are measured in the laboratory. The exchangeable sodium content and cation exchange capacity is determined to know the exchangeable sodium percentage.

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Genesis, Characteristics and Classification of Sodic Vertisols in India

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Vertisols is one of the important soil orders in the Soil Taxonomy. Vertisols are churning heavy clay soils with a high proportion of swelling clays. These soils form deep wide cracks from the surface downward when they dry out, which happens in most years. These soils have a vertic horizon within 100 cm from the soil surface; possess 30 per cent or more clay in all horizons to a depth of 100 cm or more and possess cracks which open periodically.

Vertisols are dark montmorillonite-rich clays with characteristic shrinking/swelling properties. A few, however, have mixed or even kaolinitic mineralogy. Soils with smectitic mineralogy, unlike other soils, show high swell-shrink potential resulting in different morphometric configuration in profiles. Since the phenomenon is concomitant to the volume changes of the soil mass with the changes in soil moisture content, these soils impose a distinct problem in their management. As a result of wetting and drying, expansion and contraction of the clay minerals take place. Contraction leads to the formation of the wide and deep cracks. The cracks close after rain when the clay minerals swell. During expansion of the clay minerals high pressures are developed within these soils, causing a characteristic soil structure with wedge-shaped aggregates in the surface soil and planar soil blocks in the subsoil.

Shrinking-swelling (SS) is the main pedogenic process in Vertisols responsible for their genesis, behavior and properties. The term "swell-shrink soils" is used for describing such soils which have characteristics of shrinking when dry and swelling when wet. Repeated SS impacts the vertical and lateral (spatial) distribution of all physical and chemical properties including soil organic matter (SOM). SS is responsible for the formation of deep and large cracks, vertical sequence of structures (from granular through massive to wedge-shaped), slickensides, microrelief, and complex soil cover in Vertisols areas including subsurface cycling. All these attributes together determine the specificity of SOM properties and distribution in Vertisols. The swell-shrink properties of these soils pose special problems for their management and optimum utilization.

The Vertisols make up a relatively homogeneous order in a morphologic sense. Nevertheless, variations in moisture regimes and in the related soil colours are wide. There are also differences in base saturation, percentage of carbonates and depth to a lithic or parallithic contact. On sodification, these soils are coined as kharland or black alkali soils and taxonomically coined as Sodic Vertisols.

Extent and Distribution

Vertisols cover a total of about 340 M ha in the world. Most Vertisols occur in the semiarid tropics, mainly in Africa (the Gezira and other part of central Sudan, South Africa, Ethiopia and Tanzania), Asia (the Deccan plateau of India), America (mostly in USA, Venezuela and Argentina), and Australia. Vertisols and associated black soils occur in Peninsular India between 8º45′ to 26º N latitude and 66º and 83º 45′ E longitude and occupy about 76.4 M ha area (Murthy *et al.*, 1982) which is 23.2% of the total geographical area of the country (Table 4.1). These swell-shrink soils are distributed mainly in the states of Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu, Rajasthan and to some extent in Orissa and Bihar.

These soils are cultivated mainly with sorghum, pearl millet, cotton, pigeon pea, groundnut, chick pea, and at places with wheat and soybean under rain fed conditions. Major area under these soils is cultivated with *kharif* (July-September) crops while some area receiving winter rains (October-December) is cultivated with *rabi* crops. Rice and sugarcane cropping is also practiced where irrigation facility is available. The yields of crops grown on these soils under the rainfed condition are comparatively low but there is a great potential to increase the same. One of the reasons of low agricultural productivity in the black soils region is the unreliability of rainfall. Whenever irrigation is provided, cultivators have reaped rich harvest but in long run problems of salinity and sodicity do crop up and these soils have become saline and/or sodic. The problem of water stagnation and moisture stress are common features of the Vertisols of the semi-arid regions which further intensify on sodification. Thus, crop suffers badly due to oxygen stress in the initial stage and moisture stress after the termination of monsoon or delay in irrigation.

Table 4.1. Distribution of Vertisols and associated black soils in India

S. No.	State	Area (M ha)	Per cent of total black soil area of the country	Per cent of total geographical area of country
1	Maharashtra	29.9	39.1	9.1
2	Madhya Pradesh	16.7	22.0	5.0
3	Gujarat	8.2	10.7	2.5
4	Andhra Pradesh	7.2	9.4	2.2
5	Karnataka	6.9	9.0	2.1
6	Tamil Nadu	3.2	4.2	1.0
7	Rajasthan	2.3	3.0	0.7
8	Orissa	1.3	1.7	0.4
9	Bihar	0.7	0.9	0.2
	Total	76.4	100.0	23.2

(Source: Murthy et al., 1982)

Mapping of salt affected soils of India by the NRSA and Associates, (1996) indicated occurrence of about 3.77 M ha of sodic soils in India, out of which about 1.77 M ha represents the sodic nature among the irrigated/unirrigated black soil region (Vertisols) occurring in Gujarat, Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka, Rajasthanand Tamil Nadu States.

In south Gujarat (Bharuch, Surat, Valsad and Navsari districts) sodic soils occupy about 55,000 ha area. Typical soil profile characteristics of sodic Vertisols from Bharuch district is given in Table 4.2. In Ukai-Kakrapar command area about 40% of soils are affected by sodicity problem (Patel *et al.*, 2000). Paddy and sugarcane are the prominent crops in this command area due to availability of perennial irrigation facility and productivity of these crops is declining due to salinity/sodicity and waterlogging problems (Rana and Raman, 1999).

Table 4.2. Properties of Sodic Haplusterts at village Sadathala, district Bharuch (Gujarat)

Horizon	Depth (m)	Sand (%)	Silt (%)	Clay (%)	WHC (%)	CEC (cmol/kg)	ESP	$CaCO_3$ (%)	OC (%)
Ap	0.00-0.21	13.3	17.4	69.3	58.1	49.5	19.0	9.9	0.35
Bw1n	0.21-0.53	10.0	18.0	72.0	69.2	50.3	30.2	9.7	0.39
Bss1n	0.53-0.96	7.4	16.8	75.8	72.1	44.0	26.2	11.3	0.41
Bss2n	0.96-1.32	9.0	15.0	76.0	83.2	35.5	26.5	13.1	0.39
BC	1.32-1.70	15.0	25.0	60.0	70.0	46.6	29.4	19.8	0.43

WHC: Water holding capacity; CEC: Cation exchange capacity; OC: Organic carbon

Depth (m)	pH	EC_e (dS/m)	Extractable cations (meq/l)				Extractable anions (meq/l)			SAR $(meq/l)^{1/2}$
			Ca	Mg	Na	K	Cl	CO_3+HCO_3	SO_4	
0.00-0.21	9.1	1.6	4.0	2.7	8.6	0.1	10.0	2.0	3.2	4.7
0.21-0.53	9.1	1.9	4.0	2.3	8.7	0.1	13.0	2.0	1.0	4.9
0.53-0.96	8.5	4.1	3.0	3.3	30.4	0.1	31.0	2.0	3.0	17.1
0.96-1.32	8.4	10.9	7.0	6.5	76.1	0.4	75.0	2.5	13.0	26.0
1.32-1.70	8.5	11.6	10.0	7.1	152.0	0.2	156.0	1.5	11.5	58.6

Soil Formation/Genesis

The soil forming factors i.e. parent material, climate, topography, vegetation and time, established by Docuchaev are still the best element to comprehend the formation of Vertisols. These soil forming factors are interdependent and highly variable. They influence the property of Vertisols in many ways. The difference in the intensity of processes as conditioned by each of these factors within and among the regions is responsible for the global diversity in Vertisols. Each of the factors among them is described with the focus on the responsible for inducing sodicity in Vertisols.

Parent material: The parent materials provide, from inheritance of weathering, a high content of clay with high surface area and generally a high base status. The distinction between inherited and neo-formed clay minerals is still speculative, especially in the case of sedimentary deposits. A high base status favours formation and stability of clay minerals abundant in Vertisols. However, the base status may be relatively low in certain types of parent materials. With time the base status may increase due to release of bases from weathering and /or from external source e.g. leaching from upland, flood waters, base rich water tables or aeolian deposits. Weathering of sodium feldspar and/or base rich water tables are the causes for the development of sodic Vertisols in India.

Climate: The pedo-climatic environment supporting Vertisols vary from the semiarid to the sub-humid tropic in India. Such climates are characterised by hot and dry pre-monsoon summer months (March to May) followed by well expressed summer monsoon months (June to September). The subsequent short period of October and November receives uncertain and infrequent showers followed by fairly dry mild winter (December to February). The mean annual (air) temperature ranges from 24 to 27^{o} C. The mean summer (April, May & June) and mean winter (December, January & February) temperature vary respectively from 30 to 33^{o} C and from 15 to 22^{o} C. The mean annual rainfall ranges from 500 to 1500 mm, of which 80 to 90 per cent is received during monsoon months. It represents 42 to 77 per cent of mean annual potential evapotranspiration (PET). The soil moisture control section remains dry either completely or in part for 4 to 8 months in a year, suggesting an Ustic moisture regime. Periodicity, duration, intensity of rainfall events or other hydrological events such as runoff, surface run-in, and fluctuation of groundwater table or flooding may influence Vertisols formations. Surface run-in, fluctuation of base rich groundwater and flooding are the factors inducing sodicity in Vertisols.

Topography: Vertisols occur normally on the lower elements of the topography, comprising gently undulating, gently sloping to nearly level piedmont, flood and coastal plains and favours the accumulation of silica, thus promoting the formation of chemical equilibrium of smectites. Such soils are likely to have a high CEC and smectitic mineralogy. The associated Vertic intergrades are observed normally on relatively higher elements of the topography, comprising gently sloping to moderately steep subdued plateau, mesa and pediment surfaces. Micro-topography may also cause for formation of sodic Vertisols by modifying distribution of water across the landscape.

Genesis of Sodic Vertisols

This issue is discussed in the light of sodic Vertisols formed at Purna valley in Central India (Pal, 2004). The chemical degradation of the soils of the Purna Valley in terms of increase in ESP and/or EMP (exchangeable magnesium percentage) with depth has adversely affected the hydraulic and other properties important for crop growth. The general increase of both coefficient of linear extensibility (COLE) and water dispersible clay (WDC) and the decrease of saturated hydraulic conductivity (HC) with depth suggest that the swelling of clay smectite, together with dispersion of the clay, have adversely affected the hydraulic properties of these soils. The observed correlation between WDC and EMP indicates that saturation of these soils, not only with Na^{+} ions but also with Mg^{2+} ions leads to greater dispersion of the clay, which is the opposite effect from that of saturation with Ca^{2+} ions, which leads to the blocking of small pores in the soil. Recent work by Kadu *et al.*, (1993) clearly shows that an HC of 1.0 mm/hr represents the lower limit for a satisfactory physical condition in these highly smectitic soils in which magnesium behaves negatively.

The absence of carbonate ions in the saturation extract suggests that during high evaporative demand for soil-water in the semiarid climatic conditions, maintenance of a proper Ca/Mg ratio in the soil solution becomes difficult because Ca^{2+} ions get precipitated as $CaCO_3$ resulting in an increase in the SAR of the soil solution and the ESP of the soil. Although the correlation between carbonate clay and SAR was not significant, the HCO_3/Ca ratio of the saturation extract has a significant positive correlation with SAR (r = 0.57 at the 1%) (Balpande *et al.*, 1996). This suggests that if this ratio increases, then SAR will also increase and as will the ESP. The mean monthly temperature is higher in the western region throughout the year by 0.2-1.1^{o}C. Akola receives less rainfall than Amravati in almost all months, with the total annual rainfall being 100 mm less at Akola. This indicates that the Akola region is more arid than Amravati, and this appears to be most important factor in the development of sodicity in soils in the southwestern part of the valley.

Formation of Vertisols

Vertisols form under multiple genetic pathways which are complex. In general, soil forming processes that lead to the formation of Vertisols are those which control the formation and stability of smectites in the soil. However, subsidiary processes, such as fluctuations in the moisture status, accumulation of organic matter, carbonates, gypsum or soluble salts and acidification processes through leaching result in the differences within the Vertisols.

The development of Vertisols requires conditions that ensure the formation and preservation of smectites. These clay minerals may form either in-situ through the weathering and development of a solum (autochtonous Vertisols) or from a sediment which is composed of materials that can produce vertic properties (allochtonous Vertisols). The latter is geographically more extensive and occupies the lower parts of the landscape. The development of smectitic clays is favored by a high pH with sufficient Ca^{2+} and Mg^{2+} in the soil system. The presence of a relatively impermeable layer at some depth within the soil prevents the leaching of the various components needed to form smectites.

Shrinking and swelling causes shearing and as aresult slickensides are formed. This process is attributed to smectitic clays and alternations in dry and wet seasons. As a result of this process, Vertisols develop deep and wide cracks in a polygonal pattern.

Pedoturbation (churning) is a process which homogenizes the soil profile due to the infilling of the cracks by surficial material during dry season. The process in Vertisols is also called self-mulching or self-swallowing.

During the drying cycles, cracks develop, whereas on moistening, shear stresses form which result in the formation of slickensides and/or smoothened surface of sphenoids. Both features require the material to be in a plastic state. The lateral pressures developed in these soils are much greater than the vertical swelling pressures. Within the soil, the vertical component of the swelling pressures includes the weight of the overlying material. The moisture conditions above and below a point within the soil determines the net pressure and angle of shear. As such, the near surface horizon develops cracks and may have only a few slickensides since both the horizontal and vertical pressures are small (the net pressure being much lower than the sheat strength of the material). In deeper horizons, typically from 50 to about 125 cm below the surface, slickensides development is maximum. In these deeper layers, the net pressure is much greater than the shear strength of the material and soil movement occurs with swelling. Sphenoids develop as a result of the existence of much lower vertical and horizontal pressures in comparison to that needed for the development of slickensides. In the typical case, sphenoids would be found in between the surface horizon with cracks and deeper horizons with slickensides. Their development has been related to lower clay contents, as well as smaller proportions of smectitic clays in the colloidal fractions.

Clay translocation is not phenomenal in Vertisols, nevertheless, the presence of smectitic clays has all the conditions necessary for dispersion, translocation, and accumulation in subsurface horizons in Vertisols. In some Vertisols there is some evidence of illuviated clays in the lower soil profile, which is subjected to the least amount of pedoturbation. This process tends to obliterate all evidence of the illuviation process and it is unlikely that well-defined clay skins will be preserved, instead any translocated clay is probably engulfed in the matrix and/or slickensides as a result of shrink-swell processes.

Pedogenic Models for the Formation of Vertisols

Pedoturbation Model (Self-swallowing Model): Pre-requisite for the formation of Vertisols is the presence of expanding clays (smectites). After clay formation shrink-swell processes begin to operate. During the dry season the soil cracks. While the cracks are open, surface soil material falls into them due to wind, animal acitivity, or water erosion. On rewetting the clays hydrate and expand. As expansion takes place, the cracks close, but because of the 'additional' material now present in the lower parts of the profile, a greater volume is required and the expanding material presses and slides the aggregates against each other developing slickensides.

Soil Mechanistic Model: This model is based on the failure along shear planes (slickensides) of plastic soil material when swelling pressures generated by hydration of clays exceed the shear strength of the soil material. Stress is relieved by an upward movement that is constrained by the weight of the overlying soil material, resulting in a failure shear plane that is usually inclined at 10 - 60° above the horizontal. This model does not require that surface material falls into cracks. Instead, surface material is transported upward along the slickensides to produce the micro-knolls of the gilgai-relief. Once micro-relief is established, soil processes are driven largely by small-scale variations in hydrology and microclimate, and less so by pedoturbation.

Characteristics of Vertisols

Dry Vertisols have a very hard consistence; wet Vertisols are (very) plastic and sticky. It is generally true that Vertisols are friable only over a narrow moisture range but their physical properties are greatly influenced by soluble salts and/or adsorbed sodium.

Infiltration of water in dry Vertisols with surface mulch or fine tilth is initially rapid. However, once the surface soil is thoroughly wetted and cracks have closed, the rate of water infiltration becomes almost nil. If, at this stage, the rains continue (or irrigation is prolonged), Vertisols flood readily. The highest infiltration rates are measured on Vertisols that have a considerable shrink/swell capacity, but maintain a relatively fine class of structure. Vertisols, by and large, are soils with good water holding properties. However, a large proportion of all water held between the basic crystal units; is not available to plants.

Vertisols and associated soils are heavy textured soils and have clay content varying from 40 to 70%. These soils are low in organic carbon content and are generally calcareous in nature. When these soils are irrigated, the high seepage leads to a shallow water table causing secondary salinisation or sodiumisation.

Most Vertisols have a high cation exchange capacity and a high base saturation percentage. The pH values are in the range of 6.0 to 8.0. Higher pH values (8.0-9.5) are seen in Vertisols with high ESP. Salinity in Vertisols may be inherited from the parent materials or may be caused by over-irrigation. Leaching of excess salts is hardly possible. It is possible to flush salts that have precipitated on the wall of cracks. Surface leaching of salts from the paddy fields in India was achieved by evacuating the standing water at regular intervals.

The electrolyte concentration, ESP and 2:1 swelling clay are important parameters governing the swell-shrink behaviour of saline Vertisols. In the soils with dominantly smectitic clay mineralogy, the increase in 2:1 swelling clay, pH and ESP increase the swelling potential whereas the increased electrolyte concentration of the soil solution decreases the swelling potential.

Saline Vertisols: Saline soils contains excess neutral soluble salts like chlorides and sulphate of sodium, calcium and magnesium with EC_e > 4 dS/m, pH <8.2 and ESP <15. Saline black soils due to their inherent physico-chemical properties, high clay content, low hydraulic conductivity and narrow working moisture range are very difficult to manage. Osmotic effect of salt, toxic concentration of soluble ions like Na, Cl, B and reduced availability of essential nutrients due to competitive uptake affect plant growth in this type of soil. Excess salinity in black soils results into delayed germination, poor crop stand, stunted growth and reduced yield.

Sodic Vertisols: The distinguishing characteristics of sodic soils are high ESP, EC_e <4 dS/m, pH >8.2 and presence of higher amount of carbonate and bicarbonates of sodium. Some sodic soils are also termed as saline sodic as they contain large quantity of soluble salts and EC_e >4 dS/m. In sodic soils the dominant cation on the exchange complex is sodium which disperses clay and imparts adverse soil physical conditions such as low permeability, crusting and hardening of the surface soils upon drying. Dense, slowly permeable sodic sub-soils reduce supplies of water, oxygen and nutrients necessary to obtain optimum yield (Rengasamy and Olsson, 1991). Besides, high Na content is often toxic to many plants, which exhibit poor growth and yield in these types of soils.

The critical values of ESP in sodic Vertisols depend on the electrolyte concentration of soil solution and range from 5 to 15 (Shainberg, 1984). Loveday and Pyle (1973) working on a range of soil types from two regions of Australia reported that the differences in critical ESP are due to the differences in EC of the soil solution. They put forward a critical value of ESP 8 and above which the surface soils are found to disperse. Northcote and Skene (1972) suggested that above ESP 6, the soils begin to disperse. Kadu *et al.*, (1993) reported that drainage in these soils gets completely impaired due to higher dispersion of clay even at an ESP of 5. Robinson (1971) working on Vertisols of Sudan reported highest cotton yields were associated with ESP of 8-16. The hydraulic conductivity of the sodic soils is affected by the initial swelling followed by clay dispersion (Gupta and Verma, 1984; 1985). Swelling reduces the pore size and dispersion clogs the soil pores. The sodicity increases the bulk density, which limit the root perforation. The plant cannot take up all of the water remaining in the root zone as rapidly as needed because it is held too tightly by the soil particles. Even at sufficient moisture content, the survival of crops in such soil is very difficult in the absence of sub-soil contribution due to low hydraulic conductivity and diffusivity. The hydraulic conductivity is an important property affected by the salinity and sodicity and can serve as the basis for classification for the degree of degradation. Chaudhari (2001) reported that an increase of EC from 0.5 to 5 dS/m resulted in more than threefold increase in the hydraulic conductivity irrespective of SAR. A threshold electrolyte concentration (TEC) in the soil solution is necessary for flocculation. Nayak *et al.*, (2004) reported that at EC <2 dS/m, Vertisols can be grouped as sodic if the ESP >6 and >10 in clayey and silty clay soils respectively and at EC of <4 dS/m, Vertisols can be grouped as sodic if the ESP >13 and >21 in clayey and silty clay soils respectively.

Available water capacity is greatly retarded in sodic Vertisols. Surface waterlogging gives rise to high rates of evaporation and rapid drying of the surface soil and can result in the development of hard setting or surface crusting to an extent depending on the soil texture.

Vertisols - Classification

The requirements to qualify for a Vertisol are the following:

- Clay content of at least 30% to a depth of at least 50 cm, or a lithic or paralithic contact, duripan, or a petrocalcic horizon if shallower
- Cracks that open and close periodically
- Evidence of soil movement (e.g. slickensides, wedge-shaped aggregates)
- Any soil temperature regime, except pergelic (i.e., Gelisols)
- Soil moisture regime must be erratic to allow for cracking in dry season and swelling in wet season

Six suborders are recognized in the Vertisol order. They are differentiated by aquic conditions, soil moisture regime, and on the cracking characteristics of the soil.

Aquerts: Vertisols which are subdued aquic conditions for some time in most years and show redoximorphic features are grouped as Aquerts. Because of the high clay content the permeability is slowed down and aquic conditions are likely to occur. In general, when precipitation exceeds evapotranspiration ponding may occur. Under wet soil moisture conditions iron and manganese is mobilized and reduced. The manganese may be partly responsible for the dark color of the soil profile.

Cryerts: They have a cryic soil temperature regime.

Xererts: They have a thermic, mesic, or frigid soil temperature regime. They show cracks that are open at least 60 consecutive days during the summer, but are closed at least 60 consecutive days during winter.

Torrerts: They have cracks that are closed for less than 60 consecutive days when the soil temperature at 50 cm is above 8°C.

Usterts: They have cracks that are open for at least 90 cumulative days per year. Globally, this suborder is the most extensive of the Vertisols order, encompassing the Vertisols of the tropics and monsoonal climates in Australia, India and Africa.

Uderts: They have cracks that are open less than 90 cumulative days per year and less than 60 consecutive days during the summer.

Great groups are differentiated by subsurface diagnostic horizons (e.g. salic, calcic, natric, gypsic horizons), the presence of a duripan (e.g. Duraquerts, Durixererts), organic carbon content (e.g. Humicryerts), or reaction (EC <4 dS/m and pH in 1:1 water of 5 or less in 25 cm or more within top 50 cm - e.g. Dystrusters, Dystraquerts).

Several soil moisture regimes are considered at subgroup level ranging from dry to wet conditons: Xeric (e.g. Xeric Epiaquerts), Aridic (e.g. Aridic Epiaquerts), Udic (e.g Udic Haplusterts), Ustic (e.g. Ustic Dystraquerts), and Aquic (e.g. Aquic Dystrusterts, Aquic Salitorrerts).

Shallow Vertisols are classified using the designation 'leptic' (soil with a densic, lithic, or paralithic contact within 100 cm of the mineral soil surface) or 'lithic' (e.g. Leptic Salaquerts or Lithic Haploxererts).

Vertisols which are low in clay content are differentiated as 'entic'. To meet the 'entic' designation the Vertisol must have a layer 25 cm or more thick that contains less than 27 percent clay in its fine-earth fraction and has its upper boundary within 100 cm of the mineral soil surface (e.g. Entic Salaquerts, Entic Haplotorrerts).

Soils are defined by the designation 'halic' if their salt content is high. They must meet the following criterion: throughout a layer 15 cm or thicker the electrical conductivity must be at least 15 dS/m or more (1:1 soil:water) for 6 or more months per year in 6 or more out of 10 years. Vertisols with a high sodium content are classified as 'sodic' (e.g. Sodic Haplusterts). They must have an exchangeable sodium percentage of 15 or more (or a sodium adsorption ratio of 13 or more) for 6 or more months per year in 6 or more out of 10 years.

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Geochemical Cycles influencing Origin of Poor Quality Waters

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All irrigation waters contain some dissolved salts, the type and quality of which depends on the origin of water and the course followed by it before use. The chemical nature of most surface water and ground water reflects the resultant interaction between rain and rocks near the earth's surface. Most of these interactions take place in the soil zone. Soils can be divided into two major categories on the basis of the humidity/aridity of the environment under which they develop. Where moisture remains available in sufficient amount, calcium released from primary minerals is removed in solution and soils free of calcium carbonate and usually rich in aluminium and iron develop. In semiarid or arid climates, where the moisture is available in limited amount, calcium carbonate precipitates in the soil zone and calcareous soils develop. In general, the drier the climate, the calcium carbonate concretions occur closer to the surface. Most of the soils in the states of Haryana, Punjab, Rajasthan, Uttar Pradesh, Bihar, Madhya Pradesh, Maharashtra, Karnataka, Gujarat, Andhra Pradesh and Tamil Nadu are calcareous. Non calcareous soils occur in the mountainous region of the Himalayas in the parts of Jammu and Kashmir, Himachal Pradesh, Uttaranchal, Sikkim, West Bengal, Assam, Tripura, Meghalaya and in parts of Orrisa, Chhattisgarh, Karnataka, parts of Maharashtra and Kerala states. The type of soil formed under a particular climate is strongly influenced by the nature of the bed rock; topography, vegetation and the time over which soil forming processes have operated, leaving their impact on water chemistry.

Source of Dissolved Constituents

The sources from which the dissolved constituents in surface water are derived is explained by the following mass balance equation.

Rock + Atmospheric input = Altered rock + solution

The atmospheric input consists of water, carbon dioxide, oxygen and various species dissolved in the water. The composition of rainfall is quite variable. In most natural waters, the amount of materials derived from rains is small compared to the amount derived from interaction with rocks.

Composition of Rain Water

Rain is not pure H_2O but contains a wide range of dissolved substances. Over the oceans and near coasts, the main source of dissolved material is sea salt, when waves break, fine droplets of sea water are injected into the atmosphere. The water evaporates, leaving a solid aerosol particle which is transported by winds until it is dissolved by rain. The concentration of sodium and chloride in rain water as the input of sea salts is usually high near the coast, and less far inland.

The solutes in rain in inland areas are quite different from those in the oceans. The ratios of the concentrations of calcium, magnesium, potassium, sodium, ammonium, sulphates and nitrate to that of chloride are much higher than in sea water. These constituents appear to be derived from dissolution of dust particles (especially calcium), gaseous emission from plants and soil (especially ammonium and sulphate) and industrial emissions (especially sulphate and nitrate). Burning of fossil fuels introduces large amounts of sulphur and nitrogen oxides into the atmosphere, which end up as sulphuric acid and nitric acid in rain. The concentration of rain at any one location varies greatly with time. The first drops of rain at the beginning of storm may contain most of the soluble material available in the atmosphere; rain toward the end of storm is relatively dilute.

The chemistry of rainwater undergoes drastic changes as it comes in contact with the earth's surface. Even before it reaches the ground, rain may pickup solutes from plants and much of its acidity may be neutralized. As water passes through the soil zone it acquires solutes from dissolution or partial dissolution of minerals and some solutes (notably nitrogen compounds and phosphates) are extracted from the water by plants. The organisms of the soil release soluble organic compounds in the water and these compounds accelerate the breakdown of minerals. When there is no rainfall, evapotranspiration removes essentially pure water from the soil, so that any solutes in the water, either brought in by rain or dissolved from the soil minerals, tend to build-up in concentration and may even precipitate as solid phases.

Environmental Factors Affecting Water Quality

Although it is difficult to evolve a thumb rule and draw standard generalization about the effect of various environmental factors influencing water chemistry, the most commonly observed phenomenon are described below.

Rock Type: Waters draining igneous and metamorphic rocks are relatively dilute (TDS often less than 100mg/l), and have bicarbonate as the major anion and sodium and calcium as the major cations. Basic rocks (basalt, gabbro, amphibolite) tend to produce more concentrated waters with higher Ca/Na and Mg/Ca ratios than acidic rocks (granite, rhyolite). In very dilute waters from igneous rocks the contribution of solutes from the atmosphere may be as large as the contribution from the rock weathering. In such waters the solutes derived from rock weathering often have high Ca/ Na ratios and high Ca/ SiO_2 ratios.

Water draining limestones and dolomites often have calcium, magnesium, and bicarbonate as the only significant solutes, although sulphate is commonly present from pyrite oxidation or associated gypsum. The following transformation of pyrite takes place.

$FeS + 3.75\ O_2 + 3.5\ H_2O = Fe\ (OH)_3 + 4\ H+ + 2\ SO_4$
$4\ H^+ + 2\ CaCO_3 = 2\ Ca_2^+ + 2H_2CO_3$

The TDS are limited by the solubility of the carbonate minerals in water which has been enriched in CO_2 from the soil zone. TDS values generally vary between 100 and 600 mg/l. Limestones weather more rapidly than igneous rocks, so that, on average waters draining limestones are more concentrated than those draining igneous rocks. In natural waters, the CO_2 concentration is small compared to the HCO_3 concentration. It is only in unusual high RSC waters that pH values above 9 are encountered.

Shales commonly contain pyrite, which contributes sulphate to solution after oxidation and calcite contributes calcium as a result of dissolution. Waters draining shales often contain chloride and sodium and are highly variable in composition. They usually have sulphates or chloride as major anions and lower silica/total cation ratios than waters draining igneous rocks. The TDS values remain highly variable.

The "evaporites" or weathering products accumulating on the surface by simple solution and give rise to waters of very high salinity in arid climates. Typically the principal anions are sulphate and/ or chloride and the principal cations are sodium and calcium. In arid climates saline waters resulting from solution of evaporites are quite common.

Relief: With increasing relief, the rate of chemical weathering is generally believed to increase primarily due to increased physical erosion, which exposes fresh rock to weathering. But it is difficult to evaluate the contribution of relief alone, because with it often remain closely related difference in rock types, climate and vegetation.

Climate: As rainfall increases, the TDS of runoff waters decreases, but the total mass of dissolved solids carried off per unit time increases. In general, as the rainfall decreases, the time of contact between water and rock increases and evaporation becomes more significant. Temperature appears to be less important than other variable, provided that liquid water is present. Weathering reactions are more rapid at higher temperatures, but this is offset in many environments by the fact that physical erosion, which exposes fresh bed rock, is more rapid at lower temperatures or at higher elevations, which correspond to lower temperatures.

Vegetation: The effect of vegetation is complex, and is not independent of climate, rock type and relief. Vegetation supplies CO_2 and organic acids to the soil, which increases the rate of chemical weathering. On the other hand vegetation stabilizes the soil and prevents physical erosion. Fresh rock is than not exposed at the surface, there is less contact between rainwater and fresh rock and the rate of chemical weathering is decreased.

Time: Time, in the sense of time of contact between rock and water is the most important variable in determining the chemistry of run off from igneous rock, but contact time is itself a function of other environmental parameters. High rainfall leads to rapid fluxing of water and short contact time. Local drainage is also important; well drained areas have short contact times and tend to have more weathered kaolinitic, where as poorly drained areas have longer contact times and tend to have smectitic clay minerals. If the permeability is high, contact time in the weathering zone may be short because the water drains rapidly, and may be short or long in the ground water system, depending on local hydrology.

By stabilizing the soil, vegetation has the effect of increasing the contact time of initial weathering of the products with incoming rain water. Thus forested areas tend to have kaolinite in the soil. Even if a smectite was initially formed it will be leached to kaolinite in the soil. Vegetation also plays a more active role, particularly in creating an acid microenvironment around rootlets. In the absence of vegetation, an initially formed smectite would probably have been eroded before it could be weathered to kaolinite.

Waters in limestone aquifer generally have Ca and HCO_3 as the major dissolved species, and are generally close to equilibrium with calcite. The Ca concentration (and TDS) depends on the pCO_2 of the water, which is generally controlled by the soil atmosphere in the recharge area. The main exceptions to these generalizations are waters in deeper aquifers, which have received solutes by mixing with waters from other sources, or which have received solutes by dissolution of gypsum or halite.

Surface Water: The amount and nature of salts present in surface waters is influenced by the rocks present at the water source, the nature of the soil over which the water flows and the climate of the area. The predominant ions present in river water are bicarbonate, sulphate, sodium, calcium and magnesium.

Ground Water: The salt content of ground water depends on the source of the water and the course over which it flows. Mineralization of ground water is governed by laws of dissolution. Changes in the salt content of ground water in the recharge process result from reduction, base exchange medium, transpiration, evaporation and precipitation. While the ground water is flowing, the soil acts as an ion exchange and cations in the water reach equilibrium with the soil cations. The general salt content increase is due to evapotranspiration or dissolution and is mostly affected by climate. While deep ground water tables as a rule do not have seasonal fluctuations in salt content, the salt content of high (shallow) ground water table changes as a function of evaporation, rainfall, drainage and irrigation practices.

Irrigation Water – Soil – Interaction/Dilution: Typical concentrations of the best river water vary between 0.2 and 0.5 g/l. Irrigation with such water causes very strong dilution of concentrated soil solutions. Even brackish irrigation water with 2 to 5 g/l is several times less concentrated than the saline soils solution. If the downward flow of irrigation water is maintained, even a relatively high concentration of salts in applied water remains harmless to arable plants.

Dissolution and Precipitation: In any soil there exists a sort of mobile equilibrium between components dissolved in the soil solutions and the components deposited in the form of crystallized salts. The less soluble compounds are calcium carbonate, calcium sulphate and to some extent sodium sulphate. The fresher the irrigation water, the stronger is its capacity to dissolve these deposits. Irrigation water, very fresh and even acidic owing to the presence of CO_2 can dissolve calcium carbonate, transforming it into calcium bicarbonate. Some gypsum and sodium sulphate is also similarly dissolved.

Changes in Absorbed Cations: When sodium carbonate and bicarbonate are present in the irrigated soil pronounced soil alkalization results. If the irrigation water contains more CO_3 and HCO_3 than Ca^{2+} and Mg^{2+}, than after evaporation and plant uptake calcium and magnesium precipitates as carbonates, the residue of CO_3 being Na_2CO_3.

According to Fersman, the geochemistry of salts on land is based on the solution and extraction of the ions from minerals in the course of weathering, followed by their precipitation and accumulation under specific physico-geographical conditions. The sequence of extraction of the ions, their speed of migration and the capacity of some ions to accumulate in endoreic inland depressions in the form of salt masses are proportional to the coefficient of energy of the ions, the ionic radius, the valency, and the stability of the crystal network of the compound.

The mobility of the compounds formed and the amounts in which they accumulate in the form of salts increases with the decrease of the coefficient of energy of the ions and salts, and the decrease of the ionic radius and valency.

It follows that chlorides, nitrates, sulphates and carbonates of alkalis and, in some degree, of alkali-earths inevitably are the main salts which form in the weathering crust and salinise endoreic areas. The processes of precipitation and accumulation of the salts occur in reverse order. The longest to remain in solutions (of marine, ground and underground waters) are the ions with the lowest coefficient of energy (i.e. monovalent and bivalent cations and monovalent anions).

These components play the main role in the formation of salts accumulating in soils and waters. Polynov and Kovda have divided the elements into the categories shown in Table 5.1 according to their mobility during weathering and their migration capacity.

Table 5.1. Migration categories (mobility) of elements

Virtually non-leachable	Si of quartz
Slightly leachable	Fe, Al, Si
Leachable	Si, P, Mn
Highly leachable	Ca, Na, K, Mg, Cu, Co, Zn
Very highly leachable	Cl, Br, I, S, C, B

Both the absolute and the relative participation of elements in the formation of saline soils and natural waters is greater, the higher the migration category of the element. Elements of the fourth and fifth migration categories constitute the main compounds contributing to contemporary salt accumulation either in natural waters or in soils.

The characteristics of an irrigation water to assess its quality for irrigation necessitate its evaluation for (i) total salt concentration, (ii) proportion of sodium to other cations (iii) concentration of boron, fluoride and nitrate and (iv) concentration of bicarbonate relative to concentration of calcium plus magnesium.

As the ground water moves along its flow paths, increase in total dissolved solids and several of the ions listed in fourth and fifth categories (Table 5.1) takes place. In general the shallow ground waters in recharge areas have lower dissolved solids than the waters occurring at deeper depths.

Some studies have revealed that ground water tends to evolve chemically toward the composition of sea water. This evolution normally takes place following regional changes in dominant anion species indicated below.

Ground water flow path – HCO_3 – $HCO_3 + SO_4$ – $SO_4 + HCO_3$ – $SO_4 + Cl$ – $Cl + SO_4$ – Cl

These changes take place as the water moves from shallow zones of active flushing through intermediate zones into zones where the flow is very sluggish and the water is old. In a large sedimentary basin three main zones listed below can be demarcated.

1. **The Upper Zone:** It is categorized by active ground water flushing through relatively well leached rocks. Water in this zone has HCO_3 as the dominant anion and is low in dissolved solids.
2. **The Intermediate Zone:** It has less active ground water circulation and has higher total dissolved solids. Sulphate comprises the dominant anion in this zone.
3. **The Lower Zone :** It has very sluggish ground water flow. Highly soluble minerals generally occur in this zone because very little ground water flushing takes place. It is characterized by high chloride and total dissolved solid content.

These three ionic zones cannot be correlated with distance of travel or time but a transition indicates the travel from upper zone to lower zone.

Mineral Solubility and Anion Evolution

The release of ions in ground water depends on the availability of minerals in the flushing zone and solubility of minerals. Solubility of some common minerals is indicated in Table 5.2

Table 5.2. Solubility of some minerals

Mineral	Dissociation reaction	Solubility at pH 7 (mg/l or g/m^3)
Quartz	$SiO_2 + 2H_2O = Si(OH)_4$	12
Fluorite	$CaF_2 = Ca^{2+} + 2F^-$	160
Dolomite	$CaMg(CO_3)_2 = Ca^{2+} + Mg^{2+} + 2CO^2$	90*, 480**
Calcite	$CaCO_3 = Ca^{2+} + CO_3$	100*, 500**
Gypsum	$CaSO_4.2H_2O = Ca^{2+} + SO_4 + 2H_2O$	2100
Halite	NaCl = Na + Cl	3,60,000

** partial pressure of $CO_2 = 10^{-3}$ bar; **partial pressureof $CO_2 = 10^{-1}$ bar*

The HCO_3 present in ground water is generally derived from soil zone CO_2 and from dissolution of calcite and dolomite. Since calcite or dolomite occurs in significant amounts in nearly all sedimentary basins and both these minerals dissolve rapidly when in contact with CO_2 charged ground water, HCO_3 is almost invariably the dominant anion in recharge areas.

Gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$) are considerably more soluble than calcite and dolomite but much less soluble than the chloride bearing minerals such as halite (NaCl). If calcite or dolomite and gypsum dissolve in fresh water at 25^{o}C, the water will become brackish with total dissolved solids of about 2100 and 2400 mg/l for a pCO_2 range of 10^{-3} to 10^{-1} bar. The dominant anion will be SO_4. But this situation seldom occurs because gypsum or anhydrites are rarely present in more than traces. If there is enough time lag then dissolution and ground water flushing will eventually lead to complete removal of readily soluble minerals such as calcite, dolomite, gypsum and anhydrite from the active flow zone in the ground water system.

In deep ground water flow systems in sedimentary basins and in some shallower systems ground waters pass beyond the SO_4 dominant state to a Cl rich brine. This occurs if the ground water comes in contact with highly soluble chloride mineral like halite, which in deep sedimentary basins can occur as salt strata originally deposited during the evaporation of close or restricted marine basins many millions of years ago. Chloride minerals of sedimentary origins dissolve rapidly in water.

A noteworthy characteristic of many ground waters in stratified sedimentary sequences is the occurrence of Na and HCO_3 as the dominant ions. In some situations the HCO_3 concentrations have been found to be as high as 2500 mg/l. The occurrence of Na and HCO_3 as the dominant ions can be explained by the combined effects of cation exchange and calcite or dolomite dissolution. High Na, HCO_3 waters can be produced in sequences of strata that have significant amounts of calcite or dolomite and clay minerals with exchangeable Na. The two geochemical processes can be represented by the following reactions.

$CaCO_3 + H_2CO_3 = 2HCO^-_3 + Ca^{2+}$
$Ca^{2+} + 2Na\ (ad) = 2Na^+ + Ca\ (ad)$

Where (ad) denotes cations adsorbed on the clay particles.

The removal of Ca from solution by the exchange reaction causes the water to become or remain undersaturated with respect to calcite, thereby enabling calcite dissolution to continue.

Sometimes CO_2 is generated within the ground water flow system at depths far below the water table. The CO_2 combines with H_2O to form H_2CO_3, which causes calcite dissolution. Mechanisms such as the following have been suggested for generation of CO_2 at deeper depth.

$2CH_2O + SO_4 – HCO_3 + HS + CO_2 + H_2O$

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Application of Remote Sensing and GIS for Appraisal and Characterization of Salt Affected Soils

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The challenge for sustainable food production is heightened by the expected population expansion. To meet the demand for food, we need to increase crop yield, consistently, by over 2% every year. Notwithstanding advances in technology, increasing food production would certainly lead to intensification of agriculture in areas that are already cropped, and necessitate conversion of other lands such as forests and grasslands into cropping systems. Much of the changes will happen in semiarid regions and on lands that are marginally suitable for cultivation, increasing the risk of soil erosion, accelerated water use, salinity/alkalinity and further land degradation. The resulting land-use changes will be the single cause for global change over the next century. Consequently managing soil and water resources and conserving them requires intense futuristic research to enhance the ability to predict the future.

Salt affected and waterlogged soils are a serious impediment to agriculture. Found both as geogenic deposits and in irrigated areas, they are widespread over the world in arid, semiarid and subhumid areas. Soil salinity is currently spreading at the rate of 2 M ha per year. An estimated 1,965 M ha of land are subject to some kind of degradation all over the world. Of this, 1094 M ha are subject to soil erosion by water and wind (UNEP/ISRIC 1991). In addition, an estimated 954.8 M ha of arable land are affected by soil salinity and/or sodicity (Szabolcs, 1992). In India alone, an estimated 6.73 M ha suffer salinisation and or alkalization, water logging. Salinity is present in most irrigation commands over India indicating the need for managing their sustainability by providing information that is efficient and accurate.

Management needs reliable, timely and accurate data supply coupled with powerful, automated tools of analysis and interpretation to support the planning and decision making process. The advances in Remote Sensing technologies complemented by advances in computational methods in signal processing open up new possibilities for the integrated acquisition of multi-sensor, multi-spectral, multi-resolution data to provide spatial information describing our environment. The developments in the domains of Computer Science, Earth Observation and Environmental Sciences are all too often treated in isolation. We expect new insights and opportunities to emerge in a context where the integration of intelligent techniques, remote sensing and environmental sciences will come together to provide solutions for monitoring and management.

The Predicament

Remote sensing and GIS have been used extensively for the study of salinity and waterlogging but because of extreme variability in their occurrence a standard methodology has been difficult to put in place. However, as research into mapping these lands intensify there is a greater understanding of the techniques and the levels that they can be used to map, manage and monitor these lands. Even though efforts have been made to create information on the extent and spread of these lands, there is an absence of a comprehensive data base. The existing data base on SAS is limited and scattered because mapping salt affected soils in the field is difficult as they are interspersed with normal soils and form no contiguous pattern. The variation of salinity/alkalinity levels in the field is extensive and techniques useful for mapping and monitoring the salt affected soils need to be experimented with and explored. Remotely sensed data are being utilized for identifying SAS but the success has been limited because of absence of either infrastructure or a detailed methodology on identifying and mapping their occurrence, characteristics and spread.

Development of Methodology

Although initial efforts in 1986 for application of visual interpretation techniques in land use mapping as a part of Remote Sensing Application Missions Projects, the major thrust for operational methodology (visual, digital) came from the project on nationwide land use/land cover mapping.

Research is on to identify the best possible sequence to identify and map the extent of waterlogged and SAS. GIS has been used by scientists of various disciplines for spatial queries, analysis and Integration for the last few decades. GIS can be a powerful tool for developing solutions for water resources problems for assessing water quality, and water availability, preventing flooding, understanding the natural environment, and managing water resources on a local or regional scale. Though there are a number of spatial modeling techniques available with respect to application in GIS, spatial interpolation techniques through Inverse Distance Weighted (IDW) approach has been used mostly to delineate the locational distribution of water pollutants or constituents. This method uses a defined or selected set of sample points for estimating the output grid cell value. It determines the cell values using a linearly weighted combination of a set of sample points and controls the significance of known points upon the interpolated values based upon their distance from the output point thereby generating a surface grid as well as thematic isolines. For ground water the physico-chemical analysis of the ground water samples collected from predetermined locations form the attribute database for study, based on which, spatial distribution maps of major water quality parameters are prepared using curve fitting method in Arc View GIS software.

Remote sensing of monitoring water quality uses an empirical approach to estimate suspended sediments using radiance, reflectance and estimating suspended sediment and/or turbidity which are used to determine spectral reflectance values and between the *in-situ* water quality parameters. Spectral reflectances can provide information about the bands or wavelengths suitable for particular water quality parameters.

Sources and Types of Soils and Crop Inventory Data

Data sources

Generally, the sources of data can be broadly classified according to whether they are primary or secondary and digital or non-digital.

Table 6.1. Data sources for salt affected, waterlogged soils crop inventory and water quality parameters (some examples)

	Primary	Secondary
Non-digital	Field mapping, Field Hand-recorded data Laboratory analyzed soil and crop samples data Soil and crop reflectance ground radiometry data	Maps Tables
Digital	GPS (Global Positioning System), Digital field observation Location. Data bases. Field instruments with data loggers Automatic weather station meterological data Remote sensing data, Satellite Imagery, Hard copy/CD-ROM	

Primary data

- Field maps and ground truth maps are prepared in the field. Field maps in the form of records of observations on air photograph/satellite images or topographic base maps are generated.
- Field hand recorded data, such as on-site auger data, soil profile morphological properties, crop conditions, water quality parameters etc. are the primary source of data.
- Primary data of soil physico-chemical properties and crop bio-physical properties are now collected to a large extent by instrument that record digitally such as the digital pH and EC meters, the spadometer for chlorophyll content and the GPS. Instruments like the Greenseeker is used to measure the NDVI (Normalised vegetation index) and the plant canopy analyser is used to study the stress that the plants maybe facing under salty and waterlogged environments. Water quality information is gathered by ground collection and surface water by studying turbidity etc.

- Geographic locations of sample sites, in many cases, established by hand from identifiable ground features shown on topographic base maps. Location on base maps may be digitized on a digitizing table or measured directly in the field with Global Positioning System (GPS) instruments using satellites.

Secondary data

Secondary data sources: - Many of the commonly used sources of secondary spatial soils and crop inventory data are not in digital form, such as maps, tables, laboratory analyzed data on paper etc. Digital secondary data include digital crop inventory/land use /land cover and soil maps, digital topographic map, preprocessed field observed instrumental digital data, ground water quality maps and well data.

General objectives of RS & GIS for identifying and characterising SAS and waterlogging are:

- Inventory (delineation and mapping)
- Monitoring temporal change
- Creation of spatial and non-spatial databases
- Evaluation of status/conditions of natural resources
- Integrating analysis
- Environmental impact assessment
- Cost-benefit analysis

Selection of Remote Sensing Data

Selection of Remote Sensing (RS) data for RS & GIS application project depends on several factors such as scale of mapping; complexity of spatial distribution pattern of natural resources; complexity of the resource; frequency of temporal analysis; extraction 3-dimensional information (elevation/height) of the terrain etc.

Mapping scale	RS data requirement
1:100,000 to 1:500, 000 or smaller	IRS-LISS l, LANDSAT MSS
1:50, 000 to 1:100, 000	IRS-LISS II & LISS III, LANDSAT, IRS-P6 LISS IV, TM, SPOT MSS, Small scale/high altitude aerial photographs (>12 km)
1:25,000 to 1:50,000	IRS-LISS + PAN; SPOT-MSS +PAN; Medium scale/medium altitude aerial photographs (3 - 12 km)
1:10, 000 to 1:25, 000	IRS-1C/1D-PAN,SPOT-PAN, Quickbird and IKONOS, GEOEYE 1 and WORLDVIEW 1data Large scale aerial photograph /low altitude aerial photographs
1:5,000 to 1:10,000	Large/very large scale aerial photographs

Softwares

- GIS software
  1. ARC/INFO (PC based, Workstation based)
  2. ILWIS (PC based)
  3. Mapinfo (PC based)
  4. Geomedia

- DIP Software
  1. ILWIS (PC based)
  2. EASI/PACE (PC based, Workstation based)
  3. ERDAS/Imagine (PC based, Workstation based)
  4. ER-MAPPER (PC based)
  5. ENVI

Image Interpretation

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.

Visual interpretation: The methodology for conducting visual interpretation of multi-date satellite comprises the following six major steps:

1. Selection and acquisition of data: Standard FCC imagery of IRS/SPOT/ IKONOS/ QUICKBIRD data of *kharif* and *rabi* seasons also for study of surface water features.
2. Preliminary visual interpretation: Different seasons are interpreted individually making uses of the interpretation keys. The boundaries of land use/land cover classes are digitized from topographical maps.
3. Ground data collection and verification: Following the previously drawn scheme and transverse plan, ground truth information is collected as per specific guidelines to cover at least 80 percent of the district as a reconnaissance initially in areas where no mapping has been conducted using the GPS and 10 percent once the mapping criteria have been established. Areas of doubtful preliminary interpretation are particularly verified.
4. Final interpretation and modification: Based on the ground truth data, modifications are made on salt affected waterlogged as well as water feature boundaries refined using GIS.
5. Area estimation: Areas under different classes are estimated digitally by conducting a supervised classification and creation of training sets.
6. Final mapping: It is done to map salt affected waterlogged and ground water parameters.

Delineation of Salinity and Waterlogging

Data acquisition: Satellite data either IRS P-6, IC LISS III, SPOT, QUICKBIRD or LANDSAT TM multispectral scenes and bands needs to be acquired for dry season (Feb-March) during which it is much more possible to accurately identify barren and severe salt affected areas and the areas with poor crop. Soil samples of the whole profile and topsoils (0-15 cm depth) are collected simultaneously during satellite over pass. Water samples from wells and surface water sources may be collected.

Digital image registration: If reference satellite image is not available, the Survey of India toposheet is scanned and used as an image for digitally registering acquired satellite data through image to image transformation. This is done by identifying ground control points (GCPs). There should be a minimum of 9 GCPs. All these bands i.e. green (0.52-0.59 µm), red (0.62-0.68 µm) and near infrared (0.77-0.86 µm) are registered to each other.

Ground truth and training site selection

Ground truth data collections for delineating salinity as well as waterlogging are in the forms of morphological and chemical analysis data for salt affected soil profiles. Soil saturation extracts are prepared to determine ion types and content. EC and pH for representative soil samples of 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. The ground water samples collected should be analysed for EC, pH, RSC etc.

- Training set should be representative and intensive
- Training sets should be adequate and uniformly distributed for each of the information class
- Training sets should be located accurately on SOI toposheet (1:50:000 scale)

Training sets of information classes such as soil salinity or waterlogging 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. Ground water quality parameters are mapped using GIS and krigging.

Supervised Image Classification

Image classification through supervised training constitutes signature generation, spectral separability and pixel labeling using a maximum likelihood classifier.

Signature generation: Training set information such as chemical analysis of representative soil samples and other surface water conditions are used to establish relationship between spectral variance and the various information classes of interest. Spectral response pattern is generated for salt affected soils, waterlogged soil and crop land. The spectral response pattern of salt affected soils is relatively higher than other two categories namely waterlogged areas and crop lands in the three bands except for NIR where vegetation reflects the maximum. Also spectral response decreases with increasing wavelength. This could be due to presence of moisture on the soil surface that tends to absorb the incident radiation in near infrared region.

Pixel labeling: After selecting optimum spectral bands, a false color composite is generated. Salt affected soils can be detected by a dull white to bright white color and irregular shape within the crop lands which are seen in red color in the FCC. Waterlogged saline soils appear blue white and have lower spectral response than barren salt affected soils and are identified by their mixed signatures. The maximum likelihood algorithm is used for digitally classifying the various spectral or information classes.

Classification Accuracy Assessment

Classification accuracy assessment has now become an integral part of satellite derived land use/ land cover mapping. Classification accuracy is mainly evaluated with the aid of confusion or error matrix. For classification accuracy assessment, it is necessary to compare two sources of information (1) classified image (2) reference test information or training sites map.

The way data are analyzed depends upon the architecture of the available software. Some systems will provide dedicated programs, which are designed to perform specialized tasks; other systems will provide a range of programs that, in combination with each other, will perform a similar task. In the later case, a higher degree of flexibility will be traded off for the higher degree of efficiency of the former case.

- Construction of legend
- Preparation of base map from Survey of India toposheet
- Peruse the image to enable quick look analysis of the terrain/land forms, land use/land cover of the area
- Identify and detect the salt affected lands as per legend
- Prepare the overlays of the thematic details
- Assign the symbols to the mapping units
- Mark the doubtful areas for ground truth verification. Prepare field traverse program to cover maximum doubtful areas which are easily accessible in the field. Ensure each traverse covers as many units as possible. Collect soil /water samples for laboratory analysis
- Enter field details directly on the preliminary interpreted maps
- Interact with villagers/officials
- Make necessary corrections on the interpreted maps
- Analyze the soil samples for EC, pH, CEC, salt content, mechanical composition etc.
- Analyze water samples
- Update preliminary map in all aspects

State of the Art

With launch of IRS-IC in 1995, space-borne spectral measurements made at the same point of time with unique combination of sensors having different spatial resolution and swath width become a reality. Taking advantage of the opportunity, a study was carried out to map salt-affected soils and waterlogged areas at 1:12, 500, 1:25,000 and 1:125,000 scale over part of Uttar Pradesh using IRS-IC, PAN LISS III and WiFS data (National Remote Sensing Agency, 1997b) in collaboration with the Remote Sensing Applications Centre, Uttar Pradesh by superimposing cadastral map after digital/optical reduction to compatible scale over salt-affected soil map at 1:12, 500 scale derived from IR 1C LISS III and PAN - merged data. Individual fields with salinity and alkalinity problem could be identified. Subsequently, multi-temporal LISS III and PAN data were used for monitoring the success and progress of the ongoing land reclamation programme under a World Bank aided project for reclamation of salt affected soils and waterlogged areas delineated from IRS-1C LISS III data through computer-assisted digital analysis revealed that the overall accuracy achieved from this data is relatively poor than the one derived from using IRS-1B.The survey and mapping is being carried out by the Regional Remote Sensing Service Centers (RRSSC's) and the State Remote Sensing Centers and Soil Survey Departments of concerned States for mapping salt affected soils at 1:250,000 scale for the entire country and for Mainpuri district of UP and Ahmedabad district of Gujarat at 1:50,000 scale. In this project not only the nature of salt affected soils, namely saline, saline-sodic and sodic but also the magnitude of the problem in terms of slight, moderate and strong based on pH, electrical conductivity (EC) and exchangeable sodium percentage (ESP) has been brought out.

IRS-1B LISS II data were used for mapping and monitoring salt affected soils in Nagajunsagar Right and Left Bank canal command areas, in Andhra Pradesh, and Periyar-Viagai command area in Tamil Nadu (National Remote Sensing Agency, 1995a, 1996 and 1997a). AICRP Indore mapped the SAS of all of the state of Gujarat using IRS IB data on 1:1m scale. This study based on visual interpretation and Ground truth. The SAS waterlogged soils were mapped in the Ukai-Karapar command area using VI and Grounth truth. The SAS of Kanpur district was mapped using IRS IB imagery on 1:50,000 scale. A digital analysis showed the area affected to be 11.9 percent of the total district.

In the presence of substantial vegetation cover, the spectral response measured by a sensor is essentially from vegetation alone. In case of native vegetation, a correlation may exist between vegetation and the underlying salt-affected soils. Some attempts have been made to derive information on salt-affected soils in partially or fully vegetated terrain (Dalsted *et al.*, 1979; Taylor *et al.*, 1994). Though these studies were experimental in nature, they provided an insight into the possibility of generating information on salt affected soils in the vegetated terrain.

The spectral similarity between normal and salt affected black soils and sandy areas makes difficult to delineate them on the space borne multi spectral data. The spectral measurements made in the narrow spectral bands of the order of a few manometers, may enable detection of otherwise spectrally similar features. Absorption at 1400, 1900 and 2500 nm due to water in saline soils containing $MgCl_2$ was observed while measuring the spectral response from vegetated and bare salt affected soils with a 23 channel field spectrometer operating in the short-wave infrared region. The mapping of SAS and waterlogged soils was attempted in phase I of the Upper Krishna command area, using both visual interpretation and ground truth and established classes of SAS based on severity.

Salt affected soils with salt encrustation at the surface are, generally smoother than non-saline surface and cause high reflectance in the visible and near infrared bands (Everitt *et al.*, 1988). Kalra and Joshi (1994) observed the maximum spectral response from natural or *in-situ* salt affected soils with salt encrustation at the surface followed by sodic soils formed due to irrigation with high residual sodium carbonate (RSC) water, natural saline soils, and saline soils formed due to irrigation with saline water. Csillag *et al.*, (1993) found the visible (0.55 to 0.57µm, 2.15 - 2.30µm and 2.33 - 2.40µm) as the key spectral bands in characterizing the salinity status of soils. The thermal infrared region registers features caused by energy absorption of sulphates, phosphates and chlorides (Siegel and Gellespic, 1980; Mulders, 1987). Latz *et al.*, (1984) studied the spectral reflectance characteristics of selected eroded Alfisols of United States. Further, attempts have also been made to identify a three band combination from Landsat-TM data which is ideal for mapping salt-affected soils in the Indo-Gangetic alluvial plain (Dwivedi and Rao, 1992).

In India, the Landsat-MSS data was used for the first time at the National Remote Sensing Agency, Hyderabad for mapping salt affected soils (Venkataratnam and Rao, 1977; Singh *et al*., 1977). Subsequently, Landsat-MSS (Sharma and Bhargava, 1988; Singh and Dwivedi, 1989), Landsat-TM (Wheaton *et al*., 1992; Metterricht and Zink, 1997; Rao *et al*., 1991; Verma *et al*., 1994), SPOT-MLA (Sharma and Bhargava, 1987; Leonardo et al. 1996), Salyut-7 (Rao and Venkataratnam, 1987) and the Indian Remote Senssing Satellite (IRS01A/1B, Linear Imaging Self-scanning Sensor (LISS-I and II) data (Dwivedi and Venkararatnam 1992; Hooda and Manchanda, 1992) were used for mapping salt-affected soils. Apart from inventorying salt affected soils, studies were also carried out to monitor their temporal behaviour using concurrent and historical satellite data/aerial photographs (Venkataratnam, 1981; Sharma *et al.*, 1989; Dwivedi, 1992; Singh, 1994).

GIS can be a powerful tool for developing solutions for water resources problems for assessing water quality, determining water availability, preventing flooding, understanding the natural environment, and managing water resources on a local or regional scale.

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Solubility and Ameliorative effect of Gypsum in Alkali Soil Management

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Although a viable technology for reclamation of alkali soils was evolved at CSSRI in the 70's, large chunks of alkali soils still await reclamation across the country. Alkali soils with preponderance of sodium bicarbonates and carbonates and having high degree of sodium saturation of the exchange complex remain infertile. These require reclamation to be brought back to cultivation. The process of reclamation envisages neutralization of free sodium bicarbonates and carbonates and replacement of exchangeable sodium by calcium. Unless a suitable amendment like gypsum is applied, these soils remain impermeable to water and their clay particles deflocculate whenever such soils are irrigated or they receive rain.

For satisfactory growth of most arable plants the level of exchangeable sodium needs to be kept below 15 per cent generally in soils having non expanding type of clay minerals. However, in case of soils having expanding type of clay minerals this limit may be around 5 per cent. Besides having poor physical conditions, these soils become deficient in Ca, Zn, Cu, Fe and Mn etc.

Gypsum and its Solubility in Water

Gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$) are the two main mineral forms of gypsum present in the soil. But the former form of gypsum is quite abundant and is being used as an amendment in India. Its solubility in pure distilled water at pH 7 is 2.1 g/l. In presence of chloride salts its solubility increases but in presence of sulphate bearing salts the solubility decreases.

Sparingly soluble nature of gypsum is a boon, as it is retained in the soil for a longer duration. It is not lost by leaching. As a part of the dissolved calcium is utilized by plants further supply takes place from gypsum.

In a pure aqueous system gypsum gives rise to a solution containing Ca and SO_4 ions as indicated below:

$CaSO_4.2H_2O + H_2O = Ca\ (aq) + SO_4\ (aq) + 2H_2O$

However in a soil its solubility depends on the fineness of gypsum particles, depth of mixing, quantity and quality of available water and composition of the soil solution. The solubilized gypsum remains in ionic form and takes part in the exchange reaction replacing sodium from the clay exchange site as indicated below:

$Ca\ (aq) + 2Na\ (clay) – Ca\ (clay) + 2Na\ (aq)$
$2Na\ (aq) + SO_4\ (aq) – Na_2SO4\ (aq)$

The replaced sodium reacts with the sulphate ions to form sodium sulphate and is leached beyond the root zone. In soils containing free sodium carbonate a fraction of dissolved gypsum reacts to neutralize it forming calcium carbonate and sodium sulphate. The former being insoluble remains in the soil while sodium sulphate is leached to deeper strata.

$CaSO_4\ (aq) + Na_2CO_3\ (aq) = CaCO_3\ (s) + Na_2SO_4\ (aq)$

Ion Exchange in a Normal Soil

Whenever a soil is irrigated or it receives rain the soil solution becomes dilute. As the time passes and the flow of soil solution under the pull of gravity stops the soil is supposed to hold water at field capacity. In such an environment the calcium ions are held more tightly than sodium ions on the exchange complex. In such a dilute solution, very little exchange of sodium for calcium takes place if the solution contains equivalent concentrations of sodium to calcium. Little exchange of sodium with calcium occurs if the sodium ions are twice in proportion and under some conditions even three times as concentrated as the calcium.

But as the calcium ions are divalent and the sodium monovalent, at constant ratio of sodium to calcium ions in the percolating solutions, the higher the actual concentration of sodium ions, the greater is their entry into the exchange complex. The ion exchange is governed by the ratio law.

The ratio law

When cations in a dilute solution are in equilibrium with a large number of exchangeable cations a change in the concentration of the solution will not disturb the equilibrium if the concentrations, or more strictly the activities of all monovalent ions are changed in one ratio, those of all divalent in the square, and those of all trivalent in the cube of that ratio.

In accordance with the ratio law, if a salt solution containing cations of different valencies is in equilibrium in a soil, adding water to the system affects the equilibrium by some of the higher valency cations being taken up from the solution and cations of the lower valency being released into the solution.

"Thus the statement that monovalent cations in solution become stronger extractors of exchangeable cations relative to the divalent as their absolute concentration in the solution increases is merely a direct consequence of the ratio law".

Ameliorative Effect of Gypsum

It is obvious that virgin alkali soils lie barren for want of a suitable ameliorative agent to neutralize the free sodium bicarbonates and carbonates and to replace the abundant sodium from the exchange complex to restore favourable growth environment in the soil. Although majority of alkali soils in our country are calcareous i.e. they contain nodules rich in calcium carbonate or both calcium and magnesium carbonate, these cannot dissolve at high pH conditions prevailing in alkali soils.

The gypsum requirement is determined only for upper 15 cm thick layer and only half (50 per cent) of the calculated quantity of gypsum is added to the soil for reclamation. While, in the US Salinity Laboratory, the practice was to calculate gypsum requirement for the upper 30 cm depth and applying the whole quantity to the 30 cm thick soil. Due to the reason above mentioned in India, rice and wheat are the only two crops, which can be grown successfully on reclaimed soils. As regards sensitive crops like legumes, it takes more than 10 to 15 years for the reclaimed soil to attain ESP levels favourable for the germination and growth of legumes. The gradual improvement of the soil upto deeper horizons results from dissolution of calcium carbonate present in these soils. The solubility of calcite varies from 100 to 500 mg/l at pCO_2 of 10^{-3} to 10^{-1} bar at pH 7. The hidden role played by calcium carbonate has not been taken note of.

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Organic and Inorganic Amendments for Alkali Soil Reclamation

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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.

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 complex 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 chemical amendments used for reclamation of these soils can be broadly grouped as follows:

1. Soluble sources of Calcium: Gypsum ($CaSO_4.2H_2O$), Calcium chloride ($CaCl_2$) and phospho-gypsum (An industrial by product).
2. Sparingly soluble calcium salts: Calcite, $CaCO_3$, and
3. Acids or acid-formers: Sulphur, sulphuric acid, sulphate of iron and aluminium, pyrites, lime – sulphur.

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. 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. 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 their solubility decreases with increase in pH of the soil.

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. Equivalent amount of any amendment can be calculated with the aid of conversion factors given in Table 8.1. Chemical reactions of some commonly used amendments in alkali soils are given below:

Gypsum

$2Na{-}X + CaSO_4 = Ca{-}X + Na_2SO_4$

Calcium Chloride

$2Na{-}X + CaCl_2 = Ca{-}X + 2NaCl$

Sulphur: Microbial oxidation

$2S + 3O_2 = 2SO_3$
$SO_3 + H_2O = H_2SO_4$
$H_2SO_4 + CaCO_3 = Ca SO_4 + Ca(HCO_3)_2$

$2Na - X + CaSO_4 = Ca - X + Na_2SO_4$

The microbial oxidation of sulphur is mediated by aerobic *Thiobacilli* group of chemoautotrophs.

Table 8.1. Relative quantities of different amendments compared to gypsum

Amendments	Amount equivalent to 1 ton of chemically pure gypsum
Sulphur	0.19
Gypsum	1.00
Pyrite (FeS_2) 22% S	0.86
Pyrite (FeS_2) 30% S	0.63
Sulphuric Acid	0.57
Lime sulphur solution 24% S	0.79
Iron sulphate ($FeSO_4 . 7H_2O$)	1.61
Aluminium sulphate $(Al_2SO_4)3. 18H_2O$	1.29
Lime stone	0.58
Calcium chloride ($CaCl_2 . 2H_2O$)	0.85

Iron sulphate

$FeSO_4 + H_2O = H_2SO_4 + FeO$

Iron pyrite

$2FeS_2 + 7O_2 + H_2O = 2FeSO_4 + 2H_2SO_4$

$H_2SO_4 + 2CaCO_3 = CaSO_4 + Ca(HCO_3)_2$

$2Na - X + CaSO_4 = Ca - X + Na_2SO_4$

The rate of oxidation of pyrite is slow and depends upon the moisture content, oxygen availability, and temperature and particle size. When applied on the basis of water soluble sulphur content, its efficiency in reclamation is quite high.

Lime – sulphur and sulphates of iron and aluminium produce sulphuric acid which further acts like the reactions given in sulphur and iron pyrite. Calcium chloride is highly soluble in water but its high cost is often an impediment in its use. Acids are not generally recommended because of the high cost involved and difficulty in handling them at the field level.

Gypsum is, by far, the most economical and commonly used chemical amendment. In India the resources of gypsum are estimated to be more than 1000 million tonnes. Gypsum should be broadcast and incorporated in the surface soil by discing or by using a cultivar. 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

Farmyard manure, rice husk, straw, pressmud (a sugar industry byproduct) and green manures are some commonly used organic amendments. The process of reclamation by organic materials is often slow. Organic materials and the action of plant roots improve biological activity in the soil. The decomposition of materials increases the concentration of CO_2 to produce organic acids in the soil which help in mobilizing calcium by dissolving calcium compounds. This is accomplished by green manuring, incorporation of crop residues, application of FYM, press-mud and other organic materials.

Crop Responses

A series of field experiments revealed that gypsum applied at the rate of 12-15 t/ha, which makes about 50 % of the gypsum requirement of surface (0-15 cm) soil, is sufficient to initiate reclamation process in rice based cropping system (Table 8.2) on calcareous sodic soils. The pH_2 of these soils ranges 10.0-10.5

throughout the soil upto a depth of 150 cm. The 100% gypsum requirement of soils (Schoonover method) is estimated at about 30 t/ha for the 0-15 cm depth. The data in Table 8.2 reveal that it is beneficial to broadcast and mix the amendment in the shallow layer of top 10 cm proved to be better than other combinations.

Table 8.2. Effect of gypsum and depth of mixing on the yield of crops (t/ha)

Gypsum (t/ha)	Depth of mixing (cm)	Barley	Rice	Wheat
0.0	10	0.00	5.18	2.04
	20	0.00	5.69	1.77
	30	0.00	4.62	0.93
13.5	10	2.64	7.02	3.28
	20	2.46	6.05	3.16
	30	0.53	5.64	2.06
27.0	10	2.83	6.71	3.67
	20	3.22	6.28	3.67
	30	2.30	5.98	3.93
CD (5%) for depth		0.35	0.73	0.41

Gypsum requirement 27.0 t/ha for initial soil pH_2: 10.5

Later studies showed that gypsum dose could be reduced from 50% to 25% of GR when FYM @ 20 t/ha is applied along with the amendment (Table 8.3). Reduction in pH and ESP and improvement in crop yields indicated that gypsum @ 25% GR along with FYM @ 20t/ha could be a better choice for the amelioration of alkali soils. It also ensures sustained high productivity of rice and wheat. Recent studies (1997-98) of field experiments at Shivri Farm, Lucknow revealed that gypsum dose could be reduced from 50% to 25% of GR when sulphitation press-mud @ 15 to 20 t/ha is applied along with 25% GR (Table 8.4).

Table 8.3. Effect of soil amendment on the grain yield of rice and wheat in a sodic soil

Treatments	Grain yield (t/ha)							
	Rice				Wheat			
	1989	1990	1991	Pooled	89-90	90-91	91-92	Pooled
Control	2.89	4.55	5.23	4.25	0.20	1.00	1.18	0.79
Gypsum 25 %	5.10	5.23	5.32	5.22	1.67	2.22	2.33	2.07
Gypsum 50 %	5.44	5.46	5.34	5.41	1.99	2.31	2.42	2.24
FYM 20 t/ha	4.05	5.20	5.30	4.85	1.42	2.00	2.16	1.86
25% Gypsum + FYM 20 t/ha	5.78	5.76	5.83	5.79	2.14	2.78	2.82	2.58
50% Gypsum + FYM 20 t/ha	6.13	6.01	5.90	6.01	2.36	2.82	2.91	2.70
CD (5%)	0.33	0.41	0.40	0.36	0.35	0.36	0.34	0.35

Table 8.4. Effect of gypsum and press mud on yield of rice and soil pH

Treatments	Grain yield (t/ha)		Soil pH
	CSR 10	CSR 13	
Gypsum 15 t/ha (50 % GR)	2.06	1.33	9.20
Gypsum 30 t/ha (100% GR)	2.86	1.86	8.00
Gypsum 7.5 t/ha + Press mud 10 t/ha	2.16	1.24	9.15
Gypsum 7.5 t/ha + Press mud 15 t/ha	2.52	1.72	9.03
CD (5%)	0.57	0.41	0.28

Efficiency of Different Chemical and Organic Amendments

Graded doses of different amendments viz. sulphuric acid, press-mud (sulphitation process) gypsum, alluminium sulphate, ferrous sulphate and FYM were tried for the reclamation of an alkali soil. In the first year, barley was grown but in subsequent years rice-wheat rotation was followed. Judging from the improvement in sodic soil and crop yields, sulphuric acid, gypsum, aluminium sulphate, ferrous sulphate and FYM were found equally effective. However, the choice of a particular amendment depended upon its availability and cost. In a field study where iron pyrites and gypsum were compared for their relative effectiveness, the pyrite did increase rice and wheat yield but was less effective to gypsum especially in the following crop of wheat. Much of the observed differences in effectiveness arise from the differences in the soluble S content of the pyrite. It has been shown that efficiency of pyrite depends on the soluble sulphur content and method of application. Proper oxidation of pyrites under moist conditions is desirable for greater efficiency. Gypsum and pyrites compared well on equal sulphur basis. Effectiveness of organic material like farmyard manure or rice husk in reclaiming alkali soils depends on the amount of CO_2 produced and reduced condition produced (drop in Eh) through their decomposition. Gypsum (50% GR), pyrite equivalent to gypsum on sulphur basis and FYM @ 30 t/ha were equally effective in increasing rice yields when a period of 30 days submergence prior to planting of rice was allowed (Table 8.5).

Table 8.5. Effect of soil amendments and pre-submergence on the grain yield of rice and wheat and changes in soil pH and ESP

Treatments	Duration of pre-submergence prior to plating of rice (days)	Yields (t/ha)		After rice harvest		After wheat harvest	
		Rice 1982	Wheat 82-83	pH	ESP	pH	ESP
Control	0	0.08	0.005	10.3	82.8	10.3	82.5
	30	0.18	0.007	10.1	81.0	10.2	81.4
Gypsum	0	5.19	2.01	9.5	37.5	9.5	37.0
	30	5.58	2.07	9.3	35.2	9.3	33.1
Pyrites	0	4.81	1.81	9.6	39.6	9.6	39.2
	30	5.43	1.97	9.4	37.5	9.5	37.8
FYM	0	3.29	0.98	9.9	72.5	9.9	71.8
	30	5.52	1.28	9.8	62.0	9.9	62.1
Rice husk	0	2.70	0.66	10.0	74.5	10.0	73.5
	30	4.52	0.99	9.9	70.1	9.9	70.0
CD (5%)							
Amendment		0.23	0.23	-	-	-	-
Submergence		0.13	0.13	-	-	-	-
Interaction		0.29	0.26	-	-	-	-

The reduction in pH and ESP were however largest in gypsum treated soil followed by pyrites. Enhanced availability of nutrients in pre-submerged FYM treated plots were chiefly responsible for better rice growth. The magnitude of increase in the yield of wheat crop as compared to rice due to pre-submergence in case of FYM and rice husk application was, however, less. This was because FYM and rice husk brought about a marginal improvement in alkali soil even though the same was sufficient to improve rice yields as the crop can tolerate high ESP. But, the change in soil conditions was not adequate to obtain good yields of wheat as the crop is only moderately tolerant to soil sodicity.

Green Manures

Green manure plays an important role in the sustainability of a cropping system. Nutrient imbalance created by continuous use of plant nutrients particularly N alone or combined with sub-optimal rates of other nutrients has been the primary cause of non sustainable yields in a cropping system. With the application of FYM and *Sesbania* green manure it has been possible to prevent the occurrence of Zn deficiency in rice. However, employing organic and green manures as the primary source of plant nutrients may not support the sustainability concept. Therefore, nutrient supply through organic manures and chemical fertilizers is extremely important for the sustainability of cropping system. Besides, use of green manure or FYM in alkali soils has a special advantage. They hasten the process of reclamation by decreasing pH and exchangeable Na of the soil. Among plants used for green manuring dhaincha (*Sesbania aculeata*) can be grown successfully in alkali soils during summer before rice. Field studies showed that incorporation of 50 day old *Sesbania aculeata* produced 3.85 t/ha/year of biomass (dry weight) which in turn contributed 110 kg N/ha/year and enhanced significantly the grain yield of rice and wheat, the average increase being 1.48 and 0.67 t/ha respectively (Table 8.6). Even if half of this N is crop usable, a green manure crop could substitute for 50 to 60 kg fertilizer N/ha. On the basis of this and other results, basal N application can be withheld till maximum tillering stage of the crop. This would have wide implications in N use efficiency. Low use N efficiency by wetland rice is because of basal N application is subjected to maximum loss through ammonia volatilization in alkali soils. The advantages of green manure in alkali soils were even more when it was decomposed for one week under submerged conditions prior to transplanting of rice. This resulted in greater mobilization of native and applied fertilizer nutrients especially N, P, K, Ca, Fe, Mn and Zn and their uptake by rice and wheat subsequent wheat crop besides improvement in alkali soils.

Table 8.6. Grain yield of rice and wheat on sodic soil

Treatments	Grain yield (t/ha)							
	!985-86		1986-87		1987-88		1988-89	
	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat
Rice-wheat	5.29	1.92	5.39	1.44	5.45	2.25	5.60	2.45
Green manure- rice-wheat	6.73	2.00	6.86	2.14	6.95	2.85	7.12	3.71
CD (5%)	0.35	NS	0.34	0.33	0.37	0.45	0.52	0.59

Recent studies on integrated nutrient management showed that 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. Yields of rice and wheat were significantly increased with integrated use of green manuring or FYM and 100% recommended (120 kg N, 22 kg P and 42 kg K/ha) as compared to 100% recommended inorganic fertilizers alone (Table 8.7). The yield of rice and wheat could be maintained even at lower (50% of recommended) dose of inorganic fertilizer application (N60 P13 K21) when conjunctive use with FYM or *Sesbania* green manuring is done.

Table 8.7. Grain yield of rice and wheat on sodic soil

Treatment	Grain yield (t/ha)									
	1994-95		1995-96		1996-97		1997-98		1998-1999	
	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat
N_{120} P_{26} K_{42}	5.57	5.00	5.50	5.16	5.52	5.05	5.57	4.96	5.45	4.87
N_{120} P_{26} K_{42} + GM	6.25	5.30	6.35	5.28	6.98	5.29	6.94	5.57	6.65	5.41
N_{120} P_{26} K_{42} + FYM	6.12	5.15	6.15	5.10	6.56	5.14	6.67	5.25	6.59	5.52
CD (5%)	0.52	0.52	0.58	0.51	0.56	0.40	0.56	0.50	0.33	0.53

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Managing Soil Physical Environment for Enhanced Input Use Efficiency through Integrated Nutrient Management

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In India, millions of hectares of land produce very low yield of crops due to unfavourable soil physical conditions as a results of poor fertilizer use efficiency in irrigated as well as rainfed agriculture. Efficient nutrient management is essential for sustainable crop production. For sustained high productivity, it is necessary to manage the soil health through integrated nutrient management (Yadav, 2003). INM is the most effective strategy to maintain and sustain a good soil quality (Masto *et al.*, 2008). Effectiveness of INM in increasing crop yields in rainfed (Acharya, 2002) and irrigated (Dobermann and White, 1999) agriculture has been very well documented. Nutrient use efficiency may be measured either as the fraction of added fertilizer recovered by the harvested portion of the crop or as unit of economic yield per unit of nutrient applied. Regardless of the manner of expression, all factors that affect crop yield with a given amount of nutrient, influence nutrient use efficiency. In fact the inefficient use of nutrients is linked to their losses from the soil plant system. Therefore, any practice that enhances nutrient uptake, maximizes yield, minimizes losses would lead to enhanced nutrient use efficiency. The major soil physical constraints are low water retention, high or slow permeability, surface and subsurface mechanical impedance and shallow depth of the soils, which either restrict crop growth or reduce efficiency of basic inputs, such as water, fertilizer etc.

Low Water Retentive and Highly Permeable Soils

These soils occur mostly in Rajasthan and some parts of Haryana and Punjab. The high permeability of these soils are associated with their sand and loamy sand texture. The soil has low bulk density but high hydraulic conductivity and infiltration rates as high as 36.5 cm/hr for some profiles, which indicate high permeability and low water retention capacity of the soil. The fertilizer and water-use efficiency of these soils is very low and the nutrient losses are very high. These problems do not encourage the farmers to use high levels of inputs. The major crops grown on these soils are pearl millet (bajra), maize, wheat and barley in western parts of India and sorghum, maize, ragi (minor millets) and sugarcane in southern parts of India.

Slowly Permeable Soils

The slowly permeable soils occur in Madhya Pradesh, Maharashtra and also in parts of Rajasthan, Uttar Pradesh, Bihar and Tamil Nadu. The infiltration rate is as low as 0.2 cm/hr and hydraulic conductivity is less than 0.15 cm/hr for some of the profiles, which indicate possibility of submergence during rainy season. The very low permeability, which is associated with black clay soils, creates oxygen stress in the root zone due to stagnation of water. The prevailing anaerobic conditions cause the accumulation of carbon dioxide and other by-products in this zone which restrict the root growth. These black clay soils are sticky when wet and very hard when dry, thus could be cultivated or tilled only within a limited soil moisture range. In the valley lands, where the topography is flat, weed menace is associated with humid climate.

Crusting, Hardening and Shallow Soils

These soils occur widely in Haryana, Andhra Pradesh and Tamil Nadu. Surface soil layer consists of 60 per cent coarse and 40 per cent fine fractions, a proportion causing crust formation when organic carbon is less than one per cent. Due to surface mechanical impedance, the emerging plumule faces resistance, bends below the crust and tries to come out at weak points of the crust; some of the seedlings injure their tips and fail to emerge. The emergence of pearl millet, cotton and jute seedlings is adversely affected if the crust is formed on the soil surface by the occurrence of rainfall within 48 hours of sowing.

The red sandy clay loam 'Chalka soil' of Andhra Pradesh dry out very quickly due to low water retention capacity and become very hard. The maximum root growth of most of the crops is confined to the surface layer, and the crop growth suffers due to hardening. The crops grown on this soil include pigeonpea, maize, castor, groundnut and sorghum. The yield of groundnut is very low due to reduced size of pods caused by hardening of the soil.

Soils with Subsurface Mechanical Impedence

The subsurface mechanical impedance may be developed either due to the formation of plough sole as in the case of rice fields on medium-textured soil, use of heavy machinery on moist soil, accumulation of clay in B-horizon under sub-humid conditions or the presence of kankar layers.

These high mechanical impedance layers are relatively impervious with the result water stagnates on the soil surface after heavy rainfall or irrigation and the crops turn yellow due to oxygen stress. These layers do not allow the roots to penetrate deep into the soil. Shallow root system makes the plant drought- prone during dry spells and promotes lodging during unusually wet conditions. In high rainfall areas, the presence of such layers at shallow depth reduces the water storage capacity of the soil with the result runoff starts even after a mild shower, which causes floods in low lying areas.

Management of Physically Constrained Soils

In highly permeable coarse textured sandy and loamy sand soils, the use of a roller to attain subsurface compaction, the application of organic manures, mixing of pond sediments or clay helps decrease the bigger pores and increase the smaller pores. This reduces the hydraulic conductivity and increase water retention which helps in enhancing the crop yields and water and nutrient use efficiency.

In the case of fine-textured slowly permeable soils, use of 'raised and sunken bed technology involving growing of upland crops in 20 cm high and 3 m wide raised beds adjacent to 20 cm deep and 6 m wide sunken beds growing rice crop is useful. The application of organic manure, crop rotation and use of phosphatic fertilizers are also useful for such soils.

For the management of soils having layers of high mechanical impedence at shallow depths, chiselling or profile modification of the dry soil up to 40-45 cm depth at 50-90 cm intervals is useful.

The structural management of acid soils involves application of lime followed by organic manures. To improve the structure and reclaim highly dispersed sodic (alkali) soils, application of gypsum/pyrites in combination with organic manures, green manuring or incorporation of crop residues would be helpful.

The 'crop residue recycling technology' involving incorporation of high C:N ratio organic materials, viz. powdered groundnut shells or paddy husk has been recommended for management of red sandy loam 'Chalka' soils which become very hard on drying. The 'seed line mulch technology' involving application of FYM or wheat straw @ 2.5 t/ha on seed-lines immediately after sowing of pearl mil1et and cotton seeds has been found useful for management of soils susceptible to form a crust.

Management of soil structure and enhancing and sustaining crop yields under rice-wheat cropping system in alluvial soils of lndo-Gangetic plains are formidable tasks. Deep ploughing along with incorporation of crop residues, FYM, leguminous green manure crops during puddling to grow paddy have been found successful. For subsequent wheat crop, tillage must be timed carefully with respect to soil moisture content to reduce and avoid large clod formation.

Soil Aeration and Plant Growth

The soil aeration may have direct and indirect effects on activities of higher plants and soil micro-organisms. The level of soil aeration determines the forms of several inorganic elements, soil reactions, microbial decay of organic matter, symbiotic nitrogen fixation and, in turn, the soil properties and plant growth. The harmful effects of poor aeration are:

- The growth of plants, particularly the root growth, is adversely affected by poor aeration. Waterlogging for more than 48 hours at knee-high and tasselling growth stages may retard the growth of maize crop. In some cases, an abnormal development of roots may occur, *e.g*. the de-shaping of sugar beet and carrots.
- The absorption of nutrients and water gets reduced in poorly aerated soils.
- Under anaerobic conditions, the formation of inorganic compounds is favoured, which are toxic to plants.
- The changes in soil oxygen content may affect the susceptibility of plant roots to diseases, the virulence of soil-borne disease organisms, or both, resulting in increased disease incidences.
- The absence of sufficient oxygen in soil affects the nitrogen fixation by Rhizobium.
- The soil organic matter cannot be decomposed properly by soil micro-organisms unless sufficient oxygen is present in the soil. If anaerobic bacteria decomposes soil organic matter, toxic substances like sulphides, methane, organic acids, etc. are liberated which are harmful for plant growth.
- In well aerated soils, the oxidized forms of most of the elements are present, *e.g*. nitrate-N. These are desirable for most common crops. The reduced forms, specifically of iron and manganese, may be present at toxic levels in the moist acidic soils.

Management of Soil Aeration for Enhancing Fertilizer Use Efficiency

The practices that enhance the air-filled pore spaces and facilitates the gaseous exchange may improve the aeration status. The variation in tendency of plant species to tolerate water stagnation/poor aeration can also be utilized to harness better crop yields from such soils. The soil aeration under field conditions can thus be optimized by the following methods:

Improving soil structure: An increase in the volume of air-filled pores can be attained by improving soil structure. The practices that help in the maintenance of stable soil aggregates such as use of animal manure, green manure, plant residue manure and growing of legume crops, will, in turn, encourage better soil aeration.

Drainage: An aerobic soil environment can be maintained by providing surface and or subsurface drainage. The soil pores get filled with water due to continuous seepage from canals, presence of perched or high water tables, and after heavy rains or irrigation. The drainage of such fields is essential for the supply of sufficient oxygen.

Cultivation: Interculture operations do not only control weeds but helps in the exchange of gases, specially in heavy textured poorly drained soils. After rains, an impermeable layer/crust are formed at the soil surface that hinders the gaseous exchange. A light cultivation will break it and help in improving soil aeration.

Plant adaptations: Plant roots, in general, are adapted to aerobic respiration. However, some of the plant species develop mechanisms such as increase in the air space of roots (root porosity) or internal aeration through leaves and cortex cells and thereby can grow even in oxygen-deficient soils. The selection of crop species, therefore, is important for growing crops in waterlogged or poorly drained soils. For example, rice thrives well in submerged soil conditions. Also, soybean crop can tolerate temporarily waterlogged soil conditions better than maize, pigeon pea and other deep rooted crops.

Soil Temperature and Plant Growth

Soil temperature influences the plant growth only indirectly, by affecting the physical, chemical and biological processes in soil and plants. Soil temperature influences the cell activity, biochemical reactions and physiological processes necessary for the overall growth and development of a plant.

Seeds of most of the crop species germinate within a reasonable time between, 10^{0}C and 35^{0}C. Unfavourable temperatures prevent the emergence of many tender seedlings.

Some plant species are adapted to low while others are adapted to high temperatures. At higher soil temperatures, the roots of low-temperature crops start decaying and are damaged by soil organisms and plant diseases but the reverse is not true for high temperature crop. The temperature optima for root growth of most crop species are between 20^{0}C to 25^0 C. The optimum temperature for the root growth is often lower than for shoot growth. The optimum temperature for the activity of most of the microorganisms is between 25^{0}C and 35^0 C. A low temperature produces toxic substances which are injurious to plants, whereas a high decomposition rate at optimum temperature usually results into the products which are beneficial to plants.

For many crops, particularly cereals, the shoot meristem, which is the site of temperature perception, lies below the soil surface for an appreciable period. The plant growth is initiated only when the minimum (or base) temperature is reached and the rate of growth increases up to the optimum temperature followed by a decline at the maximum tolerable temperature. The minimum and maximum temperatures differ in different crop species and at different stages of crop growth.

Management of Soil Temperature for Enhancing Fertilizer Use Efficiency

The primary source of heat energy to soil being the sun, practices encouraging the heat absorption and the flow in soil and those discouraging heat loss to the atmosphere would help in heat storage and temperature rise. The soil temperature under field conditions can thus be altered by mulching and vegetation, tillage, compaction, irrigation and drainage.

Mulching and vegetation: Mulches, such as straw, tend to buffer the extremes in soil temperature. Mulching with the polyethylene sheets raises the soil temperature during the day. Mulches also conserve soil moisture. A polyethylene film laid on a soil surface is transparent only to the incoming radiations. The outgoing radiation is inhibited due to the condensation of water vapour and the presence of dust particles on soil side of the polythene surface.

The vegetation, like straw mulch also intercepts both the incoming as well as the outgoing radiation from soil and therefore, reduces the temperature fluctuations. The overall effect depends on the proportion of shaded soil. Air temperature above a crop is lower than at the surface of soil on a clear night. Soil under vegetation warms up more slowly in winter than a bare soil. A soil under a dense vegetative canopy may remain at a uniform temperature in surface layers.

Tillage: Tillage of any kind affects the pore-size distribution and wetness and consequently the soil temperature. The tillage forming ridges often creates a range of soil temperature regime. Rapid changes in soil temperature are observed on ridges, whereas furrows are generally cooler. In poorly drained soils, ridging improves the soil aeration. A tilled-surface soil is generally warmer during the day time because of its higher porosity and low thermal conductivity than a compacted untilled soil.

Soil compaction: Compaction in soil brings its particles closer and regulates temperature in the root zone. The abrupt changes in soil temperature, as observed in the surface layers of a loose soil, do not occur in a compact soil due to its high thermal conductivity. The soil compaction under field conditions is often achieved using a tractor or bullock drawn roller.

Irrigation and drainage: The soil water controls absorption of solar radiation, loss of heat energy to the atmosphere, and movement of heat in soil. Water resists changes in soil temperature because of its high specific heat and high heat of vaporization. A wet soil conducts heat faster than dry soil and therefore, temperature fluctuations in the surface layers are rapid and approach extreme values easily in drier soils than in wetter soils. The dry soils prevent heat flow and encourage temperature fluctuations. The rising of soil temperature by draining of waterlogged fields and stabilizing soil temperature by irrigating dry fields are the common practices used by farmers. Irrigation reduces both rise and fall of soil temperature due to high heat capacity of water and evaporative cooling. The irrigation in summer causes large evaporative cooling of the surface soil.

Practices to Increase Input Use Efficiency

Some of the practices which interact with nutrients for their effect on crop performance by affecting nutrient-water dynamics and root proliferation in soil include tillage, water management and mulching.

Favourable effects of INM strategies are well documented in sugarcane (Babu *et al*., 2007), rice-wheat (Aulakh *et al.,* 2000, Yadvinder Singh *et al*., 2004), soybean-wheat (Hati *et al*., 2008) and intensive cultivation of 100 years (Anderson *et al*., 1990).

Amongst various soil physical properties, aggregate stability (Thakuria *et al*., 2009, Bossuyt *et al*., 2001), infiltration and water transmission properties (Franzluebbers, 2002) are the most sensitive to INM practices.

Availability of large quantities of farm yard manure for INM is considered as a major hurdle in promoting INM programmes on mega-scales. But the FYM requirements can be supplemented with other organic materials. Encouraging results have been obtained with organic amendments (Zebarth *et al*., 1999), town waste (Aggelides and Londra, 2000), animal manures (Schjonning *et al*., 1994) and crop residues (Skidmore *et al*., 1986).

Tillage influences nutrient use efficiency by affecting the availability and utilization of native and applied nutrients through its effect on soil environment and depth and density of rooting.

Deep and dense rooting induced by deep tillage of low organic matter, structurally unstable loamy sand and sandy loam soils resulting in greater N uptake by corn and thus reduced residual nitrate in the root zone. Deep tillage enhanced the production base of the crop to respond to higher level of nutrients. On very low water retentive sand soil, tillage effects on nitrogen use efficiency is also governed by frequency of irrigation. Deep tillage in combination with frequent and light irrigation gave higher NUE than conventional tillage with frequent or infrequent irrigations.

Water is a key element to influence transformation, transport and absorption of nutrients in soil-plant system. In fact water and nutrients have been reported to exhibit strong interaction for their effect in crop growth and yield. There is interdependence between N and water for their effect on crop growth. Nitrogen use efficiency in wheat decreased with successive increase in N rates, more so on low water retentive loamy sand than relatively low water retentive sandy loam. Interestingly on loamy sand at 80 kg N/ha, NUE increased with increase in water supply upto 200 mm. At 120 kg N/ha NUE did not increase with water supply upto 125 mm but showed marked improvement at 200 mm. It shows that for higher N use efficiency, there is need to match the supply of these two important production inputs.

Application of water and nitrogen should be in concert to ensure minimum losses of nitrogen from the profile and to maximize its uptake by the crop. On low water retentive highly permeable loamy sand maximum wheat yield with 150 kg N/ha in three splits was obtained when 360 mm of water was applied in seven splits. Application of 360 mm water in four splits and 150 kg N/ha at seeding resulted in the lowest yield. Heavy irrigation and lesser splits of N caused loss of N through leaching.

In arid and semiarid environments in well drained soils, crops generally suffer from water and thermal stress. In these areas, post sowing residue mulching has been found to increase nutrient use efficiency by modifying hydrothermal regime, which enhanced mineralization of N and promoted root growth. Straw mulching of corn on a sandy loam soil increased the dry forage yield by 13 per cent. It was because increase in N and P uptake was 43 and 13 per cent respectively.

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Carbon Sequestration and its Mechanism with Special Reference to Sodic Soils

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Soil is one of the important source and sink of carbon, thus indirectly influencing climate change through the production and consumption of carbon-dioxide (CO_2). According to IPCC, it contributes about 20% to the total emission of carbon-dioxide through soil and root respiration. As per India's Initial National Communication to the UNFCCC, the emission from the anthropogenic activities in India amounted to 817 Tg of CO_2 for the base year 1994 (NATCOM, 2004). The per capita CO_2 emission was 0.87 tonne which was only 4% of the US and 23% of the global average per capita CO_2 emission.

The major consequences of global climate change on soil carbon levels are expected to decrease due to decreased net primary production. Any gains by increased plant water use efficiency, due to elevated CO_2 are likely to be outweighed by increased carbon mineralization after episodic rainfall and reduced annual and growing season rainfall. The quality of soil organic matter may also shift where the more inert components of the carbon pool prevail. The residues of crops under elevated CO_2 concentration will have higher C:N ratio and this may reduce their rate of decomposition and nutrient supply. Increase in soil temperature will increase N mineralization but its availability may decrease due to increased gaseous losses through processes such as volatilization and denitrification.

Mitigation of CO_2 emission from agriculture can be achieved by increasing carbon sequestration in soil through manipulation of soil moisture and temperature, setting aside surplus agriculture land, and restoration of soil carbon on degraded land. Soil management practices such as reduced tillage, manuring, residue incorporation, improving soil biodiversity, micro aggregation, and mulching can play important roles in sequestering carbon in soil.

Mechanism of Carbon Sequestration in Soil

The principal way of carbon storage in soil is through formation of soil organic matter. Soil organic matter is a complex mixture of carbon compounds consisting of decomposed plant and animal tissues, microbial biomass and carbon associated with soil minerals. Among all these, soil organic carbon (SOC) is most important one. The soil organic carbon can remain stored in soil for infinite period or may quickly be released back to the atmosphere depending on prevailing conditions. SOC acquires a steady state at its potential value, where CO_2 loss and SOC sequestration is at the equilibrium.

Factors Influencing the Soil Organic Carbon

A close look at the process of soil degradation suggests the central role of soil organic carbon and its importance (Fig. 10.1). A high aggregation on account of increased silt and clay protects SOC from decomposition by trapping them between the aggregates. Soil organic carbon is essential for enhancing soil quality, sustaining and improving food production, maintaining clean water, reducing CO_2 in the atmosphere and an effective soil quality indicator. Its concentration influences physical, chemical and biological qualities of soils and quality and quantity of biological produce. SOC is the predominant parameter that affects other physical, chemical, and biological properties of soils. Cultivation generally depletes one third to half SOC, depending upon soil texture, erosion, and vegetative cover, management regime, initial concentration, period of fallowing and inorganic carbon accumulation. Available phosphorus and potassium were reported to increase with the stability of organic carbon and vice versa. Sodium adsorption on clay complex increased with decrease in SOC. Thus, SOC is dynamic and a widely accepted indicator, changing with land use and management history.

Carbon-dioxide emission was the function of total soil organic carbon stock over the area, as indicated by a higher flux of CO_2 from severely eroded sandy desert soils. Higher emission of CO_2 generally observed from highly degraded sandy soils.

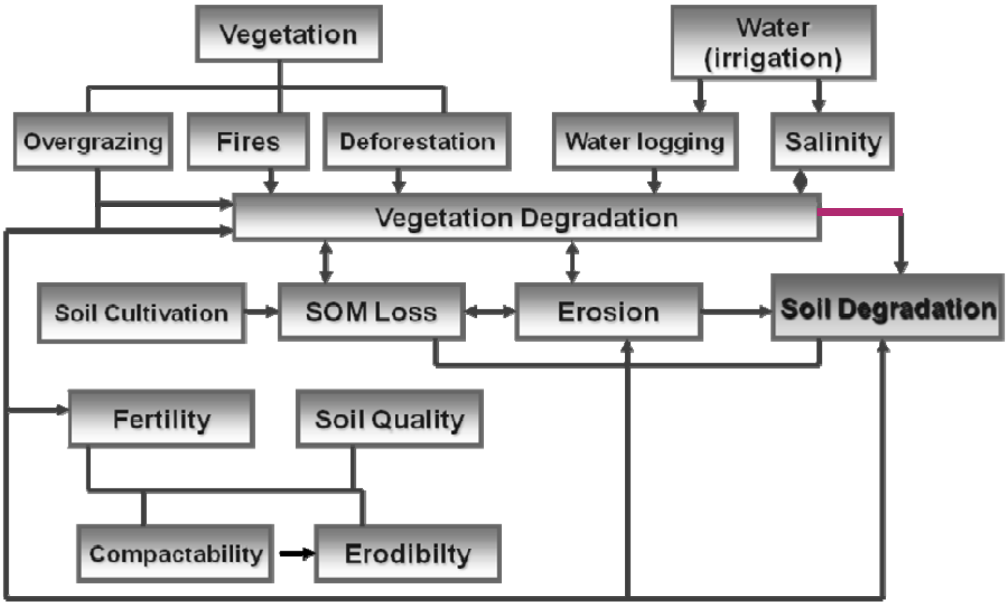

Fig. 10.1. Role of soil organic carbon

Application of carbonate and bicarbonate rich irrigation water on moderately deep soils in salt affected areas induced a higher inorganic carbon sequestration. An absence of canopy cover and lower vegetative inputs in the soils were the crucial for SOC depletion under a particular cropping sequence. Tillage during monsoon expedites the process of SOC depletion by increasing erosion severity and by opening the soils for microbial decomposition. Intermittent drought further accentuates the problem of organic residue recycling.

Limitations for Carbon Sequestration

- Soil erosion displaces and transports carbon rich soil particles, while increased inorganic carbon in the system triggers decomposition of SOC. It may also result in secondary salinization, sodification and restriction in root proliferation.
- Drought is a weather phenomenon impairing biological productivity because of moisture stress. It includes delayed onset and/or early withdrawal of monsoon, deficient or ill distribution of rainfall alone or in combination. The immediate effect of drought is the reduction of organic residues recycled in the soils. Indirectly drought stimulates soil erosion, enhances inorganic carbon sequestration and desertification.
- The ever increasing food demand for burgeoning population is being met through increased cropping intensity which ultimately enhances the process of soil organic carbon decomposition and degradation. Excessive tillage on marginal land break up soil structure, speed the decomposition and loss of organic matter. Moreover, monoculture with low recycling of residue coupled with tillage in rainfed situation expedites the depletion of soil organic carbon. The situation is further aggravated due to inappropriate land use. Soils of land quality class (LQC) I and II are recommended for arable cropping and the area under crops should not exceed from 50, 45, 40, 30, 20, 5 and 5% in LQC of III, IV, V, VI, VII, VIII and IX, respectively; soils of Class X should be excluded from agriculture.
- Depletion of nutrients from the agricultural field is one of the severe threats to the organic residue recycling. Imbalanced use of fertilizer in crops depletes soil fertility and reduces the vegetative cover and organic input to the soils.

Measures to Enhance SOC

Moisture Conservation: Increased availability of good quality water for irrigation enhances soil organic carbon by increasing period of vegetative cover, vegetative input to the soils and microbial population. This altogether leads to increase water stable aggregates that offer protection mechanism for longer residence time to soil organic carbon. *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 have beneficial effect on soil organic carbon build-up.

Integrated and Balanced Use of Nutrients: Nutrient management including chemical fertilizers, manures and biofertilizers such as *Azospirillum*, *Rhizobium*, blue green algae, phosphate solubilizing micro-organisms, and VAM fungi enhanced vegetative cover and over all biomass production. The ultimate effect of which is the greater vegetative input to the soils and a high soil organic carbon density. What is equally important is that such increase in SOC acts as cementing agent for the stability of soil aggregates, improves total nitrogen content, mineralization potentials and vis-à-vis stability of soil organic carbon.

Conservation Agriculture: Tillage operations disturb soil structure and redistribute energy rich organic substances in the soils. 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 operational definition of conservation agriculture is planting and tillage combination that retain a 30% or higher cover of crop residue on the soil surface. Conservation agriculture also increases soil organic matter, improves nutrients, water use efficiency and physical properties besides restricting soil erosion.

Management: Management tools commonly used to achieve the above operational definition for conservation tillage are; (i) non inversion tillage (usually implies replacement of a mouldboard plough with a chisel plough or cultivator) (ii) tillage depth confined to <15 cm (Deeper tillage may be retained in the row for row crops and (iii) minimization of number of tillage passes. The major outcome of these management options is to provide some degree of permanent soil cover (i.e. 30% or more residue in the non crop period) to increase the organic matter content and structural stability of the soils over time and sometimes to improve soil structure below the plough layer. Soil stratification, which mainly involves enrichment of the soil surface with organic matter, is the dominant management outcome of the conservation tillage. Stratification can also have impact on nutrient storage and soil aggregation, improved water regulation at the surface and throughout the soil profile.

Gene Mining for Drought Avoidance: There are several species which have very extensive root system for mining water from large volume of soils and can survive very low water, such as *Prosopis Juliflora* surviving in the rainfall zone ranging from 200 mm in Bhuj to 1000 mm around Ramnathpuram of 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 soil organic carbon depletion.

Adoption of Agroforestry: Agroforestry is an integrated and sustainable system of land use combining agriculture, forestry, horticulture, livestock management and agrostology. With the shrinking per capita land availability, agroforestry system with the integration of perennial woody trees with crops/pastures is most suitable technology for increasing total productivity of food, feed and fuel and thereby reducing the risk of farming. It also helps in more efficient utilization of sunlight, moisture and plant nutrients than is generally possible either by agriculture alone or forestry exclusively. Different agroforestry systems include agri-horticulture system where fruit trees are integrated with crop with an aim to provide food and nutritional security besides conserving the agroecosystem. In agri-silvi-pasture system, perennial woody trees are integrated with crop and pasture with an aim to provide food, fodder and fuel wood besides conserving the agroecosystem and this system should preferentially include animal component to enhance profitability. Silvi-pasture system is practiced where soil fertility is poor with low water availability and crops cannot be grown profitably. The system includes pasture with perennial woody trees to provide fodder and fuel wood besides conserving soils. Integration of livestock with silvi-pastoral system is essential to maximize economic returns per unit of land. In horti-silvi-pastoral system, pastures are integrated together with horticultural trees for fruit production and silviculture to ensure fuel wood. Agri-silviculture system of agroforestry integrates crops with perennial woody trees preferably of fodder value. All these systems utilize the land mass intensively and synergistically with general increase in soil fertility and soil organic carbon with time.

Harnessing the Indigenous Technical Knowledge of Farmers

Research works from plateau region clearly demonstrate that indigenous people and their knowledge are central to the adaptive changes using available natural resources essential to face the world's changing climate (Dey and Sarkar, 2011). Farmers in South Asia, often poor and marginal, are experimenting with the climatic variability for centuries. There is a wealth of knowledge for a range of measures that can help in developing technologies to overcome climate vulnerabilities. There is a need to harness such knowledge and fine-tune them to suit the modern needs of carbon sequestration.

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Integrated Nutrient Management under High RSC and Saline Water Irrigation

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In many arid and semi arid regions of the world sodic ground water is the main or only source of irrigation and its use poses a threat to agricultural production. Application of gypsum as soil or water amendment is commonly recommended to offset the deteriorating effects of that type of water. Gypsum effectiveness on soil reclamation has been extensively reported (Oster, 1982, Yaduvanshi and Swarup, 2005). Out of 188 M ha-m/year total water resources of India, contribution of ground water is 69 M ha-m/year. However, actually utilizable water resources are only 110.8 M ha-m/year and of which 38% comes from ground water. Some work has also been reported on the response of crops irrigated with poor quality water to gypsum application (Bajwa *et al*., 1983, Bajwa and Josan, 1989; Manchanda *et al*., 1985; Shainberg *et al*., 1989; Minhas *et al*., 1996; Josan *et al*., 1998; Chaudhary *et al*., 2003).

Prolonged use of such waters also creates sodicity/salinity problems and induces severe nutritional disorders/imbalances in the irrigated soils and crops leading to reduced crop yields (Yadav, 1989; Bajwa *et al*., 1993). The use of sodic waters increases pH, SAR and ESP in the soils and leaves adverse effects on crop yields (Bower *et al*., 1968; Bingham *et al*., 1979; Shainberg *et al*., 1981; Ayers and Westcot, 1985; Bajwa and Josan, 1989; Rhoades *et al*., 1992; Minhas and Bajwa, 2001; Chaudhary *et al*, 2003; Sharma and Minhas, 2004). Irrigation with sodic water also leads to soil dispersion and clogging of pores due to clay migration (Grattan and Oster, 2003). Eventually, soil aeration and permeability are adversely affected. It necessitates the development of special agronomic and nutrient management practices to minimize the adverse effects on soil properties and crop yield under sodic water conditions. The solutions needed to achieve sustainable soil quality and plant production using sodic water are salt tolerant plant species, cropping strategies that maintain favourable agronomic conditions, and optimum and balanced nutrient availability at active crop growth stages, periodic application of non-sodic irrigation waters, routine monitoring of soil solution chemistry and irrigation water quality, and periodic application of chemical amendments to neutralize sodium hazards on irrigated soils (Oster and Shainberg, 2001). Based on the understanding developed, information on specialized integrated nutrient management practices for controlling the build-up of ESP, maintaining the physical and chemical properties of sodic water irrigated soils and sustaining crop production are discussed in the following section.

Management of Sodic Water

The major approaches to improving and sustaining agricultural productivity in any stress including sodic environment involve: (i) modifying the environment to suit the available plants physiology; and (ii) modifying the plants to suit the sodic environment. They could be used separately or together to make possible the productive utilization of sodic water without compromising the sustainability of the production resource at different management levels. Sodic water has low total salt concentration (EC <4 dS/m) and composition of salts is often dominated by sodium (>70%) with very small proportion of Ca and Mg. such water usually have $NaHCO_3$ as predominant salt making their RSC >2.5 meq/l. Some times Ca-salts are nearly absent in sodic water. Irrigation with sodic/alkali water leads to increase in soil sodicity and sodium saturation. The increase in ESP adversely affects soil physical properties like infiltration, aeration and soil structure. Such soils upon wetting get dispersed and clog soils pores affecting aeration, root respiration and development, but on drying they become very hard. Poor respiration cause yellowing of crop seedlings during early irrigation. The irrigation water with low Ca^{2+} (<2 meq/l) and high CO_3^{2-} results in specific toxicity like scorching and leaf burning at early crop growth stage.

Selection of tolerant crops is one of the major practices that help to utilize sodic waters. 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 and high sodicity tolerance such as barley, wheat, mustard, oat, pearl-millet and sorghum *etc*. The other guidelines pertinent to selecting crops suitable for sodic waters are:

- Cultivation of high water requirement crops like sugarcane and rice should be avoided with sodic water use as its irrigation lead to ESP build-up in surface soil layer.
- Fields should be kept fallow during *kharif* (summer) in low rainfall areas (<400 mm) where good quality water is not available.
- Sorghum-wheat, cluster bean-wheat, pearl millet-wheat and cotton-wheat rotations can be grown successfully 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 are applied to *kharif* crops.
- In alluvial plains with rainfall ≥600 mm, rice-wheat, rice-mustard, sorghum-mustard, and *Sesbania* (GM)-wheat rotations can be successfully practiced with gypsum application.
- Sodic water should not be used for summer crops during 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. Gypsum is the cheapest source of Ca and it is available in abundance in our country. Other amendments like phospho-gypsum, pyrites, acids or those forming acids [H_2SO_4, FeS_2, S, $Al_2(SO_4)$] can also be used which on reaction with soil $CaCO_3$ release Ca^{2+}. Requirement of gypsum depends on RSC level of water, existing levels of soil sodicity, cropping intensity and crop water requirements. Field observations suggests that gypsum application increases or maintains the yield of rice based cropping systems when irrigated with water of RSC >5 meq/l under 500 mm rainfall conditions, whereas in case of fallow-wheat system water upto 10 meq/l can be used safely on light texture soils without addition of gypsum. After ascertaining the need of gypsum amendment, its amount, mode and time of application can be decided as under.

Methods and Timing of Gypsum Application in Soil

It is easier to apply gypsum in soil than with 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 amount of agricultural grade gypsum (70% purity) for neutralization of each meq/l of RSC is about 12 kg/ha/cm depth of irrigation. 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)

Nutrient Management

Management of nutrients is one of the most vital factors for sustaining crop production on sodic soils or soils irrigated with sodic water. Optimum supply of nutrients to plants provides essential elements and help in overcoming the adverse affects of salts and specific ions stress. However, like the amelioration techniques, the principle for rate and time of nutrients supply, and the processes governing their availability differ to a great extent with the nature of the salt problem in soil. Solubility, transformations, chemical forms and availability of many essential nutrients is affected by excess ESP, high > 8.2 pH, presence of substantial amounts of $CaCO_3$, soluble $NaHCO_3$, unstable soil structure and poor physical conditions of alkali soils arising due to irrigation with sodic water. Sustained alkali water irrigation for 15 years in cotton/pear millet/maize – wheat system grown on sandy loam soils has been found to cause significant reduction in available N, K, Zn and Mn while P and Cu remained unaffected (Table 11.1)

Table 11.1. Status of available nutrients in long-term (15 years) sodic water irrigated soil

Water quality			Status of available nutrients (kg/ha)						
EC	SAR	RSC	N	P	K	Fe	Zn	Mn	Cu
2	10	5	127	17.6	143	5.50	1.78	7.51	1.40
2	10	10	128	17.1	138	6.08	2.09	7.22	1.40
2	20	5	129	15.5	144	6.18	2.06	7.62	1.14
2	20	10	125	15.9	142	5.96	2.67	7.55	1.34
4	10	5	120	15.9	143	5.70	1.91	6.91	1.28
4	10	10	122	18.4	152	6.14	1.40	6.56	1.32
4	20	5	127	12.6	153	5.46	2.69	7.91	1.33
4	20	10	124	16.0	155	5.76	2.03	6.25	1.37
2	20	0	118	13.0	132	9.80	2.83	13.60	1.46
Good water			149	17.1	183	6.96	3.55	14.14	1.32
CD (5%)			11.9	2.1	18.2	1.65	0.93	3.23	NS

However, analyses of soil samples from other field experiments on sodic water irrigation have shown that sodic soils or soils irrigated with sodic water generally become deficient in Ca, N, Zn, Fe, Mn and other micronutrients. Also sodic water irrigation increases volatilization losses of applied N; and low Ca^{2+} (<2 meq/l) or high HCO_3^-/CO_3^{2-} result in specific toxicity in crops at early crop growth stages. Therefore crops respond to rates and methods of application of different fertilizers under these conditions. Processes of their transformations and availability under alkali soil conditions are discussed as under:

Calcium: Alkali soils contain sufficient amount of exchangeable Na (ESP >15) to cause soil dispersion and increase the pH (>8.5), thereby adversely affecting both the physical and nutritional properties of soil with consequent reduction in crop growth, significantly or entirely. The soils are deficient in both soluble and exchangeable calcium. Similarly, sodic water irrigation causes precipitation of soluble Ca into sparingly soluble $CaCO_3$ and thus decreasing its availability to crop plants. Further, increasing soil ESP with sodic water and its high SAR causes Na antagonism to Ca uptake in crop plants. Thereby in alkali conditions, crop plants are affected in two ways *i.e.* sodicity sensitive plants accumulate toxic levels of Na in high sodicity conditions and in moderately alkali conditions lack of supply of adequate Ca affect its availability (Table 11.2). Calcium deficiency arising with sodic water (Yadav and Kaledhonkar, 1998) use has been reported to cause physiological disorders as poor boll opening in cotton and fruit end rot in tomato. Absolute Ca contents and its concentrations in relation to Na are good indices of proper growth of crop plants under sodic environments.

Table 11.2. Ca and Na contents of some crop plants under different soil sodicity levels

ESP	Safflower		Raya		Cowpea	
	Ca	Na	Ca	Na	Ca	Na
8.0	1.36	1.01	2.98	0.50	2.35	0.16
16.0	1.28	1.85	2.80	1.00	2.24	0.25
40.0	0.63	2.81	1.84	3.02	1.72	0.66

Calcium can be supplied through addition of Ca-bearing chemical amendments, acids and acid forming substances as indicated in the above section (amendment requirements) of this chapter, which upon reaction with native $CaCO_3$ release Ca. Another option can be use of organic manures like FYM or presmud which under anaerobic conditions during flooding of sodic soils create increased pCO_2 and help in solubilisation of native $CaCO_3$ and release Ca and in turn removes Na from exchange complex (Swarup and Yaduvanshi, 2004). Similarly growing of grasses, crops and other plantations also increase solubility of native $CaCO_3$ through biological actions of their roots, thus adequate addition of amendments and adopting the agronomic practices which enhance native $CaCO_3$ solubility and neutralization of sodicity of irrigation water to avoid further precipitation of native Ca are helpful in reclamation of alkali soils and thus production of good crops.

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. Mineralization of organic matter and organic forms of N under reduced infiltration and poor physical conditions is restricted to ammonification stage only due to lack of aeration or more specifically O_2. A major amount (10-60%) of accumulated NH_3 is liable to volatilization under field moisture range. Ammonia volatilization loss rate follow a first order reaction and its half life range from nearly 62 days at field capacity to only 10 days under irrigation with alkali water causing waterlogged conditions. Singh and Bajwa (1990) observed increasing NH_3 volatilization losses with increase in EC, RSC and SAR of irrigation water.

The results of an experiment where ammonium fertilizers were broadcasted directly on the soil 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 in unreclaimed alkali soils. Another field study 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 11.3) , possibly because in the former, nitrifying population could adequately oxidize the ammoniacal - N slowly mineralized from green manuring (Yaduvanshi, 2001). 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.

Table 11.3. Ammonia losses from integrated nutrient management in rice field under reclaimed sodic soil

Treatments	Urea application			Total N lost	Urea N lost (%)	pH
	Ist	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} + GM	5.82	5.20	5.06	16.08	13.40	8.10
N_{120} P_{22} K_{42} + FYM	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 (5%) Stage of urea application	0.51 0.32	0.91	1.19			

Amount of fertilizer nitrogen: Salt affected soils in the Indo-Gangetic alluvial plains have low organic matter. Surface and profiles soil samples analyzed in these soils and reported all of them to be containing less than 0.4% organic carbon. Majority of these soils had <0.2% organic carbon. Many experiments conducted in salt affected soils clearly shows that both rice and wheat crops respond to much higher levels of N under sodic soil conditions than that commonly recommended (120 kg N/ha) under normal soil conditions. The application of 150 kg N/ha is therefore, a common recommendation for both rice and wheat grown in initial reclaimed alkali soils. The crop responses to higher levels of N may be attributed to low inherent organic matter status of these soils, losses of N through volatilization and the beneficial effect of N in increasing the ability of plant to tolerate higher salinity or sodicity.

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. For grain production rice and wheat plants use nitrogen most efficiently when it is applied at the maximum 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 in maximum efficiency (Dargan and Gaul, 1974). 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 under sodic water conditions (Yaduvanshi and swarup, 2005).

Phosphorous: Next to nitrogen, P is the most critical nutrient required for efficient crop production in normal soils. As such, sodic water irrigation does not alter the availability of P initially. However, with continuous use causing development of sodicity in soil its solubility is enhanced and availability pattern becomes similar to alkali soils. 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).

Long-term field studies were conducted on a gypsum amended alkali soil (pHe 8.6, ESP 32) with sodic water (pH 9.00 and RSC 8.5 meq L-1) used in rice- wheat cropping sequence and NPK fertilizer use for 10 years (1994-95 to 2003-04). The sources of N, P and K were urea, single super phosphate and muriate of potash respectively. Phosphorus applied at a rate of 26 kg P/ha to both rice and wheat crop in rotation significantly enhanced the grain yield of rice (Yaduvanshi and Swarup, 2005). When Olsen,s extractable P in 0-15 cm soil depth had cometo the initial level of 14.8 kg P/ha to 8.50 kg P/ha which is very close to widely used critical soil test value of 11.2 kg P/ha. Wheat responded to applied 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) in the lower depths (15-30 cm). Further studies that crop responses to applied P were limited to only level i.e. 11 kg in the initial years of cropping and that too only to rice crop in a rice-wheat cropping sequence. Application of 26 kg P/ha significantly increased the rice and wheat yield. It has been observed that rice starts responding to P application after 5 years of reclamation process in comparison to 7-8 years in case of wheat. Rice, being shallow rooted (30 cm) crop responds early because of depletion of surface layers but wheat continues to explore reasonably deeper (75 cm) for about 30 extra days as it is deep rooted and relatively longer duration crop. These results indicate that P fertilization should be made early in rice than wheat.

Potassium: Application of K fertilizer to either or both the crops had no effect on yields of rice and wheat (Yaduvanshi and Swarup, 2005). 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 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 and decreased to 69.9% with use of K. The decreased was about 50.6 % with use of K combined with organic manures (Yaduvanshi, 2001).

Zinc: Continuous use of sodic water leads to development of alkali soils. Though these soils have been observed to be sufficient (40-100 ppm) in total Zn but low in its available fraction as only 3.3% of total amount has been found as exchangeable, complexes, organically bound and occluded forms, which are considered as available during crop growth period. Reasons for low contents of available fractions of Zn under sodic/alkali conditions are high pH, formation or presence of $CaCO_3$, high soluble P and low organic matter. Availability of Zn in these conditions is regulated by solubility of $Zn(OH)_2$ and specifically of $ZnCO_3$ with sodic water irrigation, the immediate reaction products after its application. Zn deficiency has been found to be widely prevalent in rice with symptoms appearing as white appearance of young leaves at early stages, delayed crop maturity and reduced yields. Application of 25 kg $ZnSO_4$/ha/annum is essential and sufficient for crops of both seasons where sodic water is used for irrigation. In arid and semi arid regions where soils are generally calcareous the availability of all micronutrients in general and Zn in particular decreases when irrigation with high sodicity water is practiced. Minhas and Chhiba (1999) found that water soluble plus exchangeable Zn fraction increased while insoluble residual fraction decreased with increase in RSC of irrigation water. This could be due to formation of soluble sodium zincate. Singh (1999) had also recorded that with use of sodic water (RSC 10 and 20 meq/l) Zn application at 20 kg/ha improved the grain yield of rice under no gypsum treatment but in presence of gypsum increase was found to be non-significant.

Use of Inorganic Fertilizers with Organic Manures

Addition of organic materials is observed to improve sodic soils through mobilization of inherent Ca^{2+} from $CaCO_3$ and other minerals by organic acids and increased pCO_2 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.,* 1994). Nevertheless, majority of the available reports still suggest overall beneficial positive role of organic manures in proving soil properties and crop yields. Response of organic sources also varies with the nature of organic matter added. The 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. Long-term nutrient management strategies developed so far for improving rice-wheat production on sodic lands are potentially applicable to areas irrigated with poor quality underground irrigation water.

Recent studies on integrated nutrient management have shown that rice and wheat yields increase significantly with integrated use of gypsum or FYM or pressmud and 100% of recommended levels of inorganic NPK fertilizers in comparison to inorganic fertilizers alone. The mean yield of rice under recommended dose (N_{120} P_{26} K_{42} kg/ha) with gypsum or FYM or pressmud or gypsum + FYM or gypsum + pressmud was 5.23, 5.29, 5.31, 5.35 and 5.41 t/ha, respectively during 10 year cropping period (1994-2003) in comparison to 4.79 t/ha (Table 11.4) with recommended levels of fertilizer only (Yaduvanshi and Swarup, 2005).

Table 11.4. Effect of gypsum with and without different organic manures on yield of rice and wheat and soil properties

Treatments	Mean yield (t/ha)		Soil pH	Organic carbon (%)
	Rice (1994-2003)	Wheat (1994-2004)		
N_{120} P_{26} K_{42} (100% recommended)	4.79	3.69	8.52	0.26
N_{120} P_{26} K_{42} + FYM	5.29	4.16	8.38	0.43
N_{120} P_{26} K_{42} + Gypsum	5.23	4.10	8.18	0.37
N_{120} P_{26} K_{42} + Pressmud	5.31	4.46	8.29	0.42
N_{120} P_{26} K_{42} + FYM + Gypsum	5.35	4.22	8.28	0.42
N_{120} P_{26} K_{42} + PM+ Gypsum	5.41	4.52	8.28	0.40
CD (5%)	0.42	0.34	0.08	0.60
Initial soil properties			8.6	0.40

The NPK fertilizer with 10 t/ha FYM, 5 t/ha gypsum or 10 t/ha pressmud produced higher yields over the years as compared to application of recommended dose of inorganic NPK alone. The residual effect of FYM, gypsum and pressmud was significant on wheat yields after 5 years. Though yields of both crops improved further when gypsum was applied with FYM or pressmud, but the benefite were not over the FYM and pressmud alone treatment. Application of recommended NPK fertilizer combined with FYM or pressmud gave the highest profit followed by gypsum treatments. The cost/benefit ratio from 10 t/ha each pressmud (1.65) or FYM (1.59) were higher in comparison to gypsum application (1.38). There was substantial improvement in organic carbon and available nitrogen, phosphorus, potassium and zinc in soil over the initial status. (Yaduvanshi and Swarup, 2005; Swarup and Yaduvanshi, 2004)

Residue Management: Large quantities of combine harvested rice and wheat straw (37.87 Tg) are being produced in states of Punjab, Haryana and Uttar Pradesh. The residues are being burnt, presently, to clear the fields for timely sowing of crops and convenience of disposal. Rice and wheat residues have the potential of 0.634 Tg of N, P and K nutrients. One tonne of rice residue contains approximately 6.1 kg N, 0.8 kg P and 11.4 kg K, while one tonne of wheat residues contains 5.1 kg N, 1.2 kg P and 10.5 kg K. Incorporation of wheat residue 50 days prior to rice transplanting either alone or with green manuring or with sulphitation pressmud and recommended dose of 120 kg N and 26 kgP/ha resulted in significant improvement in rice yield as compared to recommended dose of chemical N and P fertilizer alone. The mean yield improvement in both the crops due to incorporated of various organic sources over 100% of recommended dose of NP was 26.1%, while it was only 6.6% in the treatment where the residue was burnt. Sodic water irrigation over three years period of experimentation, increased soil pH by 0.10-0.16 units (Table 11.5). However, in treatments with organic sources, pH remained nearly at the initial level (Yaduvanshi and Sharma, 2007a and b). As crop residues are rich source of organic mater, nutrients and energy, they must be returned to the soil. Besides the loss of organic matter and plant nutrients, burning of crop residues also cause atmospheric pollution in form of toxins and green house gases.

Table 11.5. Effect of crop residue management on yield (mean of 3 years) and soil properties of alkali soil under poor quality water

Treatments	Grain yield (t/ha)		pH	Organic carbon (%)
	Rice	Wheat		
N_0 P_0	1.05	0.87	9.35	0.25
N_{90} $P_{19.5}$ (75% NP)	2.69	2.31	9.35	0.25
N_{120} P_{26} (100% NP)	3.49	2.94	9.31	0.26
100% NP + wheat residue burning	3.72	2.99	9.33	0.30
100% NP + Incorporated wheat residue	4.34	3.19	9.20	0.35
100% NP+ Incorporated wheat residue + GM	4.45	3.35	9.18	0.35
100% NP+Incorporated wheat residue+ SPM	4.41	3.34	9.20	0.34
CD (5%)	0.58	0.45	-	0.02

Resource Conservation: The results from studies on tillage practices have shown that no-tillage (NT) practice increases organic carbon and infiltration rate of sodic water irrigated soil in comparison to conventional tillage conditions. No-tillage practice also decreased soil pH and SAR. The NT either alone or with residual effect of gypsum or pressmud or FYM has been found as an effective option to sustain higher yields of wheat under use of sodic water irrigation in a rice-wheat system; besides saving of 7.22 cm of irrigation water and three disking and planking operations (Yaduvanshi and Sharma, 2008).

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Management of Saline/Sodic Water for Crop Production

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In arid and semi arid regions, water is becoming an increasingly scarce resource and planners are forced to consider any sources of water which might be used economically and effectively to promote further development. At the same time, with population expanding at a high rate, the need for increased food production is apparent. The potential of irrigation to raise both agricultural productivity and the living standards of the rural poor has long been recognized.

Concern about the proper utilization of poor quality waters for crop production in areas where their use is inevitable is not new. Researchers have made concerted efforts for the development of management practices which prevent the build-up of salinity, sodicity and toxicity in the rootzone at levels which limit the productivity of soil. This can only be achieved if the effect of factors such as rainfall, climate and water table and water quality characteristics on soils and crops are integrated for evolving appropriate crop/agronomic and irrigation management practices.

Although there is no universal definition of 'marginal quality' water, for all practical purposes it can be defined as water that possesses certain characteristics which have the potential to cause problems when it is used for an intended purpose. For example, brackish water is marginal quality water for agricultural use because of its high dissolved salt content, and municipal wastewater is marginal quality water because of the associated health hazards. From the viewpoint of irrigation, use of 'marginal' quality water requires more complex management practices and more stringent monitoring procedures than with good quality water is used.

Typically, qualities of irrigation water which deserve consideration include the salt content, the sodium concentration, the presence and abundance of macro- and micro-nutrients and trace elements, the alkalinity, acidity, and hardness of the water. Under some circumstances, the suspended sediment concentration, bacterial content, and temperature of irrigation water may also deserve attention.

Salt is defined as a water-soluble compound resulting from the combination of an acid and a metal. Generally, we associate the terms saline, salt, and salinity with sodium chloride (NaCl), otherwise known as common table salt. However, salinity of irrigation water generally is a combination of numerous salts (Table 12.1). The cations and anions most frequently found in irrigation water are: sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), sulfate (SO_4^{2-}), and bicarbonate (HCO_3^-).

Table 12.1. Some salts commonly contributing to the salinity of water

Salt	Symbol	Common name
sodium chloride	NaCl	Table salt
calcium chloride	$CaCl_2$	Common de-icing agent
magnesium chloride	$MgCl_2$	Common de-icing agent
sodium sulfate	Na_2SO_4	Thenardite; Glauber's salt when hydrated
calcium sulfate	$CaSO_4$	Gypsum
magnesium sulfate	$MgSO_4$	Epsom salt
sodium bicarbonate	$NaHCO_3$	Baking soda
calcium carbonate	$CaCO_3$	Limestone
calcium-magnesium carbonate	$CaMg(CO_3)_2$	Dolomite

All water used for irrigation contains some salts generally having adverse effects on agricultural crop performance and can also affect soil properties. The salt in water generally comes from weathering of soil, leaching of salts, dissolution from geologic marine sediments into the soil solution or ground water, and flushing of salts off of roads, landscapes and stream banks during and following precipitation events. Typically, ground water contains more salt than surface water. Additionally, the amount of salt found in irrigation water is more in arid and semi arid areas than in humid and subhumid areas.

Effect of Salinity on Plant Growth

Salinity becomes a problem when enough salts accumulate in the root zone to negatively affect plant growth. Excess salts in the root zone hinder plant roots from withdrawing water from surrounding soil. This lowers the amount of water available to the plant, regardless of the amount of water actually in the root zone. For example, when plant growth is compared in two identical soils with the same moisture levels, one soil receiving salty water and the other receiving salt-free water, plants are able to use more water from the soil receiving salt-free water. Although the water is not held tighter to the soil in saline environments, the presence of salt in the water causes plants to exert more energy extracting water from the soil. The main point is that excess salinity in soil water can decrease plant available water and cause plant stress.

Soil water salinity is dependent on soil type, climate, water use and irrigation routines. For example, immediately after the soil is irrigated, plant available water is at its highest and soil water salinity is at its lowest. As plants use soil water, the remaining water is held tighter to the soil and becomes progressively more difficult for plants to extract. As the water is taken up by plants through transpiration or lost to the atmosphere by evaporation, soil water salinity increases because salts become more concentrated in the remaining soil water. Thus, evapotranspiration (ET) between irrigation periods can further increase salinity.

Effects of Salinity on Soil Physical Properties

Soil water salinity can affect soil physical properties by causing fine particles to bind together into aggregates. This process is known as flocculation and is beneficial in terms of soil aeration, root penetration, and root growth. Although increasing soil solution salinity has a positive effect on soil aggregation and stabilization, high levels salinity can have negative and potentially lethal effects on plants. As a result, salinity can not be increased to maintain soil structure without considering potential impacts on plant health.

Management Practices for Efficient Use of High Salinity Water

More Frequent Irrigations: The adverse effect of the high salinity of irrigation water on the crops can be minimized by irrigating them frequently. More frequent irrigations maintain higher soil water contents in the upper parts of the root zone while reducing the concentration of soluble salts. Both these factors result in reduced effect of high salts on the availability of water to plants and therefore, promote better crop growth. The sprinkler method of irrigation is generally more amenable to increased frequency of water applications. In surface irrigation methods however, more frequent irrigations almost invariably result in an appreciable increase in water use.

Identification of Salinity Sensitive Growth Stages: All crops do not tolerate salinity equally well at different stages of their growth. Differences in salt sensitivity of crops at various growth stages (ontogeny) should help in planning appropriate irrigation management measures especially where both saline and non-saline waters are available. The use of saline waters can be avoided at some of the sensitive stages to minimize the salinity damage (Table 12.2).

Selection of Salt Tolerant Crops and Varieties: There is a wide range in the relative tolerance of agricultural crops to soil salinity. Proper choice of crops can result in good returns even when using high salinity water, whereas use of saline water for growing a relatively salt sensitive crop may be questionable. Similarly, selection and breeding of salt resistant crop varieties offer tremendous possibilities of utilizing saline water resources for crop production. Some workers have suggested induction of salt tolerance by soaking seeds for a certain period in salt solutions as a method for obtaining increased yields in saline water irrigated soils, while others suggest that growing seeds obtained from parents that have been irrigated with saline water helps in obtaining higher crop yields. These suggestions, however, have to be tested extensively on a field scale.

Table 12.2. Relative sensitivity of the crops at their growth stages

Crop	Relative sensitivity
Agra, Sandy loam soil	
Mustard	Presowing (12.6) >flower initiation (16.9) >secondary branching (28.0)
Wheat	Presowing (9.0) >flowering (13.3) >milking (20.0) >crown root initiation (24.0) >jointing
Barley	Crown root initiation (15.9) >presowing (23.9) >flowering/booting (23.9) >jointing
Safflower	Presowing (8.1) = Rosette (8.1) >flower initiation (12.1) >main head opening (24.2)
Dharwad, silty clay loam, black soil	
Paddy	Transplanting (2.7) >50% flowering (6.0) >end of tillering (7.3)
Wheat	Presowing (2.9) >crown root initiation (5.7) >milking (6.7) >flowering (8.9) >jointing (9.2)
Maize	Silking (6.9) >tasseling (7.6) >presowing (14.1) >knee height
Pigeonpea	Presowing (2.1) >flowering to pod development (4.2) >flowering (5.7) >seedling to flowering (7.1)
Bapatla, silty clay loam and loamy sand soil	
Sunflower	Seeding (2.0) >flower bud initiation (4.7) >grain filling (4.8) >germination to flowering (6.2)
Onion	Transplanting to bud formation (1.6) >Bulb formation to bulb development (14.1) >bulb development to maturity (5.9)
Groundnut	Germination to pegging (2.3) >pegging to pod formation (4.5) >pod formation to maturity (5.9)
Blackgram	Flowering to maturity (1.1) >seeding (3.2) >seeding to flowering (6.1)

EC_{iw} values in parentheses indicate 10% reduction in potential yield, if water of the indicated EC_{iw} (dS/m) value is used at the specified growth stage and non-saline water is used at all other stages
(Source: Minhas and Gupta, 1992)

Use of Extra Water for Leaching: To prevent excessive salt accumulation in the soils, it is necessary to remove salts periodically by application of water in excess of the consumptive use. The excess water applied will remove salts from the root zone provided the soil has adequate internal drainage. This concept (Richards, 1954) is quantified in the term 'leaching requirement' often referred to by the abbreviation, LR. By definition, leaching requirement (LR) is the fraction of total water applied that must drain below the root zone to restrict salinity to a specified level according to the level of tolerance of the crop.

$$LR = \frac{D_{dw}}{D_{iw}}$$

Where:
D is the depth of water and dw and iw refers to the drainage water and irrigation water. Assuming strict salt balance conditions in the soil-water system:

$$D_{iw} \times C_{iw} = D_{dw} \times C_{dw}$$

Where: C is the concentration of salts

Therefore,

$$LR = \frac{C_{iw}}{C_{dw}} \text{ or } \frac{EC_{iw}}{EC_{dw}}$$

This would imply that the excess amount of irrigation water of a known EC that must be applied is determined by the maximum permissible EC of the drainage water specified for a particular crop. The values of EC_{dw} represent the maximum salinity tolerated by the species grown under particular conditions (Mass and Hoffman, 1977).

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.
- 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 "*Doruvu*" system with specially designed subsurface 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

- 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: Farmyard manure 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.

Application of excess water, above that needed for meeting the evapotranspirational needs, though useful for salinity control, puts a high demand on the water resources on the one hand and increases the salt load of the drainage water on the other. It therefore appears that controlling the interval between irrigations is the most important management practice for obtaining higher yields with high salinity water and this could be achieved by the sprinkler, drip or the surface irrigation methods.

Conjunctive Use of Fresh and Saline Waters

There are situations where good quality water is available for irrigation but not in adequate quantities to meet the evapotranspirational needs of crops. Under these conditions, the strategies for obtaining maximum crop production could include mixing of high salinity water with good quality water to obtain irrigation water of medium salinity for use throughout the cropping season. Alternatively, good quality water could be used for irrigation at the more critical stages of growth, e.g. germination, and the saline water at the stages where the crop has relatively more tolerance.

Conjunctive use: Conjunctive use refers to simultaneous use of surface and ground water to meet crop demand. In regions with primary salinity, conjunctive use of surface and ground water presents unique challenges and opportunities, to maintain both water and salt balances. In many cases, the canal water supplies are either unassured or in short supply such that farmers are often forced to pump groundwaters of varying quality for crop production. This calls for using the limited quantities of non-saline (canal) waters most judiciously in combination with poor quality waters. For the combined use of saline and non-saline waters, two options are available to the farmers:

Mixing: Mixing of low quality water with the canal water can dilute low quality water to acceptable level so that the farmers are able to use it for their choice of crops. The ratio of mixing can be worked out depending upon the salinities of saline water and the desired salinity by using the equation:

$$(EC_{cw} \times F_{cw}) + (EC_{tw} \times F_{tw}) = EC_{mw}$$

Where EC_{cw}, EC_{tw} and EC_{mw} are the EC of canal, tube well and mixed water respectively and F_{cw} and F_{tw} are the fractions of canal and tube well water.

Cyclic Use: This strategy involves the substitution of non-saline (canal) water for saline water at most sensitive growth stages/crops grown in sequence; saline water is used at other stages such that the effects of the resultant soil salinity build-up can be minimized. In most of the crops, the germination and seedling establishment has been identified as the most sensitive stage to saline water use. A failure at this stage will lead to poor stands and considerable reduction in yield. In studies conducted by Minhas *et al*. (1989, 1990a, b), it was observed that mungbean, sorghum and Indian mustard tolerated the salinity build-up due to use of higher salinity waters, once the non-saline water was substituted for presowing irrigation to leach out salts of the seeding zone. Substitution of non-saline water for presowing irrigation markedly enhanced germination, crop growth and also resulted in better utilization of soil water even from the lower soil depths. Thus, it is better to use non-saline water in early stages and switch over to poor quality waters later when the crop can tolerate higher salinity (Table 12.3).

Table 12.3. Water extraction patterns following the use of different salinity waters

EC_{iw} (dS/m)	Seed yield (q/ha)	Water extracted (cm) from soil layer (cm)				
		0-30	30-60	60-90	90-150	Total
Mung bean						
0.3 (throughout)	25.2	27.8	9.7	4.0	3.3	44.8
4.7 (throughout)	2.7	16.6	5.8	0.2	-	22.6
4.7 (PInsw)	15.6	23.4	9.7	4.2	0.7	38.1
Sorghum*						
0.3 (throughout)	97.0	18.4	7.7	2.6	2.3	31.0**
4.7 (throughout)	65.0	17.0	5.1	2.0	0.5	24.7
4.7 (PInsw)	85.0	19.1	6.9	3.7	2.0	31.7
Indian mustard						
0.3 (throughout)	23.2	19.5	9.0	6.2	2.2	36.9
12.3 (throughout)	10.5	10.7	5.1	1.8	0.5	18.1
12.3 (PInsw)	18.0	13.7	7.7	4.8	1.7	27.9

*PInsw: presowing irrigation with non saline water, * dry forage yield, ** upto last irrigation only*
Source: Minhas et al. (1989, 1990a, b)

Cultural Practices

Cultural practices can often be modified to reduce the hazard of high salts in the irrigation water. Similarly a modification in the method of irrigation can result in improved use of water for some crops.

- 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 spacing and use 20-30% extra seed than under normal conditions.

Management Practices for Sodic Water

As in the case of irrigation water with a salinity hazard, appropriate management practices can often help in better and more efficient use of water with a high sodicity hazard. These practices include:

Growing Tolerant Crops: Growing crops tolerant to excess exchangeable sodium and poor soil physical conditions will help obtain better returns than if sensitive crops are grown.

Application of Amendments: Since accumulation of the sodium ion on the exchange complex is mainly responsible for poor soil physical properties, irrigation water having a sodicity hazard could be improved by increasing the soluble calcium status of the water, thereby decreasing the proportion of sodium to the divalent cations and therefore its adsorption on the soil exchange complex. Applied soluble calcium salts will also neutralize the bicarbonate and carbonate ions thereby reducing the sodicity hazard of the water. Bhumbla and Abrol (1972) recommended that for RSC values up to 2 mmol (+)/1 there was no need to apply an amendment. For higher RSC values, the required amounts of amendment should be calculated and the recommendations made accordingly. Thus the gypsum needed to decrease RSC by 1 mmol (+)/1 works out to 850 kg/ha-m of water. Gypsum can be either incorporated in the soil or lumps of gypsum can be suitably placed in the water channel to dissolve gradually.

Mixing with Fresh Water: If an alternate source of irrigation water is available, mixing the two sources may be helpful in obtaining water which is acceptable for irrigation considering its sodicity hazard. Detailed chemical analysis and the quantities in which the water is available from the two sources can help in deciding the proportions in which they need to be mixed.

Irrigating More Frequently: Irrigating frequently with small quantities of water is an effective way to manage water with a sodicity hazard. While reduced permeability of the soils restricts water supply to the roots, applying large amounts at a time can also result in surface stagnation which would affect most crops adversely. Using sprinkler irrigation with the ability to supply controlled amounts of water at a time should be considered where feasible.

Growing Low Water Requiring Crops: When the irrigation water tends to create a sodicity problem, it is advisable to use small quantities of water, waters. Unlike saline water, where application over and above the evapotranspiration requirements is recommended, extra application of water with a sodicity hazard will further aggravate the problem. If feasible, growing crops and irrigating during periods of high evapotranspiration demands should be avoided.

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Mitigating the Influence of Poor Quality Water through Agronomic Manipulations

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Availability of fresh water supplies to agriculture sector in future is likely to reduce world over and particularly in the Asian countries due to alarming population pressure, high 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 ground water that constitutes about 30-80% of total ground water development containing varying soluble salt concentrations (Minhas and Gupta, 1992; Minhas and Bajwa, 2001). Ground water of arid regions is largely saline while it is sodic in semiarid regions. 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. In addition to reduced productivity, it deteriorates the quality of produce and also limits the choice of cultivable crops.

Long-term use of such water results in increased soil pH, and accumulation of exchangeable Na, increasing salt concentration, creating a hostile environment in the soil rhizosphere, which adversely affects plant growth. Irrigation with sodic water also leads to soil dispersion and clogging of pores due to clay migration (Grattan and Oster, 2003). Eventually, soil aeration and permeability are adversely affected. It necessitates the development of special physiological, agronomical and nutrient management practices to minimize the adverse effects on soil properties and crop yield. The solutions needed to achieve sustainable soil quality and plant production using poor quality water are salt tolerant plant species, cropping strategies that maintain favourable agronomic conditions, and optimum and balanced nutrient availability at active crop growth stages, periodic application of non-sodic/ saline irrigation water, routine monitoring of soil solution chemistry and irrigation water quality, and periodic application of chemical amendments to neutralize sodium hazards on irrigated soils (Oster and Shainberg, 2001). Efficient, balanced and integrated nutrient management, irrigation and agronomic management strategies are extremely important to increase yields to match the potential yields obtained under good quality irrigation water.

Extent and Distribution of Saline/Sodic Water

Alluvial terrain of Indo-Gangetic plains is one of the richest water bearing formations where aquifers are extensive, thick and extend beyond 150 meters. As far as quality of ground water in terms of irrigation parameters is concerned, no systematic attempts have been made so far in the country for arriving at authentic estimates of sodic/saline or high SAR saline ground water resources. However, the first approximation estimates suggest that 32-84% of the ground water resources of Indian states are either saline/or sodic and high SAR saline. Ground water is dynamic in nature and generally in equilibrium with Ca ions in the areas of discharge. When ground water approaches the surface, CO_2 escapes and its pressure dropped leading to precipitation of calcite and sometimes magnesium. Under these circumstances if evaporation process remains strong, even Ca^{2+} precipitates as gypsum making the ground water sodic. But consequently on mineralization, the ground water in arid and semiarid areas change from alkaline HCO_3-SO_4^{2-} type to Cl-Na with formation of *Kankar* in the intervening stage.

High salinity ground water is mostly prevalent in arid parts of north-western states like Rajasthan, Haryana and Punjab while alkali water is distributed mainly in semiarid parts of India where annual rainfall varies from 500-700 mm. As per Central Ground Water Board (1997) estimates, in India an area of 1,93,438 sqkm is underlain with poor quality ground water. Estimates further indicate that out of the net total ground water draft of 7.14 M ha-m in four states of IG basin, about 2.92 M ha-m of marginal/poor quality ground water is used for irrigation. Ground water quality distribution in some of the states in India is given in Table 13.1. About 50% of ground water is either marginal or poor in quality.

Table 13.1. 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

Classification of Irrigation Water

Systematic attempts have been made so far in the country to classify the poor quality 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 sub-groups (Table 13.2).

Table 13.2. Classification of poor quality ground water

Water quality	EC_{iw} (dS/m)	SAR_{iw} (mmol/l)½	RSC (meq/l)
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. Sodic/Alkali waters			
i. Marginal alkali	<4	<10	2.5-4.0
ii. Alkali	<4	<10	>4.0
iii. Highly alkali	variable	>10	>4.0

Management of Saline Water Use

The management options mainly includes the selection of crops, improved crop management/ agronomic practices, improved fertilizer, irrigation and nutrient management, and other cultural practices but there seems to be no single management measure to control salinity of irrigated soil and several practices interact and should be considered in an integrated manner.

Selection of Suitable Crops

The selection of crops and cropping sequences for saline irrigated soils is of paramount importance, since crops vary in their tolerance to salinity and are either too sensitive or semi tolerant to tolerant to a given level of salinity (Table 13.3). The selection of the first crop will depend upon the degree of soil salinity after the basic reclamation measures are implemented. Since complete reclamation may not be attainable in practice, the improvement of the soil is gradual. Hence, crops that are tolerant and can cope up with salinity are preferred in the early phase of reclamation. Appropriate cultivation practices and growing of suitable crops help in leaching of salts and the crop cover prevents re-salinization due to evaporation. 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, 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 soils up to EC_e of 6.5 and 7.5 dS/m, respectively without significant reduction in yield.

Table 13.3. Salt tolerance of some important agricultural crops

Salt tolerance	EC values	Crops
Sensitive	EC_t <1.2 EC_0 <8	Chickpea, Beans, Sesame, Onion Carrot, Green gram
Moderately sensitive	EC_t 1.2- 3 EC_0 8 - 16	Broad bean, Maize, Groundnut, Sugarcane, Alfalfa, Berseem Radish, Paddy, Cauliflower, Chilly
Moderately tolerant	EC_t 3 - 6 EC_0 16 - 24	Wheat, Mustard, Cowpea, Oats, Sorghum, Soybean, Spinach Pearl millet, Muskmelon
Tolerant	EC_t 6 -10 EC_0 24- 32	Barley, Cotton, Sugar beat, Safflower

Crop Cultivars

Saline agriculture can provide food in several ways. Appropriate salt tolerant plants and their cultivars currently growing in saline soil or water can be domesticated and their seeds, fruits, roots, or foliage used as food. In addition to inter-generic variations, crop cultivars also vary in their tolerance to salinity. Such cultivars (Table 13.4) have been identified on their rating for high yield potential, salt tolerance and stability under saline environments.

Table 13.4. 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, KRL 210, KRL 213
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, CS 56
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
Paddy	CSR 30, CSR 36	CSR 10, CSR 13, CSR 23, CSR 30, CSR 36,

In conditions where crop production with saline water use is neither feasible nor economical, such water can be used to raise tree species especially on lands that 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.* Some medicinal plants like Isabgol (*Plantago ovata*), Aloe and Kalmeg have also been found promising alternative to arable crops under saline irrigation conditions.

Agronomic Management

Establishing a good crop stand in saline irrigated soils is a challenging task. Unlike normal soils, the agronomic practices for crop production in saline irrigated soils are different. An ideal package of cultural practices besides soil fertility, nutrient and irrigation water management can ensure a good crop stand vis-à-vis good yield.

Pre-sowing Irrigation: In saline soils, 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 semiarid 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 helps to reduce salinity hazard.

Seed and Sowing: Due to inhospitable soil environment, germination is adversely affected. Mortality of young seedlings and poor tillering of the crops are common in saline soils. Higher seed rate and closer spacing are advisable to counter these effects. For cotton, pearl millet, sorghum, wheat, barley, mustard 25% higher over the recommended seed rate for normal soils ensures good crop stand. In case of transplanted crops, the number of seedlings per hill should be increased. The chemical treatment of seeds and seedlings has been reported to induce salt tolerance. In a field experiment on saline soils (EC_e 12 dS/m), irrigated with saline water (EC_{iw} 10.5 dS/m), the highest yield of wheat was obtained when seeds pre soaked in 3 percent sodium sulphate solution were used. 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.

Mulching: Crop residue at the soil surface reduces evaporative water losses, thereby limiting the upward movement of salt (from shallow, saline ground water) into the root zone. Evaporation and salt accumulation tends to be greater in bare soils. Fields need to have 30 percent to 50 percent residue cover to significantly reduce evaporation. Under crop residue, soils remain wetter, allowing fall or winter precipitation to be more effective in leaching salts, particularly from the surface soil layers where damage to crop seedlings is most likely to occur. Plastic mulches used with drip irrigation effectively reduce salt concentration from evaporation. Subsurface drip irrigation pushes salts to the edge of the soil wetting front, reducing harmful effects on seedlings and plant roots.

Improved Irrigation Management: 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. In saline soils, evapotranspiration needs of crops are modified by the presence of soluble salts. The water availability decreases with increasing salinity of the soil. In this case both matric potential and osmotic potential must be considered while deciding irrigation scheduling in crops. Light and frequent irrigations have to be adopted to keep the soil-water potential at low levels.

Laser Land Leveling: Land leveling is a precursor to good agronomic, soil and crop management practices and the levelness of the land surface has significant influence on all the farming operations including salt distribution. Laser land leveling, the process of smoothening the land surface within $\pm$ 2 mm from its average elevation using laser equipped drag scrapper is one of the few mechanical inputs in intensively cultivated irrigated farming, that meets the objectives of achieving a better crop stand, save irrigation water, improve the input use efficiencies and uniform distribution of salts on the soil surface to reduce the patchy growth.

Irrigation Methods: The irrigation methods are generally categorized as surface, subsurface and sprinklers/drip. Leaching of saline soil with irrigation water is reported to be more efficient when the soil is maintained in unsaturated condition and the rate of water flow is kept relatively slow. Therefore, flood method of irrigation is inferior to sprinkler method in leaching of saline soils. The drip method of irrigation is also suitable for saline water irrigation and helps in maintaining a zone of low salt concentration and higher moisture content resulting in favorable condition for crop growth. In addition to leaching salt below the root zone, salts can also be moved to areas away from the primary root zone with certain crop bedding and surface irrigation systems. The goal is to ensure the zones of salt accumulation stay away from rhizosphere.

Modifications in seed bed 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 (Fig. 13.1).

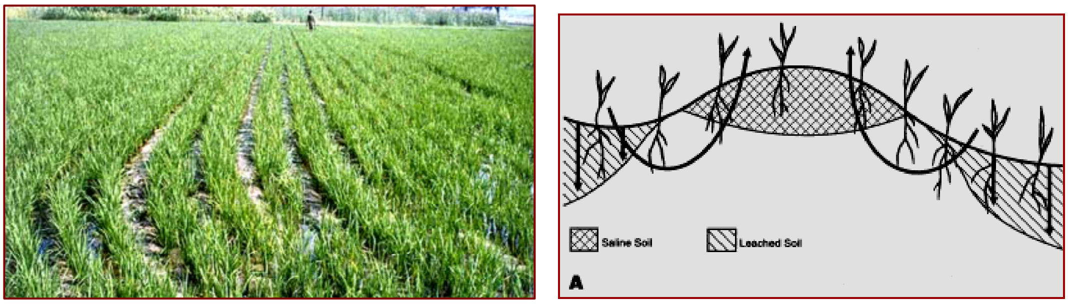

Fig. 13.1. Bed planting system (FIRB) of wheat cultivation and salt distribution in the system

Alternate furrow irrigation may be desired for single-row bed systems. This is accomplished by irrigating every other furrow and leaving alternating furrows dry. Salts are pushed across the bed from the irrigated side of the furrow to the dry side. Care is needed to ensure enough water is applied to wet all the way across the bed to prevent build-up in the planted area. This method of salinity management can still result in plant injury if large amounts of natural rainfall fill the normally dry furrows and push salts back across the bed toward the plants. This phenomenon also occurs if the normally dry furrows are accidentally irrigated.

Irrigation Scheduling: The time, frequency and quantity of irrigation depend largely on water requirement of crops, climatic conditions, and soil characteristics including texture, infiltration rate, moisture- tension relationship, irrigation methods, water quality and water table. Sorghum, pearl millet, cotton, guar, moth, wheat, barely and mustard cannot tolerate standing water and also relatively wet moisture regime whereas linseed and sugar beet will perform better with such a regime. Enough moisture should be present at the time of flowering and seed development stage. 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.

Improved Fertilizer Management: 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. The salt affected soils are often poor in most of the essential plant nutrients owing to lack of vegetation and low organic matter content. Nitrogen deficiency is widespread in saline soils and a large fraction of the applied nitrogen is lost in gaseous forms under high soil salinity. Availability of phosphorus increases up to a moderate level of salinity but thereafter it decreases.

Organic Manures: Bulky 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. However, when salinity of the irrigation water is high, the percent response was less 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.

Management of Sodic Water Use

Crop Selection: The guiding principle for choosing the right kind of crops and cropping patterns suitable for 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 × SAR_{iw} in fallow- wheat, 2.0 × SAR_{iw} in millet-wheat and 3.0 × SAR_{iw} in rice-wheat cropping sequences. Thus, based on the expected ESP to be developed, the sodicity tolerant crops and their varieties can be grown (Table 13.5).

Table 13.5. Relative tolerance to sodicity of soils

ESP levels	Suitable 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
60-70	Rice, Sugarbeat, Karnal grass

Improved Irrigation Management: Among methods of irrigation, conventional irrigation practices such as basin irrigation can be adopted successfully. Sodicity hazard can be reduced to a good extent by using sodic water by mixing with or its cyclic use with good water. This can reduce the requirement of gypsum and simultaneously additional area can be brought under protective irrigation. The sodicity (ESP) of surface soil where the most roots interact defines the potentiality of dispersion, surface crusting and ultimately the infiltration problems. For practical purposes, information on above aspects is required for deciding the suitability of water for periodic build-up of salinity and sodicity in the agriculturally most important soil layer (surface 0.3 m).

Continued irrigation with alkali water alone (AW; EC_w 2.3 dS/m, RSC 11.7 meq/l, SAR 15) in paddy-wheat rotation for 6 years has been observed to increase pH, EC_e, SAR_e and ESP of sandy loam soil (pH_s 7.8, EC_e 0.7 dS/m, ESP 5.3, organic matter 2.9 g/kg soil, clay 15%) compared with good quality water (GW; ECw 0.5 dS/m, RSC nil). However, the rate of increase was high during the initial years; thereafter these parameters get more or less stabilized. In the above case, the average values of pH, EC_e, SAR_e and ESP at the end of experiment in soil irrigated with AW were 8.71, 3.80 dS/m, 19.1 mmol/l and 27.3, respectively (Minhas *et. al.*, 2007). The development of sodicity depends on the equilibrium between the processes of precipitation of calcite and other minerals on concentration of soil solutions with water uptake during the irrigation season and the rainfall induced release of divalent cations both from exchange sites and dissolution of calcite and other minerals.

Gypsum Bed Technique: Adverse effect of alkali water on supply of Ca and physical properties of soils can be mitigated by amendment of such water with Ca-bearing substances like gypsum. Gypsum is the cheapest source of Ca and it is available in abundance in India. Other amendments like phospho-gypsum, pyrites, acids or those forming acids [H_2SO_4, FeS_2, S, $Al_2(SO_4)$] can also be used which on reaction with soil $CaCO_3$ release Ca^{2+}. The amount of agricultural grade gypsum (70% purity) for neutralization of each meq /l of RSC is about 12 kg/ha-cm depth of irrigation. This way the amount of gypsum requirement can be worked out on the basis of quality and quantity of irrigation water required. Gypsum bed technique is a way to reclaim sodic water. In this set-up, sodic water is passed through gypsum beds, a specially designed chamber filled with gypsum clods. The gypsum chamber is a brick-cement-concrete chamber (Fig. 13.2). Size of chamber depends on tube well discharge and RSC of water. This chamber is connected to water fall box of tube well 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.

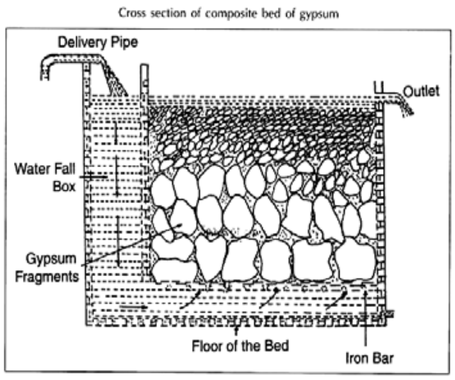

Fig. 13.2. Cross-section diagram and gypsum or pyrite beds

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 litre/sec decreased from 5. 5 to 1.9 meq /l by passing it through a chamber of size 2 .0 m ×1.5 m × 1.0 m. However, this method is not suitable for reclaiming very high RSC water (>12 meq/l) 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 meq/l of Ca. 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 meq/l) after passing through gypsum beds.

Organic Manures: Application of organic manures, besides adding plant nutrients, brings out improvement in the chemical, physical and biological properties of the soil. Increased crop growth resulting from the addition of manures tends to promote soil aggregation, reduce crust formation and causes rapid increase in the biological activity of the soil. It was found that green manuring with *dhaincha* during summer produced rice yield as much as 80 kg N/ha. Subsequent studies showed that incorporation of 60 days old *dhaincha* turns about 60 kg N/ha.

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Phytoremediation of Salt Affected Soils

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Phytoremediation encompasses different techniques of employing microorganisms, green plants and their associated microorganism and agronomic practices to remove, inhibit or neutralize (render them harmless) hazardous environmental contaminants from soil water and air. The technique was used for the first time in Germany about 300 years ago for the treatment of sewage. Phytoremediation is also used to remove organic and inorganic contaminants from soil. As an example, carrot has ability to absorb dichlor-diphenyl-trichlorethylene (DDT: $C_{14}H_9C_{l5}$) and is cultivated in soil contaminated with it. After harvest, it is dried and incinerated to destroy DDT. Phytoremediation of organic environmental pollutants may occur in different ways.

- Absorption of organic matter and accumulation of the same in plant tissues.
- Translocation of organic matter to the leaves from where it is volatilized through leaf surface.
- Metabolization of the organic matter in plant tissues or in the rhizosphere by the action of plant enzyme.
- Microorganisms living in association with plants break down the organic matter and degrade them.

Contamination of soil, water with heavy metals (those with a density greater than 5.0) is another problem. These metals at very low concentrations damage living organisms and accumulate in the food chain. The examples of the heavy metals pollutants include lead, mercury, chromium, cadmium etc. Some of the main sources of major psychiatric disorders in the environment include sewage sludge, mining waste, municipal and industrial waste. Plants can be used to remove heavy metals from the environment and thus reduce the toxic effects of heavy metals on the health of all the living organisms. Several plants often referred as hyper accumulators (metallophyte species that have evolved on metal-enriched soils), are grown for the extraction of heavy metals. Hyper accumulators plants can grow in about 100 times more heavy metals in water or contaminated soil compared to normal plants. Heavy metals are extracted from soil and accumulated in the roots, stems or leaves of plants. The plant is harvested, and then removed and the contaminated area again planted with the new facility for removal of all contaminants from the earth. Some examples of phytoremediation of heavy metals include (Salt, 1998):

1. Indian mustard (*Brassica juncea)* is used to remove heavy metals from lead contaminated soil. *Brassica juncea* can accumulate lead greater than 1000 ppm.
2. *Thlaspi caerulescens* accumulates up to 26,000 ppm of cadmium (Cd) and zinc (Zn) in contaminated soil, while a conventional plant builds about 100 ppm of heavy metals.
3. *Ipomea alpina* collects about 12,000 ppm copper in copper contaminated soils.
4. *Haumaniastrum robertii* accumulates about 10,200 ppm cobalt (Co) from the surface of contaminated soils.
5. *Astragalus racemosus* accumulates 10,000 ppm selenium from selenium contaminated soils.
6. *Sebertia acuminata* is used to extract nickel (Ni) from contaminated soils.

Soil salinity and sodicity (henceforth referred as salt affected soil) are other problems of soil contamination, which have severe negative impacts on agricultural productivity. Salt affected soils are found in every continent. Saline soils have excess of soluble salts (EC_e >4.0 dS/m), mostly chloride and sulphate of sodium whereas, sodic soils have high sodium exchangeable percentage (ESP >15) as well excess of sodium ions (Na^+) in the soil solution phase and carbonate and bicarbonate are major anions. Saline soils have low osmotic potential with high concentrations of Na^+, Cl^- and SO_4^{--} in soil solution and these ions not only create problem of toxicity if taken in excess, but also reduces the activities and uptake of other essentials nutrients like K, Ca, NO_3, and PO4 etc. Higher Na percentage on exchange complex in sodic soils results in unique structural problems like slaking, swelling, and dispersion of clay surface crusting and hard setting, besides nutritional imbalance. These problems can affect water and air movement, plant-available water-holding capacity, root penetration, seedling emergence, runoff and erosion, as well as tillage and sowing operations. In addition, changes in the proportions of nutrients in soil solution and exchangeable ions lead to osmotic and ion-specific effects together with imbalances in plant nutrition, which may range from deficiencies of several nutrients to high levels of Na^+. High pH in sodic soil had its own effects on availability of several nutrients. Impaired Zn availability to plant is one of the most prominent examples in sodic soil. The reclamation of salt affected soils requires removing excess of salts by leaching from root zone and drainage to manage high water table or replacing excess of sodium from exchange complex by calcium. Both these approaches are costly and some time may not be environment friendly. Phytoremediation (biological approach), a plant-based strategy for improvement of salt affected soils is an appropriate option. Phytoremediation of salt affected soils can be done by cultivating suitable plant species as well as by exploiting the ability of plant roots to improve the dissolution of native $CaCO_3$ thus enhancing levels of Ca in soil solution to efficiently remove Na from the soil cation exchange complex which is leached out of the root zone when irrigated. Removal of Na^+ from exchange complex favours soil-aggregates stability, root proliferation, soil hydraulic properties and availability of nutrients to plants is also improved, facilitates cultivation of less tolerant plants, mends the environment in general and the climatic conditions by enhancing carbon sequestration

Phytoremediation of Salt Affected Soils

Most plants do not require Na as a nutrient at least in such a high concentration as often found in salt affected soils. Nevertheless, there are several plant species mostly from *Chenopodiaceae* and *Gramineae* families, which are known to grow comfortably in moderately salt affected soil without substantial adverse effects on total biological yield (Qadar *et al*., 2007). A number of these plants are given in Table 14.1. Some of these are salt excluder, salt excreter and others salt accumulator. Several plants even show positive response to Na and often referred as Natrophilic. This is even true with many of the crop species and varieties at very low level of salt stress. Growing of salt tolerant plant species especially accumulator can help in reclamation of salt affected soil. Materials with higher biomass production in salt affected soils could be more useful.

Table 14.1. Salt tolerant plants identified for phytoremediation of salt affected soils

Plant species	Root zone salinity causing 50% reduction	
	EC_2 (dS/m)	Salt (%)
*Leptochloa fusca**	14.6-22.0	0.93-1.41
Sporobolus arabicus	21.7	1.39
Cyanodon dactylon	13.2-21.0	0.84-1.34
Desmostachya bipinnata	9.0	0.64
Hordeum vulgare	10.0-19.5	3.07
Suaeda fructicosa	48.0	2.43
Kochia indica	38.0	2.43
Atriplex numularia	38.0	2.43
Atriplex amnicola	38.0	2.43
Beta vulgaris	19.0	1.22

**Local name: Kallar grass, Karnal grass, Pakistan grass, Australian grass, beetle grass*

Plant based approach to reclaim salt affected soils have been advocated and found useful. However, it is slow and takes longer time compared to chemical approach or using drainage to leach out salts from root zones. It is particularly effective when used on moderately salt affected soils. In phytoremediation, plants not only take up salts and lower water table, but also enhance dissolution of native $CaCO_3$ and enhanced levels of Ca^{2+} in soil solution replaces Na^+ from the cation exchange complex. As mentioned, phytoremediation is slow but it is advantageous in several ways such as:

- It is cheap and does not put much stress on farmers in terms of finance. It is viable solution for resource poor farmers.

- Cultivation of salt tolerant crops and their varieties in moderately salt affected brings financial benefit.
- Promote soil-aggregate stability and creation of macropores, which improve soil hydraulic properties and root proliferation.
- Availability of plant-nutrient in soil improves after phytoremediation.
- More uniform and greater zone of amelioration in terms of soil depth.
- It is environment friendly also in terms of carbon sequestration.

It is important to have better understanding of the processes associated with phytoremediation, the selection of appropriate plant species having potential to tolerate ambient salinity and sodicity levels in soil and water, and also of the uses and marketability of the produce. In case where stress is too much, a combination of chemical amendments and phytoremediation can help to improve the physical and chemical properties of salt affected soils, thus making these soils suitable to grow conventional crops. One of the earliest studies on phytoremediation and use of chemical amendment to reclaim salt affected soils is that of Kelly (1937) and Kelly and Brown (1934) carried out in 1920s and 1930s. Gypsum was applied in two splits, 22 t/ha in 1920 and 15 t/ha in 1921 in sodic soil. Phytoremediation started with cultivation of barley (*Hordeum vulgare* L.) without any gypsum application for 2 years. It was followed by a one year green manuring each by Indian sweet clover (*Melilotus indicus* L.) and white sweet clover (*M.albus* Medik.), and 5 years under continuous alfalfa (*Medicago sativa* L.). Thereafter, cotton (*Gossypium hirsutum* L.) was grown as the first post amelioration crop. Cotton yields were 1.82 t/ha for the gypsum treatment and 2.1 t/ha for the phytoremediation treatment. Kelly started phytoremediation experiment in 1930 with Bermuda grass [*Cynodon dactylon* (L.) Pers.] as the first phytoremediation crop, which was grown for two years followed by cultivation of barley for 1 year, alfalfa for 4 years, and oats (*Avena sativa* L.) for 1 year. In all, there was 8 years of cropping. Exchangeable sodium percentage (ESP) of the upper 0.3 m soil depth decreased from 70 to 5 in the gypsum-treated soil and from 65 to 6 in the plots subjected to phytoremediation (Table 14.2).

Table 14.2. Effect of gypsum and phytoremediation treatments on ESP

Soil depth (cm)	1920-1930				1930-1937	
	Gypsum[1] + cropping[2]		Cropping[3]		Cropping[3]	
	Initial	Final	Initial	Final	Initial	Final
	ESP					
0.0-30	70	5	65	6	57	1
30-60	67	8	70	21	97	4
60-90	54	9	46	26	90	13
90-120	35	19	28	53	46	4
Profile mean	49	10	52	27	73	6

1. Gypsum application at 37 t/ha in two splits: 22 t/ha in 1920 and 15 t/ha in 1921
2. Cultivation of barley for two, green manuring using clovers for 2 years and alfalfa grown for 5 years
3. Cultivation of Bermuda grass for 2 years, barley for 1 year, alfalfa for 4 years and oats for 1 year
Source: Kelley and Brown (1934); Kelley (1937)

Several grasses including naturally occurring ones are good materials to start with phytoreclamation of salt affected soils. Cultivation of Karnal grass (*Leptochloa fusca*) and Para grass (*Brachiaria mutica*) has reclaimed barren sodic soils. *Leptochloa fusca* is natrophilic (loves Na) and showed optimum growth at pH_2 ~9.8 and is equipped with glands to excrete out excess of salts, which are found both on abaxial and adaxial surface of leaf and also on leaf sheaths. Salt excretion per unit area of leaves is shown for NaCl and KCl salinity in Table 14.3 and 14.4. These glands are not specific to Na, but can also excrete K when plants are exposed to KCl salinity. There may not be enough salt harvesting through vegetative parts as salts excreted on the leaves surface may go back to soil when washed with rain/dew or even gentle rubbing of leaves with each other because of wind. It is the root, which is reported to play important role by adding organic carbon, and stimulating microbial activities and dissolution of native $CaCO_3$, thus resulting improvement in soil physical and chemical properties. Changes in some of the physical properties and the concentration of soluble cation (Na) in saturation extract of soil at different depths as a function of growing *Leptochloa fusca* for different time period are shown in Table 14.5 and 14.6.

Table 14.3. Excretion of Na and Cl ions by *Leptochloa fusca* under NaCl salinity at different intervals of exposure (mg/100 sqcm)

Salinity (dS/m)	Ion	Time (hr)						
		24	48	72	96	120	144	Mean
1.7	Na	0.034	0.039	0.040	1.042	0.038	0.041	0.039
	Cl	0.710	0.743	0.787	0.800	0.830	0.83	0.783
7.0	Na	0.31	0.61	0.726	0.843	1.163	1.490	0.857
	Cl	0.807	0.927	1.657	2.370	3.397	4.167	2.221
11.2	Na	0.586	0.700	0.890	1.210	1.500	1.776	1.112
	Cl	0.807	1.227	2.500	3.270	4.327	5.473	2.934
Mean	Na	0.310	0.450	0.552	0.698	0.900	1.102	
	Cl	0.775	0.966	1.648	2.147	2.851	3.490	

		Na	Cl
CD (5%)	Salinity level (S)	0.014	0.054
	Time (T)	0.020	0.076
	SxT	0.034	0.131

Table 14.4. Excretion of K and Cl ions by *Leptochloa fusca* under KCl salinity at different intervals of exposure mg/100 sqcm

Salinity (dS/m)	Ion	Time (hr)						
		24	48	72	96	120	144	Mean
1.7	K	0.243	0.355	.440	0.570	0.653	0.783	0.507
	Cl	0.753	0.763	0.803	0.826	0.870	0.883	0.816
7.0	K	0.323	0.620	1.325	2.196	3.425	4.690	2.097
	Cl	0.736	0.950	1.557	2.513	3.520	4.993	2.378
11.2	K	0.500	1.220	2.496	3.060	4.433	5.600	2.885
	Cl	0.790	1.325	2.773	3.546	4.983	5.916	3.220
Mean	K	0.355	0.732	1.274	1.942	2.837	3.670	
	Cl	0.760	1.013	1.711	2.295	3.124	3.930	

		K	Cl
CD (5%)	Salinity level (S)	0.110	0.022
	Time (T)	0.150	0.030
	SxT	0.260	0.053

Table 14.5. Improvement in some of the soil physical properties as a result of growing *Leptochloa fusca* for different time period

Treatment	Available water (kg/kg)	Bulk density (mg/cum)	Porosity (%)	Hydraulic conductivity (mm/day)
Control (no crop)	0.155	1.62	38.9	0.04
L.fusca (1 year)	0.175	1.61	39.1	1.5
L.fusca (2 years)	0.184	1.58	40.4	9.0
L.fusca (3 years)	0.195	1.55	41.5	18.0
L.fusca (4 years)	0.216	1.54	42.3	38.0
L.fusca (5 years)	0.214	1.53	42.8	55.6

Cultivation of Karnal grass for one year in barren sodic soil made it possible to grow rice without adding gypsum. However, it required two years of cultivation for getting reasonable yield of wheat (Table 14.7). Growing of *L. fusca* reduced soil pH_2 from 10.6 (original barren soil) to 9.5 (0-15 cm) after two years.

Table 14.6. Concentration of Na in saturation extract of soil at different depths as a function of growing *Leptochloa fusca* for different time period

Growth year	0-20 cm	40-60 cm	80-100 cm	Mean depth
	Na (meq/l)			
1	207	226	128	187
2	116	136	96	116
3	73	101	40	71
4	26	38	40	35
5	18	38	16	35
Mean year	77	98	56	

Table 14.7. Yields (t/ha) of rice and wheat in response to gypsum treatment and cultivation of grasses in barren sodic soil (pH_2 10.2)

Treatment	1979-80			1980-81			1981-82		
	Rice	Wheat	Forage	Rice	Wheat	Forage	Rice	Wheat	Forage
Rice-wheat with 12.5 t/ha gypsum	3.7	2.60	-	4.5	2.32	-	5.8	3.38	-
Rice-wheat (no gypsum)	0.0	0.00	-	1.0	0.00	-	4.6	0.60	-
Para grass 1 year	-	-	4.8	3.8	0.13	-	5.8	1.59	-
Para grass 2 year	-	-	-	-	-	21.3	5.3	2.56	-
L. fusca 1 year	-	-	19.9	4.1	0.26	-	5.4	2.07	-
L. fusca 2 year	-	-	-	-	-	31.0	6.1	3.41	-

Phytoremediation of salt affected soils particularly sodic and saline sodic start through processes at the soil–root interface resulting in increased levels of Ca in soil solution because of dissolution of native $CaCO_3$. About 30% of carbon fixed through photosynthesis is lost through roots in the form of various organic compounds including amino acids, sugars, organic acids etc. The dissolution of calcite mineral is favoured by increased partial pressure of the CO_2 in the rhizosphere as a result of root respiration and microbial activities (Ashraf *et al.,* 2010). Calcium released from this dissolution replaces Na from exchange complex, which in turn leached down with water when conditions are favourable. Contrary to sodic or saline sodic soils, saline soils invariably have good soil physical properties, as exchangeable percentage on exchange complex is <15. However, there may be problem of waterlogging. Under such situations plants having potential to tolerate excess salts as well as waterlogging are likely to perform better and also bring improvement in soil (reducing waterlogging and salinity). Several species of trees (*Tamarix, Eucalytus, Prosopis, Acacia* etc), saltbush (*Atriplex*), *Kochia, Suaeda* are known for their ability to grow in saline soils and are used for phytoremediation of saline soil.

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Tree Plantations in Alkali and Saline Soils

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Out of 329 M ha geographical land area of the country about 175 M 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. 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 the country and recommended afforestation on all types of lands otherwise considered unsuitable for arable crops. Salt affected soils represent one such category of lands. 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. 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. 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.

In order to rehabilitate salt affected soils, appropriate tree planting techniques and choices of tree species are very crucial for reducing mortality and consequently initial establishment of saplings. Since alkal and saline soils differ in many characteristics, methods of working the soils will be different. For example, in alkali soils a hard kankar layer of calcium carbonate is generally found at a depth of about 1.25 m to 1.50 m. 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 content in root zone is minimized. We must, therefore, diagnose the soils first and then choose the method accordingly.

Plantation of Alkali 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 depth with the help of a tractor mounted auger after digging pits of 35 cm x 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, 6-9 months old, are planted in the refilled pit-auger holes followed by irrigation. 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 cm x 90 cm x 90 cm. 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 even in these 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 in diameter and 180 cm in depth. 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.

Suitable tree species for Alkali Lands

The choice, of which species should be grown, is determined by the ability of tree species to survive and withstand adverse conditions. 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. 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. Eucalyptus 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 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. A* field trial was conducted during 1995 at Sivri farm, near Lucknow 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. Dagar *et al*., (2001) evaluated about 30 tree species 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 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. *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). The relative salt tolerance of tree species has been prepared (Table 15.1).

Table 15.1. Relative tolerance of tree species for soil sodicity

Average pH_2 (0-1.2 m)	Fulewood/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, Terminalia arjuna*	*Carissa carandus, Psidium guajava, Zizyphus mauritiana, Emblica officinalis*
9.0-9.5	*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 azadirach, Leucaena leucocephala, Hardwickea binnata, Moringa olifera, 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*

Ameliorative effect of plantation in alkali 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 on the basis of 5 year study conducted in highly alkali soil at Gudha farm of CSSRI, Karnal (Gill *et al*., 1987) 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 maximum reduction in ESP and pH. *Tamarix articulata* 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 %.

Plantation of Saline Soils

For more than a decade, Central Soil Salinity Research Institute, Karnal conducted several long - term experiments for developing afforestation technologies for highly saline waterlogged soils at its experimental farm, Sampla (Tomar *et al.,* 1998). In saline waterlogged situations, 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. To achieve this objective, three planting methods viz. subsurface, ridge - trench and furrow methods were tried for the initial establishment of tree saplings. In the subsurface 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. Earthen rings were provided around each sapling for applying irrigation water by buckets. 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 subsurface 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 subsurface 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 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 improved uniformity in water application and helped in creating a favorable zone of low salinity below the sill of the furrow through downward and lateral fluxes of water making salts to move away from the furrow (root zone) especially when low salinity water was used. Creation of such niches favored the establishment of young seedlings of trees. However, subsurface 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 disadvantageous position resulting in 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 Saline Lands

Like suitable planting technique, saline soils also require 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. More than 40 native and exotic tree species of arid and semiarid areas were evaluated by Tomar *et al.,* (1998). Based upon periodical observations for survival, height and girth, woody species like *Acacia farnesiana, Parkinsonia aculeata, Prosopis juliflora* and *Tamarix spp.* were 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. tortilis, Casuarina glauca, C. obesa* and *C. equisetifolia* could grow on sites with EC_e 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 were compared when these were grown with different methods of plantation. The data on biomass 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 subsurface 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. It has been experienced that the tree species which transpire less water are more suitable for such soils than those that 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. Relative tolerance to soil salinity studies have yielded in the data presented in Table 15.2.

Ameliorative effect of plantation in saline waterlogged soils

The beneficial effect of tree plantation on soil structure and infiltration etc. has been well documented. The tree plantation to lower water table in saline waterlogged areas has been quoted as one of the major benefit. The lowering effects of a range of *Eucalyptus spp*. on water table in Australia are well documented (Heuperman, 1991). *Tomar et al*., (1994) reported that water table for most of the time

Table 15.2. Relative tolerance of tree species for soil salinity

Very high tolerant (EC_e >35 dS/m)	**Trees and shrubs** *Prosopis juliflora, Salvadora persica, S. oleoides, Tamarix ericoides, T. troupii, Salsola baryosma*
High tolerant (EC_e 25-35 dS/m)	**Trees and shrubs** *Tamarix articulata, Acacia farnesiana, Parkinsonia aculeata*
Tolerant (EC_e 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 and forbs** *Ziziphus nummularia, Chenopodium spp, Dichanthium, Eragrostis, Panicum, Spartina, Paspalum, Sporobolus, Brachiaria, Chloris*
Moderately tolerant (EC_e 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 and forbs** *Andropogon annulatus, Anthistria prostrata, Paspalum notatum, Urochloa mossiambicensis, Glycine javanica, Phaseolus lunata, Cenchrus pennisetiformis, Lasiurus sindicus, Echinochloa colonum*

remained deeper with an average of 5 cm under the tree canopy as compared to 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 water table 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 whereas in the upper soil layers (0- 0.6 m depth), salts were considerably reduced under tree canopies than the bare fallow land.

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Need for Surface Drainage in Waterlogged Lands

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Surface drainage is the oldest drainage practice in the world and is as old as the history of agriculture. The adverse effects of excess water were known even during pre-historic times. According to a hymn in the *Narda Smirty*, a Hindu Epic, The sage Narada has said "*No grain is ever produced without water, but too much water tends to spoil the grain. An inundation is as injurious to growth as is the dearth of water*". The ponds, a common feature of the landscape of the rural India used to serve the dual purpose of draining the excess water and providing irrigation water during dry spells. Worshipping of the ponds in many parts of India probably reveal their usefulness and ingenuity of the people to maintain these structures through participatory mode. Surface drainage, defined as the removal of excess water over the ground surface through natural or constructed channels with adequate outlets, is an essential pre-requisite for optimum crop production. Surface drainage is carried out to meet one or more of the following objectives:

- In flat areas for timely removal of water so as to allow optimum growth of plants.
- In sloping areas for orderly removal such that it does not cause erosion.
- For the collection and disposal of surface irrigation runoff.

Many times surface drainage is used in a broader sense to include the prevention of surplus water from getting on to the surface through construction of levees although in most cases this issue is included under flood control. Probably, the scale of work will determine whether to call it a surface drainage or flood control measure, surface drainage being on a smaller scale.

The field surface drains are designed on the basis of the crop drainage requirement while the collectors and the main drains of the system are designed on the basis of peak rate of runoff or some multiple of this value. Clearly, crop is the kingpin in the design of field surface component of the drainage system. The current lecture briefly describes these issues for the case of surface drainage design.

Surface Drainage Problem

Flat or nearly flat areas, heavy soils with low permeability and lands in humid tropical or sub-tropical regions where high intensity storms are common, are subject to surface inundation and therefore, require surface drainage (NIH, 1996). Surface drainage problem in many cases might not be of local origin as in the case of low lands where problem is caused due to the ingress of surface runoff from uplands. Overflow from rivers or natural channels sometime contribute to the drainage problem of an area. The following reasons could be ascribed to the problem:

- Uneven land surface causing hindrance in the natural runoff from the area. The problem is severe in heavy textured soils and under humid climate.
- Inadequate capacity of the drainage channels particularly during critical periods could cause surface stagnation. It is one of the main reasons of surface stagnation in many parts of the Indo-Gangetic plains. During intense storms, the main drainage channels are full to the brim thereby reducing the capacity of the lateral and collector channels causing inundation upstream.
- Inadequate outlet conditions partly due to developmental works, which obstruct the flow and partly due to choking up of the outlet of the natural drainage systems.
- Back water flow.

Surface stagnation is and would continue to be a major stress factor under monsoon climatic conditions. Although, most agricultural lands in monsoon climatic conditions are prone to short term surface stagnation, the most affected areas are as follows:

- Around 40 M ha land area in India is prone to floods but on an average, floods affect an area of around 7.5 M ha agricultural lands annually. While floods are more devastating and a recurring phenomenon, short term water stagnation is of more common occurrence resulting in sub-optimal crop yields. The flood affected areas are quite prone to surface stagnation.
- All lands in humid and subhumid regions and even lands in semiarid regions are prone to surface stagnation particularly during the *kharif* season. Rainfall exceeding 125 mm in 24 hours practically occurs all over the country except in arid regions (Table 16.1).
- The rising water table is an inevitable consequence of introduction of irrigation through inter-basin transfer of water. Since it adversely affects the rainwater absorption into the soil, areas with high water table are prone to increased degree and duration of water stagnation.
- Lands under rice-wheat system are prone to surface stagnation because of the development of plow sole/hard pan at the bottom of the plough layer impeding vertical movement of water.
- The problem is also severe in the case of alkali lands under reclamation since the lower layers continue to have high exchangeable sodium percentage (ESP) even after several years of reclamation.
- Lands under irrigation with poor quality waters that is saline water with high Sodium Adsorption Ratio (SAR) or alkali waters with high Residual Sodium Carbonate (RSC) are prone to surface stagnation particularly during rain events.
- Areas where drainage system with unrealistic drainage designs have been laid and/or the drainage systems are inadequately maintained.
- Besides, the changing land use patterns, field-to-field irrigation, flood irrigation and poor on-farm development, all favour short-term stagnation of water. It may be mentioned that there are large areas in the irrigation commands where field-to-field irrigation is still practiced. In such cases, irrigation water far in excess than required is applied such that short-term water stagnation is bound to occur particularly at low spots.

Table 16.1. Storms of various durations expected to occur at different probabilities

Station climate rainfall (mm)	Duration (days)	Storm rainfall (mm) at % probability				
		10	25	50	75	90
Hisar arid (375)	1	64	39	25	18	11
	2	102	75	60	42	39
	3	119	93	75	60	52
	4	135	110	81	78	62
Ludhiana semiarid (681)	1	178	145	95	58	42
	2	220	179	116	69	50
	3	232	189	125	77	56
	4	237	195	132	85	66
Cuttack subhumid (1514)	1	198	167	128	85	70
	2	275	229	173	109	87
	3	293	246	188	123	101
	4	312	264	205	138	115
Dapoli humid (3372)	1	363	309	227	166	140
	2	530	463	362	286	254
	3	623	555	452	376	342
	4	719	641	523	435	398

In the light of above discussions, it is clear that surface drainage congestion in monsoonic climatic conditions of India depends largely on the following factors:

- Climate
- Soils including topography
- Depth to water table
- Crops

Besides the seasonal and annual rainfall, frequency analysis procedures are used to determine various return period rainfall events, number of storms and the dry periods to plan effective drainage and reuse strategy (Table 16.1).

Kind of the soils and topography determines the degree of surface congestion. For the same event, degree of stagnation would be more in a heavy than a light textured soil. A flat terrain would be more prone to congestion than a rolling topography.

Absorption of water into the soil profile would depend upon the depth to water table. An area with relatively high water table would be subjected to relatively greater depth of water stagnation and for periods larger than the area with deep water table.

Agricultural land drainage is influenced to a great extent on the kind of crops grown and their tolerance to surface stagnation. Experimental evidences have been generated world over on the tolerance of crops to surface water stagnation. On the basis of this limited evidence, Bureau of Indian Standards has prepared some guidelines according to which the crop tolerance to water stagnation varies from 1-7 days depending upon which group of crops is grown (Table 16.2). For this purpose, crops have been categorized under four groups.

Table 16.2. BIS guidelines on crop tolerance to surface stagnation of water

Crops	Tolerance to stagnation (days)
Vegetables	1
Cotton	3
Maize/sorghum/food grains	3
Sugarcane/banana	7
Paddy	7-10

Drainage Coefficient for Field Drainage

Any drainage system design is to prevent the harmful effects of waterlogging on crops. This can best be achieved by reducing the duration for which crops experience waterlogging condition. In order to design a surface drainage system, selection of an appropriate drainage coefficient is necessary. If a low value of the coefficient is adopted, it will not solve the problem of waterlogging while a high value would materially increase the cost especially when the drainage areas are large. Crop characteristics should invariably be considered while selecting the drainage coefficient.

Drainage coefficient is defined as the amount of water that runs off from a given area and is to be removed in 24 hours. Commonly, the units are depth of water per day but in surface drainage many times the drainage coefficient is expressed in flow rate per unit area. It is not often possible to determine the drainage coefficient with a known degree of accuracy though it is the key factor in establishing the needed capacity of the drainage system (Murthy, 1985 and Suresh, 2000).

Surface drainage in India is mostly a phenomenon of the monsoon season. A number of methods and techniques are used to evaluate drainage coefficients. The use of a particular method mainly depends on the availability of data. The simplest method of evaluating surface drainage coefficient for an area is described in the following steps (Gupta *et al.*, 1995, Gupta and Tyagi, 1996):

1. Evaluate maximum 24 hr rainfall depth, which might occur with a probability of 10-20 percent. For agricultural drainage, a probability of 20% or a return period of 5 years is often selected.
2. Evaluate the basic infiltration rate of the soil and determine the expected potential evapotranspiration.
3. Estimate the tolerance of crop to surface inundation, for example 'n' days. Multiply the infiltration rate and expected potential evapotranspiration by the number of days, n.
4. Subtract the value calculated in step (3) from the value in step (1). The resulting value when divided by number of days, n will give the drainage coefficient in depth of water/day.

These steps could be described mathematically in the form of an equation, which is written as:

$$q = \{R - n(E + I)\}/n \quad (16.1)$$

Here q is the drainage rate in mm/day, R is the rainfall in mm, E and I are potential evapotranspiration and infiltration rate in mm/day and n is number of days. When n is greater than one, it may be useful to increase the duration of rainfall in step 1 also from 1day maximum to n-day maximum. The drainage coefficient calculated with this modification will be closer to the actual field values. For rice crop, the drainage coefficient would be less as at the end of drainage period some depth of water is allowed to stand in the fields. This depth is subtracted before dividing by number of days, n. Surface drainage coefficients for various durations and for five year return period rainfall amounts calculated using equation (1) for the selected districts of Haryana state revealed that if the crops can withstand waterlogging for more than two days, there is no problem of surface drainage expect in Karnal and Gurgaon district of the state. If the crops can tolerate waterlogging for four days, surface drainage problem is only in district Karnal and that too only in alkali soils.

The field surface drainage system includes a number of activities. First and foremost is the land grading or smoothing. Land grading for flat lands requires that general slope of the land in the range of 0.1 to 0.2% be retained and surface irrigation and drainage systems be designed to take advantage of this grade. Irrigation channels at the top end and drainage channels of appropriate dimensions at the lower end should be constructed. The common functional dimensions of surface drains are a minimum 0.5 m bottom width and 0.6 m depth. The drainage channels should lead the drainage water to a dug out pond or to the natural drainage system.

Three Tier Rainwater Management Strategies for Surface Drainage

Drainage, commonly understood as the quick removal of surface water from the fields, may be difficult to achieve in alkali soils even with high drainage rates of 20-25 mm/day. In view of this, the purpose of drainage in case of alkali lands should not be the speedy removal of water. Instead, the objective should be the best possible utilization of the rainwater within the catchment. A three-tier system of surface drainage has been developed at the Central Soil Salinity Research Institute, Karnal, which consists of storage, detention and let off. Briefly, the 3 tiers of the system are:

1. Rainwater is allowed to accumulate and remain on the cropland till such time and extent as will not be harmful to crops.
2. Excess water from the fields is led to the dugout ponds of sufficient capacity. The stored water is utilized subsequently during dry spells or for irrigating winter season crops.
3. Rainwater in excess of these two components of storage is led out of the area to the natural drainage system through tertiary and main drains.

Design Considerations for Collector/Main Drains

The state government provides collectors and main drains to safeguard against floods and surface stagnation. For the design of these drains, simple formulae and guidelines are used. Some of these guidelines reported in Table 16.3 reveal that the design discharge is mainly a function of the area. More elaborate calculations are made in designing permanent structures for which frequency analysis procedures are used. The design frequencies for various structures are given in Table 16.4. The design procedure of an intermediate drainage channel constructed in Orissa under reclamation of waterlogged area programme is illustrated through an example in Table 16.5. The design section of a drain is furnished in Fig. 16.1. Normally, drains up to 20 cusecs discharge capacity are constructed under this programme.

Table 16.3. State wise formulae or guidelines used in design of main/collector drainage

State	Formulae / guideline	Remarks
Punjab and Haryana	Q= C√A/5 (old) Q= C√A/6 Q= C√A/4 Q= C√A/2	 Up to 260 km² 261-650 km² >651 km²
U.P. and Andhra Pradesh	R= 0.11 A	
Madhya Pradesh	Q= 0.22 A Q= 0.44 A	For A >79 km² For A <13 km²
Tamil Nadu	Q= 0.44 A $Q= 0.6A^{2/3}$	A= 13km² A >52km²
Orissa	$Q= C A^{5/6}$	C= 0.3 for discharge of 10-12 cusecs

Q: discharge in cumecs, A : catchment area in km² and C is a coefficient, which depends upon rainfall. Values vary from 3.5 for 500 mm rainfall to 35 for rainfall in the range of 750- 1000mm. # The values vary from 0.22 to 0.44 for areas in between 13 to 79 km². Source: WAPCOS (1987)

Table 16.4. Design frequencies for minor structures

Type of minor structure	Probability/return period	
	Per cent	Years
Highway cross road drainage	10-2	10-50
Air fields	20	5
Storm drainage	50-10	2-10
Levees	50-2	2-50
Drainage ditches	20-2	5-50

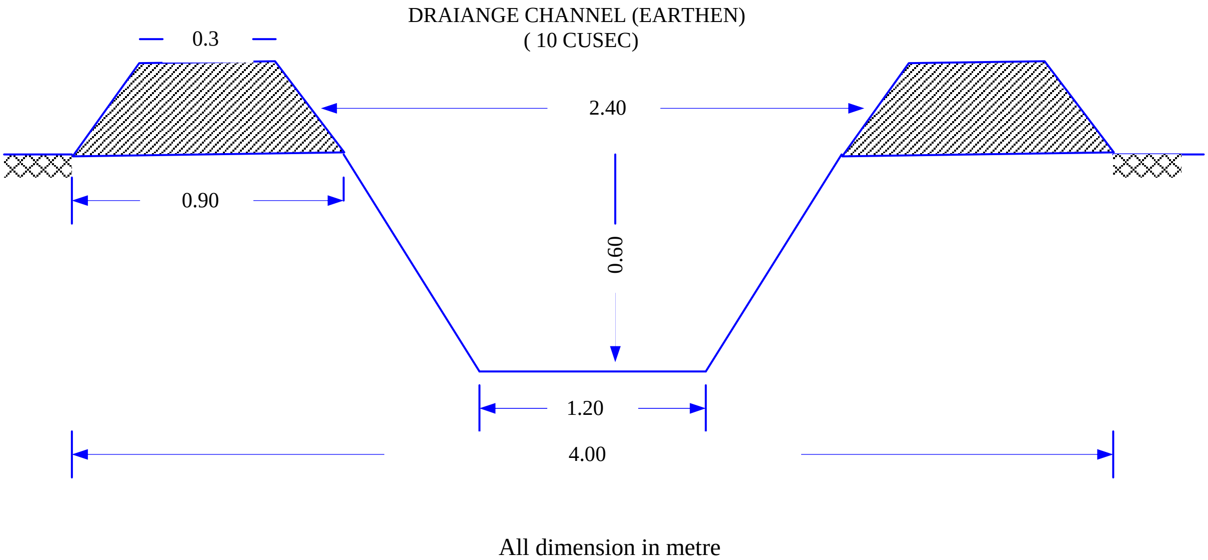

Fig. 16.1. Section of a field channel under reclamation of waterlogged area programme in Orissa

Benefits of Surface Drainage

Land loss in surface drainage has been a common argument against implementing on-farm surface drainage. However evidences generated at CSSRI (Table 16.6) and Navsari (Table 16.7) amply prove that benefits outweigh the loss due to drainage in terms of land loss. The data in Table 16.6 reveal a loss in the crop yield to the extent of 2-50% depending upon the crop and the duration of water stagnation. Clearly, these losses would turn into benefits upon implementation of land drainage. The data in Table 16.7 highlights the real benefits in the range of 20-50% in the Ukai-Kakrapar project in Gujarat.

Table 16.5. A typical design of a field drain

1	**Salient Information**	
	Catchment area	100 ha
	Land slope	0.10%
	Soil type	Clay loam
	Average annual rainfall	1220 mm
2	**Assumed Parameters**	
	Slide slope	H: V = 1.1 (depending upon soil type)
	Channel bed slope S=0.10%	0.001 (as per survey)
	Run off coefficient	C=0.30
3	**Design run off**	$Q = C \times A^{5/6}$ A = Catchment area in sqkm $Q = 0.30 \times (1.0)^{5/6}$ = 0.30 cumec or 9.96 cusec
4	**Design of section**	
	For efficient channel section	b=2 d R = 0.6213 d Where R = hydraulic radius d = depth of flow $A = 3d^2$
	Velocity of flow For clay loam soil value of	$V = 1/n \times R^{2/3} \times S^{½}$ n = 0.035 $V = 1/0.035 \times (0.6213d)^{2/3} \times (0.001)^{½}$ = 0.6578 d Q = A x V $= 3d^2 \times 0.6578^{2/3} \quad = 1.9736 \times d^{8/3}$
	Since Solving	Q = A x V $0.30 = 1.9736 \times d^{8/3}$ d = 0.0.49 say 0.50 m
	With 20% free board total depth of flow Where	D = 1.20 x 0.50 = 0.60 m b= 2 d = 1.20 m T= b + 2 x z x d Z = side slope = 1 T = 2.40 m
	Therefore, the design section is Top width Bottom width Depth	 2.4 m 1.2 m 0.6 m

Table 16.6. Yield in drained plots and percent yield reduction due to water stagnation of various duration for tested crops

Crop	Yield (t/ha)	Yield reduction# over drained (%) for water stagnation (days)			
	Drained	1	2	4	6
Sorghum	4.13	3	11	16	20
Pearl millet	2.22	6	15	22	27
Pigeon pea	1.52	4	14	18	21
Wheat	4.20	8	17	27	39
Barley	3.65	4	7	13	25
Mustard	1.43	8	16	22	29
Berseem (seed)	0.48	2	21	35	48
Sunflower	1.86	13	19	26	30

 # Yield reduction due to water stagnation is relative to drained plots

Table 16.7. Yield increase in various crops achieved after improvement in surface drainage

Crop	Yield improvement (% over poorly drained)
Sugarcane	19.1-27.7
Paddy	19.7-24.7
Gram	32.1
Indian bean	49.8

Command Area Guidelines on On-Farm Water Management/Drainage

Ministry of Water Resources, GOI restructured the CAD programme as CAD & WM during the year 2004. The revised ceiling as well as funding pattern has also been revised as shown in Table 16.8.

Table 16.8. Revised guidelines on expenditure and sharing of expenditure by various stakeholders

S.No.	Items	Cost norms per ha	Central share	State share	Farmers share
1	Construction of field channel	Rs. 10,000/-	50%	40%	10%
2	Construction of field drains	Rs. 4,000/-	50%	50%	
3	Reclamation of waterlogged area	Rs. 15,000/-	50%	40%	10%
4	Adaptive trials, action research and demonstration	As per location specific need (Rs. 5,000/ha)			
5	Farmer training	As per location specific need (Rs. 10,800/per training)			
	New Items				
6	Correction of system deficiencies above out let up to distributaries of 150 cusec capacity	Rs. 4,000/-	50%	50%	
7	Renovation and desilting of existing irrigation tanks within the irrigated command	Rs. 15,000/-	50%	40%	10%

Improved Drainage: the Long-term Solution

Lack of drainage or inadequacy of it is rapidly becoming a major constraint to limit agricultural production. Productivity of agricultural lands can only be sustained if drainage improvements are undertaken on cropland currently affected by submergence or high water table. Very often, the natural drainage in an area along with good water management is sufficient to eliminate excess water and to preclude the need for drainage systems. The degree of drainage needed in an area could be assessed through a drainage index proposed by Gupta and his coworkers. It may be noted that if the problem is low, drainage may not be a serious issue and good crops can be grown with land and crop management that would avoid the adverse effect of drainage (Table 16.9). As the value of the drainage index increases, the degree of drainage to be provided also increases. Management alone would not be sufficient if the index is more than 50.

Table 16.9. Drainage index and the degree of the problem

Index	Degree of problem
< 25	Low
25-50	Moderate
50-75	High
75-100	Acute

With low to moderate degree of the problems, a group of farmers can join hands to provide reasonably good drainage to the crops. Following activities can be initiated at the farmer's land:

- Land levelling is an essential component of a drainage programme. Deviations in land levels within the field can affect production and productivity. Such variations can be minimized through levelling. Farmers with heavy textured soils, soils with plow sole as develops in lowland rice-wheat system, alkali lands with poor water absorption characteristics or those who rely mainly on surface irrigation should have adequate surface drainage facilities to remove excess water. A uniform slope of about 1:1500 is desirable to drain irrigation water or rainfall off a field.

- Many times, drainage problem stems from inadequate maintenance of an existing drainage system. In this era of fund crunch, farmers should maintain the system falling in their territory. If a group of farmer's joins hand, a good portion of the system could be maintained.

- Depressions around farm/village or village ponds could be deepened or multi-purpose farm ponds could be constructed to drain the surplus surface drainage water.

- At the individual level, cavity wells commonly used to develop groundwater in this part of the country (Haryana, Punjab and Western U. P.) can be used to drain excess water resulting from the occasional heavy rainfall events to minimize damage. As a short-term measure, this practice has been successfully tried and adopted by many farmers.

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Drainage Investigations and Design

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Subsurface drainage aims at the removal of excess ground water to maintain such a water and salt regime in the root zone that is favourable for sustained crop production. Drainage measures are generally location specific and vary according to soil, climate, irrigation and geo-hydrological conditions, and cropping patterns. For drainage of waterlogged saline soils, information on hydraulic conductivity, drainable porosity, infiltration characteristics, soil salinity, fresh water supplies, depth of impermeable layer, aquifer parameters, ground water fluctuations and quality and availability of outlets is often needed. In addition, knowledge of drainage requirement of different crops and criterion for drainage design is also required. The pre-drainage investigations can be conducted at three levels: the reconnaissance, semi detailed and detailed surveys of the area.

Reconnaissance Survey

Reconnaissance survey helps in determining the technical and economic feasibility of the proposed project. To begin with, a preliminary exploratory survey based on available information and some limited fieldwork is conducted. All kinds of available information, maps (geological, topographical, soil and land use), and reports related with surface and ground water, climate, cropping pattern and yields, and the logs of shallow and deep wells are useful. It is helpful to visit the project area and make inquiries from local people on seasonal variations of drainage problem and the response of the water table and crops to water management practices and also to locate on the base map information on physical and surface water boundaries, source of irrigation water and natural drainage outlets.

(a) Topography, Geology and Physiography: A topographical map, on a scale of 1:100,000 to 1:250,000 and contour interval of about 30 cm, of the area of interest and the surrounding areas which may be contributive to the excess water problem is an essential requirement of the drainage investigations. Geological reports and maps of the area, a few lithological profiles, the depth and thickness of water transmitting layers and the depth of the impervious layers may be examined to identify sources of ground water that might influence drainage requirements.

(b) Soil and Land Use: In addition to making use of information contained in the standard soil surveys, a few soil profiles in the project area should be studied to a depth of about 1.2 m to test its suitability for the production of proposed crops. Special attention should be given to upper root zone (0.0 to 0.3 m) for its infiltration rate, water holding capacity, workability and possible formation of impeding layers. Limiting impeding layers for water percolation are to be identified in the lower root zone (0.3 to 1.2 m).

(c) Irrigation Supplies: The source of irrigation water and its distribution network in the area need to be investigated. In a canal irrigated area, information on the delta of the command, and system of supply, irrigation intensity and irrigation method is useful to estimate field percolation losses to the drainage system.

(d) Surface Drainage Conditions: The surface drainage of an area is governed primarily by the volume of expected runoff water and the time allowed for its removal. Rough estimates of the runoff potential of the area and carrying capacity of the natural drains may be worked out to judge the need for an artificial drainage system in the area.

(e) Outlet: Outlets for disposal of excess subsurface drainage water in irrigated areas may sometimes be difficult to obtain. During reconnaissance survey, special attention may be paid to the location and the capacity and flow characteristics of possible outlets. The outlets may be gravity or pumped outlets. Gravity outlets may include open ditches, pipe drains, constructed or natural channels with sufficient capacity to carry the surface runoff and drain flow. For pumped outlet, the location and installation of the pump and its operational costs must be considered.

(f) Hydrologic Data: The detailed climatic and hydrologic data of the area should be collected; a ten year record of various hydrologic parameters is a strict minimum. If reliable data for estimating different water balance components are not available, an immediate programme for collecting observations should be set up.

(g) Subsurface Drainage Conditions: This involves a preliminary assessment of (i) the ground water situation based on existing records on the depth and quality of watertable and its variation during the year and direction of ground water flow, (ii) the drainability (possible outlet) of the area, and (iii) the average hydraulic conductivity of subsurface layers and the depth to the first layer of poor hydraulic conductivity. These require 1.5 m deep soil pits as well as hand borings upto 5.0 m depth. The hand borings may be made at the soil surface or bottom of the soil pits. The zone between 1.5 m and 2.5 m below the soil surface is of great importance. The number of soil pits and auger borings should approximately be in 1:10 ratio depending upon the geology and expected variability. If no impervious layer (a layer having hydraulic conductivity one tenth or less than that of the layer above) is found within 5 m below soil surface, a few borings upto 15 m depth should be made to investigate the layers below 5 m. The information should be adequate to make clear statements on:

- whether the soil profile is homogeneous or layered
- the nature and extent of soil salinity
- the depth to the impervious layer
- the presence or absence of a pervious to highly pervious horizon at or below drain depth (between 1.5 and 2.5 m) which may cause unstable drain bed and or quick sand conditions
- the presence or absence of impeding horizons within the upper 2 m of the soil profile
- the depth to the watertable and the zone in which it fluctuates during the year
- the salinity of ground water (EC and SAR)

Areas where the watertable is always shallower than 2 m should be indicated as problem areas on maps. A number of deep borings penetrating the entire aquifer, made along the boundaries of the project area, can help in estimating its natural drainage and also the lateral seepage from outside. The transmissivity of the aquifer estimated from a few pumping tests and the watertable contour map of the area can be utilized to determine the rate of ground water inflow into or outflow from the project area.

In summary, a reconnaissance survey provides information on the necessity for drainage, enables a tentative layout of the main drains and the outlet and allows for the feasibility of the drainage scheme to be determined. It also suggests the future programme and intensity of surveys and studies needed in the semi-detailed study phase.

Semi Detailed Surveys

Alternate plans are identified on the basis of the results obtained through the project feasibility studies. Semi detailed and more detailed field surveys (of the types mentioned above) are conducted to permit the estimation of cost of designed project to an accuracy of 10%. The topographic and soil maps of 1: 25,000 or 1: 10,000 scales and contour lines of upto 0.30 m interval are generally required at this stage. At the location of projected canals, ditches and structures, detailed levelling surveys for length and cross sections should be performed. Further, the information on the nature of salts in the soil and ground water, and flooding conditions are collected. The semi detailed studies correspond to the level of ‘feasibility studies' which enable to decide the optimal plan for execution.

Detailed Surveys

A detailed drainage survey involves the collection of all relevant field data that will allow the design of an effective drainage system. All the topics discussed earlier reappear but in a much more detailed and precise form.

(a) Topography: Topographic maps on a scale of 1:2,500 to 1:10,000 with contour interval of 0.30 m or less are required at this stage.

(b) Field Drainage Data: The results of the detailed surveys are expected to give elaborate information on the following aspects:

- the soil texture and salinity to a depth of 4 to 5 m below ground surface
- nature and extent of soil salinity, amendment and leaching water requirements
- the occurrence and depth of the impervious layer
- the occurrence and depth of impeding layers in the upper 4 to 5 m soil profile
- the occurrence, depth and thickness of highly pervious sandy or gravel layers
- the hydraulic conductivity of the soil profile at regular depth intervals, especially in the range of 1.5 to 2.5 m or even deeper
- the depth and fluctuations of the ground water table, and direction of ground water flow
- the chemical composition of ground water, its EC and SAR
- the potentiometric head at boundaries and at different depths (e.g. at 3, 5 and 10 m) for estimation of natural drainage, the vertical gradient and lateral flow of ground water into or out of the project area

The design of a subsurface drainage system requires intensive field tests of a few parameters (Dielman and Trafford, 1976). The procedures for determining hydraulic conductivity and drainable porosity, and recording ground water observations are described below:

Hydraulic Conductivity

The horizontal hydraulic conductivity (K) is one of the most important parameters for design of subsurface drainage system since it controls the spacing of drains. The hydraulic conductivity of a soil represents its average water transmitting property. There are several laboratory and field methods for determination of hydraulic conductivity, but for drainage design purpose, it is always desirable to conduct in situ determination of hydraulic conductivity. In soil layers above the watertable or where no watertable is present at the time of conducting of test, inversed auger hole method can be employed to determine the hydraulic conductivity. The augerhole method is the most widely recommended method where a watertable exits at a sufficiently high level. This method is usable on both homogeneous and layered soils. This is generally usable to a depth of 5 m. Where the desired depth for obtaining information is greater than 5 m, piezometer method is considered practical which can be used to determine horizontal hydraulic conductivity for soil layers as thin as 10 cm and can be usable upto depth of 8 m.

Augerhole Method: The procedure is to bore a hole of 10 cm or more in diameter with an auger to a certain depth below the watertable. When equilibrium is reached with the surrounding ground water, a part of water in the hole is bailed out. The water seeps back into the hole and the rate at which water rises in the hole is measured and then converted by a suitable formula or a monograph to hydraulic conductivity (K) of the soil. Care must be taken that not more than about 25% of the volume of water removed from the hole flows back till the end of measurements. Also the water level in the hole should be reduced 20- 40 cm only (20 cm if expected K is high and 40 cm if expected K is low). For homogeneous soil with the impermeable layer at a certain depth, $S \geq 1/2\ H$ below bottom of augerhole, Ernst formula can be used (Beers, 1958):

$$K = \frac{4000\, r^2}{(H + 20\, r)\,[2-(h^\wedge / H)]\,h^\wedge} \; \frac{\Delta h}{\Delta t} \qquad (17.1)$$

$$= C\, (\Delta h / \Delta t)$$

Where:
K = hydraulic conductivity (m/day)
$\Delta h/\Delta t$= rate of rise of water level in the auger hole (cm/sec)

C = Geometry factor = f(h, H , r ,S)

$$= \frac{4000\, r^2}{(H + 20\, r)\,(2 - \hat{h}/H)\,\hat{h}} \qquad (17.2)$$

'C' can be calculated from equation (17.2). This can also be obtained using nomographs given in standard text books on drainage.

$\Delta h = h_o - h_t$, where h_o and h_t are the depth (cm) of the water level in the hole below equilibrium (initial) watertable at time t_o and t (sec) respectively (Fig. 17.1).

$\Delta t = t_n - t_o$ (sec)

$\hat{h} = 1/2\,(h_o + h_t) = h_o - 1/2(\Delta h)$

H = depth of the time bottom of the hole below the equilibrium watertable (cm)

S = depth of an impermeable layer below the bottom of the hole (cm)

r = radius of hole (cm)

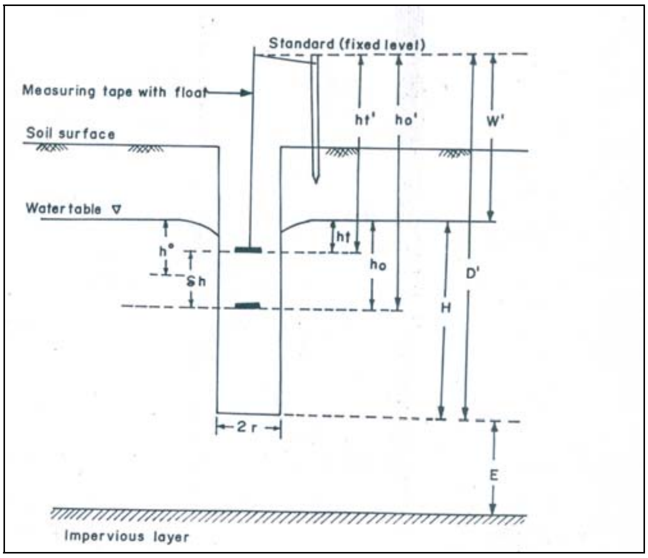

Fig. 17.1. Schematic view of Augerhole technique

Example: Determination of hydraulic conductivity by augerhole technique using observations of watertable levels at various times after bailing out of water

Test No. 12 Location Sampla (Haryana)	D' = 252 cm r = 5 cm W' = 144 cm
t (sec)	h' (cm)
t_0 = 0	h_o' = 168.2
t_1 = 15	h_1' = 167.4
t_2 = 30	166.6
t_3 = 45	165.8
t_4 = 60	165.0
t_5 = 75	164.2
t_6 = 90	163.5
t_7 = 105	162.8
t_8 = 120	162.2
t_9 = 135	161.6
t_{10} = 150	161.0

$H = D' - W' = 252 - 144 = 108$ cm
$r = 5$ cm
$h_o = h_o' - W' = 168.2 - 144.0 = 24.2$ cm
$\Delta h = h_o' - h_t' = 168.2 - 162.2 = 6.0$ cm
$\Delta t = 120 - 0.0 = 120.0$ sec
(Select the value of time such that $\Delta h < \frac{1}{4} h_o$. Note that $\Delta h = 6.0 < 6.05$ [i.e. (1/4)24.2]
$h\hat{} = h_o - \frac{1}{2}(\Delta h) = 24.2 - 3.0 = 21.2$

Using these values in equation 17.2, we get K = 0.63 m/day

The method of determining K in a homogeneous profile can be easily extended to a two layered profile. In a layered profile, initially a shallow auger hole is made which terminates at least 20 cm above the interface of two layers and ensuring that the bore hole contains minimum 40 cm thick water body. The value of hydraulic conductivity of upper layer, K_1 is calculated using normal auger hole test. The auger hole is then deepened at least 50 cm below the interface into the second layer and the rise of water level is measured.

If there is no time or money to conduct hydraulic conductivity tests in the field, Table 17.1 is commonly referred to for qualitative estimates of K from information on soil texture.

Table 17.1. Soil texture - hydraulic conductivity relationship

Soil texture	Hydraulic conductivity (m/day)
Clay	< 0.01
Silt clay	0.010 - 0.015
Silt clay loam	0.015 - 0.024
Clay loam	0.024 - 0.012
Sandy clay loam	0.012 - 0.091
Silt loam	0.091 - 0.231
Loam	0.231 - 0.427
Very fine sandy loam	0.427 - 0.732
Fine sandy loam	0.732 - 1.036
Sandy loam	1.036 - 1.524
Loamy fine sand	1.524 - 2.134
Loamy sand	2.134 - 2.743
Fine sand	2.743 - 3.658
Sand	3.658 - 4.877
Coarse sand	4.877 - 7.315

Selection of Representative Hydraulic Conductivity Values: The hydraulic conductivity values obtained in the field by auger hole or other methods have lot of variability. For drainage system design, however, we need only one representative value of K for each soil layer. Log mean and sometimes arithmetic mean are the most widely used practices for selecting a single value. However, if there are any erroneous or suspect values in the data, the mean value may not yield the true hydraulic conductivity value. Plotting the result helps to spot doubtful values. The distributions that are generally used for such purposes are normal and log normal probabilities. The plotting position in any of these distributions is given by:

$$P = \frac{100\,R - 50}{M} \quad (17.3)$$

Where: P = probability of occurrence of hydraulic conductivity corresponding to rank R
R = rank number of the ascending series of K values
M = total number of K values obtained in field

The values of K are plotted on normal or log normal probability paper to get a straight line fit. The value corresponding to 50% probability gives the representative value of K. An example on the variation of K values for different layers at Sampla subsurface drainage project and procedure for selecting a representative K value is presented in Appendix 1.

How Many Hydraulic Conductivity Tests: The number of hydraulic conductivity tests required for a drainage survey is related to the soil variability in the project area. When soil survey data is available, the sites for hydraulic conductivity tests are selected on the basis of soil type. Otherwise, the tests should be made on a regular grid. The size of the grid is governed by soil variability and the time and budget considerations. At each site, a minimum of two tests should be conducted in two holes a few meters apart. If the results of two tests are significantly different, then a third test should be conducted. For Sampla subsurface project, K tests were conducted at 10 sites (2 tests at each site) in a 10 ha area which was on higher side. At another site (Hisar), K tests were conducted at 24 sites (2 tests for each site) in an area of about 100 ha. Actual number of tests is also governed by available time and funds.

Drainable Porosity

The effective porosity or drainable pore space is defined as the volume of water released or taken into storage in an unconfined aquifer per unit cross sectional area per unit decline or rise of watertable as a fraction of total volume of soil. For drainage conditions, drainable porosity of a soil relates the amount of fluctuation of the water table to the amount of ground water added or drained from the system. Representative drainable porosity values for use in transient state drain spacing equations are difficult to measure accurately. Whenever possible, the drainable porosity should be determined from the measurements of drain discharge and draw-down of existing drains or pilot drains. The representative values of drainable porosity of different textures of soil can be taken as 3-5% (volume basis) for heavy clays, 6-9% for medium textured soils and 10-15% for sandy soils. US Bureau of Reclamation (1984) has developed a generalized relationship between hydraulic conductivity and drainable porosity.

Ground Water Observations

Depth to watertable and its seasonal and annual fluctuations determine the extent and severity of the drainage problem. These are measured with the help of observation wells which are mostly installed on a square grid pattern. Piezometers are used to measure the hydrostatic pressure at different depths in the sub- soil layers. Though both observation wells and piezometers are required in the initially stages, piezometers are installed selectively. A battery of piezometers is installed first at one location where the lower end of each piezometer terminates at a different depth. The number is increased if the problem of artesian pressure is indicated. It is advisable to include additional areas adjoining the project site in any ground water investigation programme. For drainage area of about 100 ha, minimum 20 observation wells should be installed for routine studying general ground water behaviour. For specific studies on system evaluation or drainage materials, the intensity of observation wells will have to be increased considerably.

Other Field Tests

In addition to the parameters described above, it is also necessary to determine total porosity and infiltration as well as aquifer characteristics. Total porosity is needed to study the leaching properties of the soil; infiltration characteristics for studying ground water recharge and leaching of salts; aquifer parameters are important if vertical drainage is considered for controlling waterlogging and soil salinity. Total porosity can be determined using pycnometer rings while pumping tests are conducted to determine aquifer parameters like transmissivity and specific storage coefficient. The details of these tests, not covered here, can be found in any standard textbook on drainage or ground water.

Drainage Coefficient

The drainage coefficient of the drainage system, based on the estimation of volume of water to be drained per unit time during different parts of the year should be determined accurately since it governs the drain spacing as well as dimensions of the field laterals, collectors and pumping station (if any). The computation of design drainage rate requires the consideration of deep percolation losses resulting from rainfall, leaching water, and excessive or non-uniform application of irrigation water, seepage from canals or adjoining areas including where applicable artesian inflow, and natural drainage of the area to be drained. The most common unit of drainage coefficient is mm/day.

The drainage coefficient for determining drain spacing can be arrived by considering the general water balance of the area using the following water balance equation:

$$q = R_f + S_c + S_i - D_n \quad (17.4)$$

where, in terms of volume per unit time per unit area

q = water to be removed by the on -farm drainage system i.e the drainage coefficient
R_f = on- farm recharge to the ground water, i.e. deep percolation losses resulting from rainfall, leaching water, and excessive or non-uniform application of irrigation water
S_c = seepage from canals
S_i = in- seepage, i.e. ground water flow into the area to be drained including artesian inflow
D_n = natural drainage, i.e. ground water flow out of the area to be drained

There are detailed procedures/guidelines/tests for estimating different components of equation 17.4, which will be covered in other lectures. In practice, design rates are likely to be in the following ranges, if natural drainage or in- seepage are negligibly small:

< 1.5 mm/day : for soils having a low infiltration rate
1.5- 3.0 mm/day : for most soils, with the higher rate for more permeable soils and where cropping intensity is high
3.0- 4.5 mm/day : for extreme conditions of climate, crop and salinity management, and under poor irrigation practices
> 4.5 mm/day : for special conditions, e.g. rice irrigation on light textured soils

The drainage coefficient for some of the sites in India has been observed to be in the range of 1-5 mm/day (Table 17.2). It would be appropriate to mention that the drainage coefficients based on rainfall are much less applicable in India compared to the recommendations emerging from USA or other countries. It is due to the fact that rainfall in India is received only during the monsoon season that too in few storms. As such, the runoff is much more under the rainfall pattern in India. Moreover, under the irrigated conditions of arid and semi arid regions, the main function of the drainage is to help in leaching of the salts than to improve aeration. Since excess salts in the root zone are critical to the reclamation process than improvement in the aeration. The emerging guidelines on subsurface drainage coefficient reveal that a drainage coefficient of 1-3 mm/day would be sufficient to reclaim waterlogged saline lands (Table 17.2).

Table 17.2. Subsurface drainage coefficients at different locations (based on pilot studies)

Site	Rainfall (mm)	Recommended rate (mm/day)	Range (mm/day)
Chambal (Rajasthan)	850*	3.0	2.5-3.5
Sampla (Haryana)	600	2.5	2.0-3.0
Hisar (Haryana)	400	2.0	1.5-2.5
Dabhou (Gujarat)	800	4.0	3.0-5.0
Mundlana (Haryana)	500	5.0	5.0
Kailanakhas (Haryana)	500	6.8	5.0-7.0
Muraj (Gujarat)	500	2.8	2.0-4.0

* *Variation in the range of 600-1400 mm*

Design of Subsurface Drainage System

(a) Calculation of Drain Spacing Using Hooghoudt Equation: The Hooghoudt equation is commonly used to calculate the drain spacing L, if the factors q, h, k, D and r_o are known. The formula can also be used to calculate the soil constants K and D if q, h, L and r_o are known. Since the drain spacing L depends on the equivalent depth de, which in turn is a function of L, the formula can not be given explicitly in L. Its use in drain-spacing formula involves a trial and error procedure or through use of standard nomographs**.**

Example: For the drainage of an irrigated area drain pipes with a radius of 0.1 m are to be installed at a depth of 1.8 m below the soil surface. A relatively impermeable soil layer was found at a depth of 6.8 m below the soil surface. From augerhole tests the hydraulic conductivity above this layer was estimated at 0.8 m/day

Suppose that irrigation is applied approximately once in 20 days. The average irrigation losses, which recharge the already high groundwater table, amount to 40 mm per 20 days so that the average discharge of the drainage system amounts to 2 mm/day. What drain spacing must be applied when an average water table depth of 1.20 m below the soil surface is to be maintained?

From the above information we have:

r_o = 0.1 m
q = 0.002 m/day
K_a = K_b = 0.8 m/day
D = 5.0 m
h = 0.6 m

Substitution of the above values into Hooghoudt equation gives:

$$L^2 = \frac{8K_b d_e h^2 + 4K_a h^2}{q} = \frac{8 \times 0.8 \times 0.6 \times d_e + 4 \times 0.8 \times 0.6^2}{0.002}$$

$$L^2 = 1920 d_e + 576$$

Where d_e is called the equivalent depth which is dependent on L, D and $r_{o,}$ corresponding to these parameters, d_e can be estimated from standard nomographs or tables or computed from following formula:

$$d_e = \pi D L^2 / \{\pi(L - 2D)^2 + 8DL \ln (2D/u)\} \quad (17.5)$$

Where u is the wetted parameter equal to πr_o

<u>Trial 1</u>:

Take L = 80 m and calculate from eq. (5): d_e = 3.55 m.
$L^2 = 1920 d_e + 576 = 1920 \times 3.55 + 576 = 7392$ m².
This is not in agreement with $L^2 = 80^2 = 6400$ m².
Therefore L = 80 m is apparently too small.

<u>Trial 2</u>:

Take L = 87 m and calculate: d_e = 3.63 m.
$L^2 = 1920 d_e + 576 = 1920 \times 3.63 + 576 = 7546$ m².
This is sufficiently close to $L^2 = 87^2 = 7569$ m².

<u>Conclusion</u>: The drain spacing required to satisfy the above conditions is L = 87 m.

Note: In the equation $L^2 = 1920\ d_e + 576$, the term 576, representing the flow above drain level is comparatively small. Neglecting it, one obtains:

$$L = \sqrt{1920 d_e} = \sqrt{1920 \times 3.56} = 83\text{m}.$$

(b) Drain Design for Size of Laterals and Collector Pipe Drains Consisting of One Pipe Diameter

For practical field conditions, discharge through corrugated PVC pipes can be computed from following equations:

$Q = q^* A = 2.0 * 10^6 * d^{2.67} * i^{0.5}$ if $d \leq 100$ mm (17.6)

$Q = q^* A = 2.5 * 10^6 * d^{2.67} * i^{0.5}$ if $d > 100$ mm (17.7)

Where:
Q = drainage volume (m^3/d)
A = drainable area (m^2)
q = drainage coefficient (m/d)
d = internal diameter of the pipe (m)
i = slope of lateral line (m/m)

Worked Example: Design lateral drains of a drainage system assuming:

q = 2 mm/day
Spacing (L) = 80 m
Length of laterals (B) = 250 m
Drains are to be installed at a slope = 0.001
Corrugated pipes are to be applied, available in diameters as given in Table 3.

Question: Which diameter is to be applied?
Solution:

Prepare a table of maximum drainable areas for the different diameters using eqs. (17.2) and (17.3)

Table 17.3. Maximum discharges and drainable areas with pipe drains of diameters as indicated valid for q = 2 mm/day and i = 0.001

Type of pipe	Diameter (mm)		Q (cum/day)		Drainage area (ha)
	Outside	Inside	d >100 mm	d ≤100 mm	
Corrugated PVC	60	52	-	23.5	1.2
	65	57	-	30.0	1.5
	80	72	-	56.0	2.8
	100	91	-	104.0	5.2
	125	115	244	-	12.2
	160	148	477	-	24.0
Concrete	-	100	-	134	6.7
	-	150	495	-	25.0
	-	200	1065	-	53.0
	-	250	1930	-	97.0
	-	300	3141	-	157.0

- Area to be drained by each lateral = 250 m x 80 m = 2 ha;
- The area per lateral falls in- between the maximum drainable areas for pipes 65/57 mm and 80/72 mm; so the next larger size is to be selected: 80/72 mm pipes.

The laterals as specified above discharge into a collector. Other laterals, each 150 m long, are entering the collector on the opposite side.

- Slope of collector i = 0.001;
- Length of collector = 1760 m;
- Concrete pipes are available with inside diameter of 150 mm, 200 mm, 250 mm, 300 mm, respectively:

Question: Which diameter is to be used?
Solution:

- Prepare a table of maximum drainable areas (see Table 3 lower part);
- Determine area drained by the collector: A = BL = 400 m x 1760 m = 70.4 ha;
- Inspection of the table shows that 250 mm concrete pipe have to be used.

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Skimming and Ground Water Recharge Using Harvested Rainwater

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About 60 percent of irrigation and 80 percent of drinking water requirements of India are met from ground water sources. Proliferation of about 20 million private open wells/shallow tubewells and 90000 deep public tubewells has been vital for about seven fold increase in India's irrigation potential over the last five decades. Due to easy access, operational convenience and private ownership, the ground water development has been quick but unregulated and has resulted in alarming decline of water tables in about one seventh of country's geographical area. In the susceptible states of Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Tamil Nadu and Uttar Pradesh, declining water levels are facing gradual deepening of the existing abstraction structures causing escalation in the cost of pumping. At current rate of development, about two fifth of the country's area is likely to be over-exploited (ground water abstraction > 85% of annual replenishment) by 2017.

Declining water levels in the arid and semi arid areas are often accompanied by increase in solute concentrations and deterioration of ground water quality. Saline water ingress has occurred in the coastal regions of West Bengal, Gujarat, Tamil Nadu, Pondicherry and other states due to excessive pumping and declining ground water levels. *Upconing* is a phenomenon due to which the interface of fresh and saline waters rises to enter the lower end of the well screen, resulting in a gradual deterioration in the pumped water quality. Besides extensive coastal regions of the country, *upconing* is prevalent in inland areas where excessive withdrawal of usable fresh water overlying saline groundwater results in inferior water quality and degradation of the aquifer. In particular, irrigated areas in many arid and semiarid regions are underlain by aquifers of poor quality where very little ground water development takes place resulting in waterlogging and secondary soil salinization like in a significant part of Haryana, Rajasthan, Gujarat and Punjab. Under these conditions, it is aimed that the saline water is not disturbed and the fresh water accumulated over saline ground water in thin layers is selectively pumped through specially designed skimming structures and by enhancing ground water recharge.

In this paper, basic features of different skimming structures are discussed in the context of Indian conditions. Further, field experiences on a number of new technologies for skimming and recharging of fresh water in saline ground water regions of Haryana, Andhra Pradesh, Gujarat and Tamil Nadu under a National Agricultural Technology Project are reviewed. Further, initial results of an extensive project on individual farmer based ground water recharge structures for augmenting groundwater, improving quality and enhance water productivity in 100 farmers' fields in declining water table areas of Haryana, Punjab, Uttar Pradesh and Gujarat are presented.

Ground Water Skimming Structures

Various skimming well configurations such as single, multi-strainer, radial collector and scavenger wells (Fig. 18.1) can be used to abstract fresh water from thin layers overlying saline ground water. The basic concept of skimming structures is to modify the flow lines in such a way to maximize horizontal contribution of aquifer zones of acceptable quality to pumped water (Sufi *et al.*, 1998). A single well (Fig. 18.1a) is used in unconfined aquifers in most parts of India. While using these wells in saline ground water regions, well penetration is kept deep into the fresh water layer with a large gap between the bottom of the well and the fresh- saline water interface. These types of tubewell drainage projects have been executed at Masitawali in IGNP (Hooja *et al.*, 1995), Ghaggar depressional areas in Rajasthan and in Fatehabad branch area of Haryana.

A multi-strainer well (Fig. 18.1b), with relatively shallower penetration than single well, can be used for water table control to reduce *upconing* in fresh water layers of restricted depth. The system consists of closely spaced interconnected wells, each of low capacity, pumped by a central suction pump. Such structures are being extensively used close to canals/ distributaries in Punjab in India (Shakya, 2002) and in the Indus plains of Pakistan (Sufi *et al.*, 1998; Mazhar Saeed *et al.*, 2003). There are sporadic reports on the use of these systems in marginally saline regions of Haryana, Rajasthan, Andhra Pradesh and Tamil Nadu in India. Air leakage and priming problems have been reported from these studies.

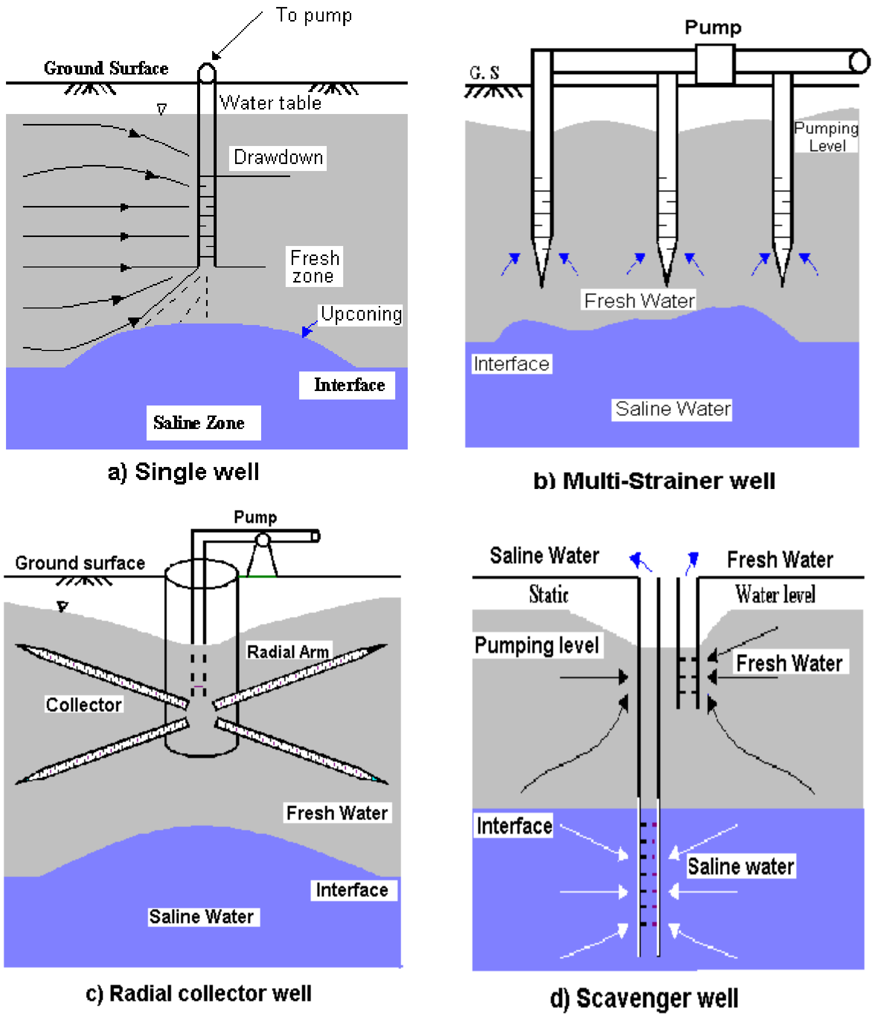


Fig. 18.1. Different types of fresh water skimming wells

Radial collector wells consisting of an open well and input radial drains on one or more sides (Fig. 18.1c) involve shallower penetration than a single vertical well operating at the same discharge. Since the radial drains collect water from shallow depths, *upconing* of saline water from lower depths is prevented. Large diameter open skimming wells experimented at Hisar in Haryana (Kumar and Singh, 1995) and at Luni-Ki- Dhani in Rajasthan (Hooja *et al*., 1995) and a drain line - sump based *Doruvu* technology embarked on a large scale in coastal sandy soils of Andhra Pradesh (Raghu Babu *et al*., 1999; Raghu Babu *et al*., 2004, NATP, 2005) are the local variants of radial collector wells.

Scavenger wells (Fig. 18.1d) involve simultaneous abstraction of fresh and saline waters through two wells having screens in different quality zones, for controlling the rise of interface. The scavenger wells have been tested in the lower Indus basin of Pakistan (Sufi *et al*., 1998) and have shown their potential in skimming of fresh water. Despite apparent problem of disposal of saline water, the scope of scavenger wells needs testing for cases involving two cavity wells (non- strainer tubewells common in saline groundwater regions of Indo- Gangetic plains) installed at different depths or a combination of a strainer and a cavity wells. Geological, hydrological and geo- chemical characteristics of the aquifers must be studied in an integrated way to study the hydraulics and evaluate the performance of these skimming structures.

National Agricultural Technology Project (NATP)

A NATP 'Technologies for skimming and recharging fresh water in saline ground water regions' was operated at CSSRI (the lead center) and four collaborating centers. Over a period of 5 years, the project has made impressive accomplishments in proposing, testing and evolving ground water skimming and recharging technologies in saline ground water regions of Haryana, Andhra Pradesh, Gujarat and Tamil Nadu. Features of the promising technologies are briefly discussed below:

(a) **Haryana:** The north- western Indian state of Haryana is a part of Indo- Gangetic alluvial plains. About two third of the geographical area is currently underlain with saline groundwater and the situation is deteriorating further due to disproportionate pumping vis- a- vis ground water recharge. In most of the marginally saline ground water regions, low discharge shallow cavity wells are used for irrigation, which are inexpensive pumping structures not requiring strainer. Deep tubewells are not feasible due to increasing ground water salinity with depth while many shallow tubewells are abandoned due to *upconing* of saline water from the deeper layers.

A skimming cum recharge structure (Fig. 18.2) was constructed at a downstream location prone to runoff flooding at village Jagsi/ Sarfabad in Saffidon block of Jind district. The system consists of two cavity tubewells, installed at 7 m and 40 m depth in the respective fresh and saline ground water zones, which can be operated separately or together to obtain water of different qualities. The system is similar in features to a scavenger type skimming structure (Fig. 18.1d) discussed above but consists of cavity wells instead of strainer tubewells. A recharge chamber of 6 m x 2.5 m x 2 m size and containing a graded filter of fine sand, coarse sand, gravel and boulders was constructed close by to facilitate recharging of one or both cavities with filtered runoff during rainy season or excess canal water. The objective was to increase the availability of good water in upper cavity or improve the quality of lower cavity for possible use at time of water scarcity.

Kamra *et al,* (2006) report general improvement in the groundwater regime of area due to combined effect of the natural and imposed recharge interventions. The estimated recharge rates through injection in cavity wells were low at about one quarter of the pumping rates under shallow ground water conditions.

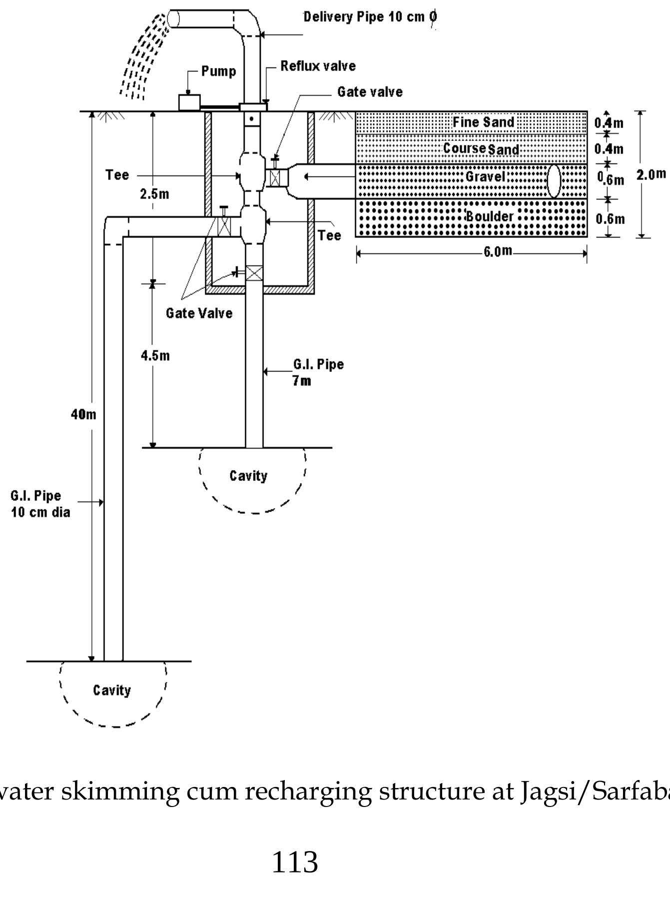


Fig. 18.2. Ground water skimming cum recharging structure at Jagsi/Sarfabad, Haryana

(b) **Coastal Sandy Soils of Andhra Pradesh and Tamil Nadu**: In Andhra Pradesh, about 1.74 lakh ha coastal sandy soils are characterized by good quality water floating over saline ground water at shallow depths which cannot be extracted with conventional tubewells. These soils occur in a 10 km wide and 972 km long strip extending from Ichapuram in Srikakulam district to Tada in Nellore district. The annual rainfall in this belt ranges from 700 - 1200 mm with an average of 855 mm. Farmers traditionally draw out manually the fresh water that collects in dug out conical pits locally called *doruvus* and use it for cultivation of vegetables, flower plants and raising crop nurseries. Similar practices involving shallow pits (locally called *Oothu Kuzhi*) are prevalent in nearly 600 km long coast line and 6.8 lakh ha coastal area in Tamil Nadu. These *doruvus* waste about 20% fraction of the productive coastal sands and are also subjected to high evaporation losses.

Over last decade, a radial collector well type (Fig. 18.1c) skimming structure, called '*Improved Doruvu*', had been evolved through All India Coordinated Research Project on Saline Water Scheme at Bapatla in Guntur district of Andhra Pradesh. The radial arms (perforated drain lines of 30- 40 m length) installed at 2- 4 m depth skim fresh water from thin zones and carry it to an open well (called sump) from one or more sides. The system yields a discharge of 5 to 15 lit/sec or more depending upon number of arms and nature of sand and can operate in combination with sprinkler/drip system. The system has been extensively adopted at more than 70 sites in 20 villages in Guntur and Prakasam districts of Andhra Pradesh. A major deterrent for large- scale adoption among small and marginal farmers had been the high cost and lack of optimal designs and layouts for sustained supply of fresh water.

Geohydrological and geophysical studies, conducted under NATP in Guntur district in Andhra Pradesh and Nagapattinam district in Tamil Nadu, indicate the existence of a sand layer of less than 8- 10 m followed by a clay layer saturated with saline water. The EC of water increases with depth and with increasing nearness to the sea. Radial collector wells of different designs (2 to 4 drain lines at same or variable depth and drain length) were evaluated for hydraulics and economics at a number of sites in these districts of Andhra Pradesh and Tamil Nadu. Pumping tests indicated 90 m as the safe spacing between two skimming wells. The tracer studies revealed that radial arm contribute 80% of pumped water while the remaining 20% comes from the bottom of the well. Multiple filter point systems (Fig. 18.1b), tested at a number of sites in these districts and indicated limited scope for skimming due to insufficient water in the flow domain. The improved D*oruvu* technology was found to increase the farmers' income by 25 to 40% due to enhanced crop yield but is extremely costly at about Rs. 75,000 for two arm wells. Horizontal drilling of radial drains needs to be standardized for sandy soils to reduce the cost of installation of these structures. Further details on the features and performance evaluation of the above and a few additional ground water skimming and recharge structures can be found in NATP (2005).

Salient Observations and Emerging Issues of NATP

1. Radial collector well type structures have considerable scope in coastal sandy soils for skimming of fresh water from thin sandy zones. The cost of the system can be considerably reduced by standardizing the techniques for horizontal drilling of drains in sandy soil.
2. The performance of skimming structures in coastal sandy soils is significantly influenced by the depth and nature (coarse/fine) of sand. Govt. may provide subsidy for installation of these structures in the identified areas. Multiple well point systems have restricted scope for skimming in coastal sandy soils due to limited depth of sand column.
3. Individual farmer oriented recharging schemes are socially viable and have better chance of success and sustenance than the community/govt. sponsored and maintained large recharge systems.
4. Incorporation of small and less costly recharge filters in the existing or abandoned dug wells/ tubewells can contribute to significantly enhance ground water recharge. Design of alternate filters for artificial recharge structures need to be tested for efficacy as well as economy.

Farmers' Paricipatory Action Research Project (FPARP)

The escalation in pumping costs due to falling water tables and associated socio-economic and environmental impacts are threatening the sustainability of agriculture, particularly in the productive states of Haryana, Punjab and western Uttar Pradesh. The water productivity of widely prevalent rice- wheat cropping system in these states is declining. 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 ground water regions where aquifers of 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. The water table depth in most fresh ground water districts of Haryana and Punjab has fallen below 15- 20 m and still deeper at 28.8 m and 41.1 m in Kurukshetra and Mahendragarh districts in Haryana. This is forcing farmers to use deep submersible pumps in place of centrifugal pumps resulting in huge additional expenditure and extra power consumption. The ground water decline can be deferred by enhancing artificial recharge using rain and excess canal water through surface spreading and well injection techniques.

Central Ground Water Board (CGWB) and other agencies including research institutes, universities and NGOs have conducted a large number of studies on induced recharge through a number of methods such as injection wells, check dams, subsurface dykes and surface spreading in several declining watertable areas of the country. Well injection techniques are getting increasingly accepted due to failure or delay in arrival of natural or artificially recharged water with surface methods to deeper aquifer zones. A number of pilot studies on vertical and lateral recharge shafts and injection wells have been undertaken by CGWB in Punjab and Haryana including a major study in Dhuri Link drain in Punjab.

A Ministry of Water Resources (GOI) funded FPARP is operational at CSSRI, Karnal and its Regional Research Stations at Bharuch (Gujarat) and Lucknow (Uttar Pradesh) since 2008. Over a period of two years, individual farmer based technologies on groundwater recharge, integrated farming and laser leveling technologies/interventions have been implemented and evaluated at 93 village sites including 53 in six districts of Haryana, 8 in one district of Punjab, 17 in three districts of UP and 15 in one district of Gujarat (Table 18.1).

The watertable depth in most selected sites in four states varies between 10- 30 m and has been falling @ 20- 60 cm every year. Despite semiarid climate at selected sites, there are depressional areas where water accumulates during rainy season and can be recharged to ground water. About one third sites of Haryana and all sites of Punjab have high ground water salinity and residual sodium carbonate (RSC) problems. Ground water in Unnao district has high fluoride concentration that is adversely affecting the health of the people and livestock.

Technologies

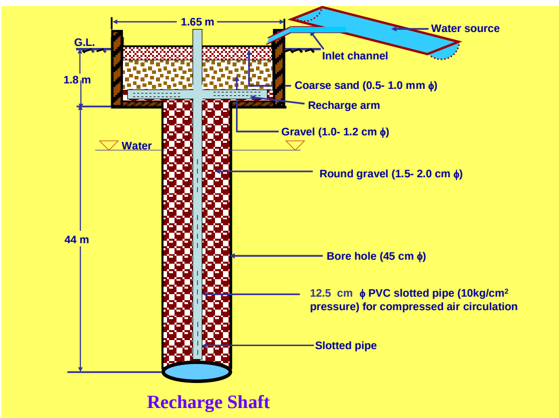
Ground water recharge systems are based on well injection techniques and involve passing of excess rain and canal water under gravity to suitable aquifer after filtration. The demonstration sites were identified based on interaction with farmers, local tubewell mechanics and NGOs. Selection of recharge structures of different designs, depths and costs (recharge shafts, recharge cavities, recharge wells, dry cavities, and abandoned wells) was based on hydro- geological investigations and quantum of potential runoff water available at specific locations. A typical recharge structure consists of a recharge well coupled to a recharge filter. The integrated farming systems involve horticultural crops and fisheries in fresh and saline groundwater regions while laser levelling and improved irrigation interventions aim to increase uniformity of water application for enhancement of water productivity and farmers' income.

Table 18.1. Technologies/interventions introduced under FPARP in different states

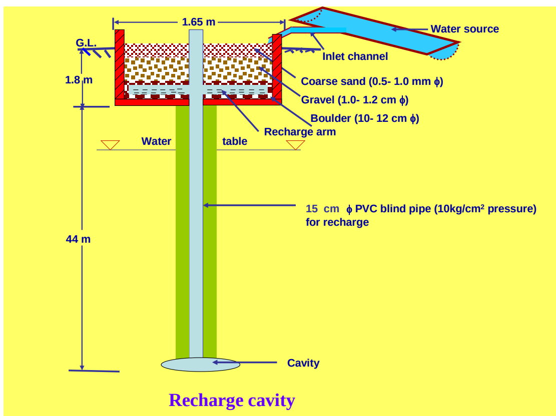
States/District	Technology/intervention	No. of sites
Haryana		53
Karnal, Kaithal, Jind, Kurukshetra, Yamunanagar, Sonipat	Recharge shaft	21
	Recharge cavity	08
	Laser leveling	19
	Other (abandoned cavity, dry cavity, saline fisheries)	05
Punjab		08
Patiala	Recharge shaft	05
	Laser levelling	03
Uttar Pradesh		17
Unnao, Raebareli, Muzzafernagar	Recharge cavity	03
	Laser leveling	03
	Improved irrigation methods	11
Gujarat		15
Bharuch	Recharge well	12
	Renovation of farm pond/IFS	03
Total		93

(a) Recharge Shaft (26 sites, Fig. 18.3a): It consists of a bore hole of 45 cm ϕ filled with gravel to carry filtered recharge water to subsurface sandy zones. The surface runoff is first passed through a recharge filter consisting of layers of coarse sand, small gravel and boulders in a small masonry chamber to safeguard against clogging. A high pressure PVC pipe, of 12.5 cm ϕ and slotted in sandy zones, is provided for cleaning of clogged sediments in the shaft with compressed air, if needed. The depth of recharge shafts was decided based on the criterion to provide minimum 10 m cumulative sand layers for recharge.

(b) Recharge Cavity (11 sites, Fig. 18.3b): A recharge cavity is similar to a cavity tubewell coupled with a graded sand filter of the type used in recharge shaft. It is constructed by drilling a bore hole until a sandy layer is found below a clay layer. A blind PVC casing pipe is drilled into the clay layer and sand is pumped out until a stable cavity is developed below the clay layer. A recharge cavity can also be used for occasional pumping. In Uttar Pradesh, strainer well (slotted pipe) in sandy zones was combined with cavity for recharging of water.



(a)



(b)

Fig. 18.3. Design features of recharge shaft (a) and recharge cavities (b) installed in Haryana, Punjab and Uttar Pradesh

(c) Recharge Wells (12 sites): Installed in Bharuch district of Gujarat, the recharge wells are similar to recharge shaft except that boreholes of different sizes (17.5- 40 cm ϕ) and filter chambers of different shapes have made at different sites. Placement of 12.5 cm ϕ PVC pipes and 8-20 mm ϕ pebbles in the bore hole was facilitated through air compressor; pebbles not used in 2 sites having rocky substratum.

(d) Laser Leveling (25 sites): The laser guided leveler is a new farm implement that is making a major headway in saving irrigation water vis-a- vis conventional leveling implements in rice-wheat cropping system in Indo- Gangetic states. The implement costs about Rs. 3.5 lakh and is operated with a high HP tractor. It has been introduced in large numbers in Punjab in a custom hiring mode and is also coming up fast in Haryana. Under FPARP, laser leveling intervention was demonstrated in one acre fields and compared with convention leveling systems in terms of improvement in water productivity.

(e) Improved Irrigation Methods (11 sites): Based on location and stream size of irrigation water and general slope estimated by contour survey, demonstrations on border (45- 60 m long, 5-6 m wide) and check basin (10 m x 10 m to 15m x 15 m) irrigation methods were made. The saving in applied water and improvement in yield of wheat were recorded.

(f) Pond Renovation (3 sites): Renovation of existing farm ponds (desilting, deepening and shaping) helped in rainwater conservation and further use to provide supplemental irrigation to crops. At one site in rocky substratum, rain water conservation achieved through an open well and a recharge well to provide irrigations in agri- horticultural system of Mango-Soybean.

Brief features and cost of main technologies are summarized in Table 18.2.

Table 18.2. Features of demonstrated recharge structures and interventions

Structure	Depth (m)	Thickness of sandy layers (m)	Cost (Rs.)
Recharge saft	30- 46	10- 18	35000- 48000
Recharge cavity	40- 55	NA	35000- 45000
Recharge cavity cum strainer well	50	25	55000- 58000
Recharge well	25- 45	15- 18	22000- 31000
Laser leveling and improved irrigation methods	-	-	4000- 5000/ha
Pond renovation	-	-	10000-20000

(g) Other Technologies (5 sites): These included recharge of abandoned cavities, dry cavities and saline fisheries.

Evaluation of Recharge Technologies

Individual farmers can construct recharge structures at any low lying location where runoff gets accumulated and adversely affects the production of rice during monsoon rains and of wheat during occasional winter rains. At most sites in Haryana and Punjab, runoff water from 10-20 ha surrounding area was available during monsoon for recharge through these structures. It was observed that more than one recharge structure was required at certain sites where transplanted paddy was damaged severely by flood water, though it helped in the survival of crop in the upper surrounding fields. There are encouraging results on the effectiveness of recharge structures (shafts, cavities, wells) to replenish ground water and improve its quality. Depth to ground water and EC, pH and RSC of ground water were determined periodically to assess the impact of recharge structures. The temporal changes in depth, EC and RSC or pH of ground water at two representative sites are presented in Fig. 18.4. It is seen that recharge events, indicated by arrows, caused both a rise in water table and reduction in EC and RSC of ground water.

The clogging of the recharge filter has been observed to be a major constraint in the performance of recharge structures. Farmers need to be trained to clean the deposited sediments on the sand layer of recharge filter after every recharge event and replaced with new or washed sand to maintain optimal water intake. Mechanisms for farmers' involvement and marginal sharing of cost of recharge structures need to be developed. Field and lab studies are in process to devise improved designs of recharge filters to minimize clogging problem. Thickness of upper sand layer of recharge filter has been found to be a primary factor influencing clogging, while size of gravel in the middle layer also controls effectiveness of sand as a filter.

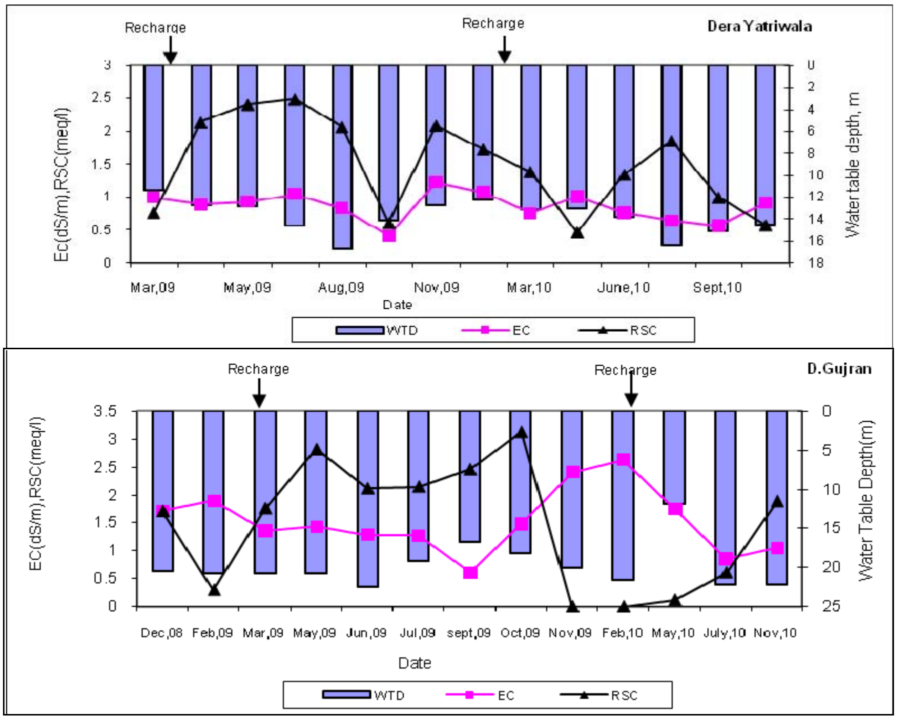


Fig. 18.4. Temporal changes in depth, EC and RSC of groundwater at two recharge sites (Dera Yatriwala and Dera Gujran) in Haryana

Impact of Recharge Structures

The results of 1-2 rainy seasons indicate these structures to be highly effective in augmentation of ground water and improving its quality.

- Runoff water from 10- 20 ha surrounding area was available for recharge at sites in Haryana and Punjab during 2009 and 2010. The recharge structures were successful in saving of transplanted paddy in all or a part of water submerged area. Considering the volume of flood water, additional structures are needed at some sites for which farmers were keen using their own resources. Field hydrological studies and socio- economic surveys with farmers at selective sites indicate that :

- 21.4 cm rainfall occurring in 4 storms of 5 cm or more over 2-3 consecutive days during July-September, 2009 produced 10.4 cm cumulative runoff at specific sites in Haryana. Based on results of one rainy season, capital investment cost has been worked out @ Rs. 3.5 to Rs. 2.1 / m^3 recharge water for locations collecting runoff from 12- 20 ha area.

- At 2 sites having 20 ha and 12 ha water contributing areas, recharge structures reduced damage to basmati rice in 2 ha and 1 ha area by 30 % and 25 % respectively. This translates into a net saving of Rs. 58,800 and Rs. 24,500 from rice crop only and payback period of 1-2 years for these systems.

- Based on limited studies, recharge capacity of recharge shafts and cavities installed in Haryana and Punjab has been estimated @ 4-6 litre/sec or 2500- 3500 cum/week provided sediments retained in recharge filter are cleaned timely. The life of recharge structures, with periodic cleaning of clogged sediments in subsurface layers, is expected to be 15- 20 years. The farmers prefer recharge cavities over recharge shafts due to the possibility of its occasional use for pumping water for irrigation.

- There are encouraging results on the effectiveness of recharge structures to replenish groundwater and improve its quality. The recharging of water resulted in 0.6- 3.3 m and 0.3 to 3.3 m rise in water table at different sites in Haryana and Punjab during rainy seasons of 2009 and 2010 respectively. The corresponding reduction in salinity and RSC of groundwater at different sites ranged from 0.2- 2.4 and 0.1- 0.8 dS/m and 0- 6.6 and 0- 8.3 respectively during these two years. The temporal changes in groundwater quality due to recharge interventions at selected sites during 2009 and 2010 are presented in Table 18.3.

Table 18.3. Improvement in ground water quality due to recharge interventions at FPARP sites

State/ Year	Name of village	EC (dS/m)			RSC		
		May/ June	July/ August	October/ November	May/ June	July/ August	October/ November
Haryana							
2009	Nabiabad (Karnal)	1.9	1.1	0.5	6.0	2.4	0.2
	Paju Kalan (Jind)	1.2	0.9	0.5	5.6	3.4	0.6
	Dussain (Kaithal)	1.4	1.1	0.5	6.7	3.9	2.1
2010	Newal Khurdh (Karnal)	1.3	0.7	1.1	3.7	2.3	1.0
	Paju Kalan (Sonipat)	1.7	0.6	1.5	4.4	0.7	2.1
	Dussain (Kaithal)	1.0	0.8	1.1	6.9	3.4	2.6
Punjab							
2009	Jodhpur (Patiala)	2.0	1.7	1.1	7.1	3.4	3.2
2010	Budhmor (Patiala)	1.3	1.1	1.1	4.8	3.0	3.1
Gujarat							
2009	Borebhete (Bharuch)	1.9	0.3	0.6	-	-	-

- GR through 12 recharge wells constructed in Bharuch district of Gujarat also resulted in prolonged availability and improvement in quality of groundwater during rainy season of 2009. At one site (Borebhata), reduction in groundwater salinity from 1.9 dS/m to 0.3 dS/m resulted in 37.5 % increase in income (Rs. 2.0 lakh to 2.75 lakh/ ha) in Banana plantations and 14.3 % increase in income (Rs. 3.5 lakh to 4.0 lakh /ha) in papaya plantations. At another site (Netrang), well recharge caused 2.3 m rise in watertable and reduction in groundwater salinity from 1.02 to 0.15 dS/m. This resulted in improvement in yields and additional incomes of Rs. 14000/ha and Rs. 33250/ ha in Soybean crop and mango plantations.

- GR of excess canal water through newly installed recharge cavities at 3 sites in Unnao district of UP reduced fluoride concentration of groundwater from 2.5 ppm to 0.6 ppm, i.e below prescribed limit of 1.5 ppm for drinking water during 2010 rainy season.

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Use of Pressurized Irrigation Systems in Salt Affected Soils

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Globally as well as in India, providing food security to burgeoning population is going to be a very difficult task in near future. Per capita availability of land resource is rapidly declining in relation to annual population growth of 1.4% in India. Increasing urbanization and industrialization is taking more and more agricultural lands for non-agricultural purposes (CWC, 2004). In this situation, there is need for increasing area under cultivation by reclaiming salt affected soils. The salt affected soils can contribute significantly to national food basket if managed scientifically and in a sustainable manner. This could be achieved in association with proper soil and water management.

Irrigation Management in Salt Affected Soils

The irrigation management for crop production in salt affected soil requires an understanding of how salts affect plants and how cropping and irrigation activities affect soil and water salinity. 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. The most practical way to accomplish this is through use of improved irrigation techniques by applying small quantity of water frequently and in controlled manner.

The depth of water to be applied at each irrigation and the time interval between successive irrigations are also important. Applying water too frequently or too infrequently can result in reduced crop yields and water use efficiency. The optimum depth of irrigation and the interval between two irrigations are determined by such factors as the atmospheric evaporativity, proliferation and depth of root penetration, capacity of the soil to store and transmit water and the nature of plant responses to soil moisture stress. For crops other than rice, irrigation management presents major difficulties in obtaining optimum crop yields in sodic soils. Excess exchangeable sodium profoundly influences soil water behaviour and therefore the irrigation management needs of these soils. It is found that for best results in sodic soils, the depth of irrigation should be governed by the infiltration characteristics of the soil rather than the conventional criteria of the soil storage capacity. Quantities of water in excess of what can be absorbed in a few hours could result in an oxygen imbalance in the root zone adversely affecting crop growth. In sodic soils, limited root penetration, lowered capacity to store water in an available form and poor transmission characteristics require that the irrigations are applied more frequently than would be required for crops grown under normal soil conditions. The optimum frequency will depend chiefly on the stage of soil deterioration. For the same reasons, pressurized irrigation systems are better than surface water application because of the ease of applying light and frequent irrigations through these method and at the same time by virtue of applying nutrient frequently in small quantities.

Pressurized Irrigation Systems

In traditional irrigation methods, water flow from the source to the field and on-field distribution is under gravity and due to elevation difference. In contrast, in pressurized irrigation, water moves from source to field in pipe and its conveyance and distribution is under pressure created by pumping unit. These irrigation systems are able to achieve high water application efficiency. Against the backdrop of the rapid decline in irrigation water potential and low water use efficiency in the conventional methods of irrigation, efficient irrigation methods have recently been introduced in Indian agriculture to save limited water resource available and manage irrigation precisely and effectively in salt affected soils and poor quality water.

Sprinkler Irrigation: This is a pressurized irrigation system based on overhead sprinklers, sprays or guns, installed on permanent risers. In sprinkler irrigation, water is sprayed into the air and allowed to fall on the ground surface somewhat resembling rainfall. The spray is developed by the flow of water under pressure through small orifices or nozzles. The pressure is usually obtained by pumping. With careful selection of nozzle sizes, operating pressure and sprinkler spacing the amount of irrigation water required to refill the crop root zone can be applied nearly uniform at the rate to suit the infiltration rate of soil. Sprinklers provide efficient coverage for small to large areas and are suitable for use on all types of properties. It is also adaptable to nearly all irrigable soils since sprinklers are available in a wide range of discharge capacity.

Advantages of Sprinkler Irrigation: The following are major advantages:

- Elimination of the channels for conveyance, therefore no conveyance loss
- Suitable to all types of soils except heavy clay soil
- Suitable for irrigating crops where the plant population per unit area is very high. It is most suitable for oil seeds and other cereal and vegetable crops
- Water saving and increase in yield
- Closer control of water application convenient for giving light and frequent irrigation and high water application efficiency
- Mobility of system
- Useful for undulating area, no bunds are required
- Influences greater conducive micro-climate
- Possibility of using soluble fertilizers and chemicals
- Less problem of clogging of sprinkler nozzles due to sediment laden water

The trials conducted in different parts of the country revealed water saving due to sprinkler system varies from 16 to 70% over the traditional method with yield increase from 3 to 57% in different crops and agro--climatic conditions (INCID, 1998, Table 19.1). Uniformity of water spraying governs response of different crops to the system.

Table 19.1 . Water saving and increase in yield under sprinkler irrigation system

Crops	Response of different crops to sprinkler irrigation	
	Water saving (%)	Yield increase (%)
Bajra	56	19
Barley	56	16
Bhindi	28	23
Cabbage	40	3
Cauliflower	35	12
Chillies	33	24
Cotton	36	50
Cowpea	19	3
Fenugreek	29	35
Garlic	28	6
Gram	69	57
Groundnut	20	40
Jowar	55	34
Lucerne	16	27
Maize	41	36
Onion	33	23
Potato	46	4
Sunflower	33	20
Wheat	35	24

Source: INCID (1998)

The water discharged from a single sprinkler is not uniformly distributed over the entire area. A greater quantity falls near the sprinkler and less in the periphery. To ensure a uniform spraying over the entire area, the sprinklers are always placed so that they overlap each other from both directions. In order to obtain good distribution uniformity by overlapping, the sprinkler spacing should not exceed 65 percent of the sprinkler diameter coverage under light to moderate wind conditions in the square and rectangular patterns. In the triangular pattern, the spacing can be extended up to 70 percent of the diameter coverage. In strong wind conditions, the spacing should be 50 percent of the diameter coverage with the lateral direction perpendicular to the wind direction. Sprinkling is not recommended for the wind speed over 3.5 m/s.

Micro-sprinklers: Microsprinklers are smaller in size than the conventional sprinklers and with flow rates up to 250 litre/hr. They are placed on a relatively close rectangular or triangular spacing for the maximum overlap to irrigate potatoes, carrots, leafy vegetables, groundnuts and other densely planted field crops. This method is reliable, highly efficient, and easy to apply, operate and handle. The system is a seasonal, low pressure, micro-irrigation solid installation which can be easily placed in the field and quickly removed at the end of the season.

These emitters are low capacity rotary sprinklers designed for low discharges uniformly distributed over the irrigated area in a rainfall pattern. The performance characteristics are (i) operating pressure: 2.0 bars (ii) flow rate (discharge): 130-250 litre/hr (recommended 160-180 litre/hr) (iii) wetting diameter (coverage): 12 m average (iv) precipitation rate: 4-7 mm/hr (recommended) (v) filtration requirements: 40-60 mesh (300-250 microns) approximately.

Bubbler Irrigation: Bubbler irrigation is a localized, low pressure, solid permanent installation system. Bubblers are very similar to the point source external emitters in shape but differ in performance. These small emitters discharge water at flow rates of 100-250 litre/hr.

Drip Irrigation System: Drip irrigation is an advance method of irrigation and based on the fundamental concept of irrigating root zone rather than the entire land surface, which results 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. Some of the common features of all type of drip systems are that they consist of pipe network to transport water and a water emission device to deliver water precisely. In addition to this, the system requires relatively fine mesh filtration and some level of pressure regulation.

Advantage of Drip Irrigation: Main advantages are:

- Drip irrigation saves water and increases yield of crop (Table 19.2)
- Drip irrigation makes possible to grow crop in all types of soils
- Drip irrigation allows the crop to approach production potential for more days of the season
- Higher water use efficiency
- Saving of fertilizer
- Early and uniform maturity of the crop and improved quality of produce
- Uniform plant growth
- Reduces the incidence of pests and diseases

Salt Accumulation under Different Irrigation Methods

The method of irrigation directly affects 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 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. 19.1 illustrates several typical salinity profiles resulting from surface flooding or sprinkler irrigation at leaching fractions varying from 0.1 to 0.4. Fig. 19.1 shows the salt accumulation patterns for surface flooding or 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 build-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.

Table 19.2. Comparison of surface and drip irrigation system in terms of water savings

Crop	Water applied (mm/ha)		Yield (t/ha)		Water saving over FIM (%)	Yield increase over FIM (%)	Water use efficiency (yield/ha-mm)	
	FIM	DIM	FIM	DIM				
Vegetables								
Ash gourd	840	740	10.84	12.03	12	12	0.013	0.016
Bottle gourd	840	740	38.01	55.79	12	47	0.045	0.Q75
Brinial	900	420	28.00	32.00	53	14	0.031	0.076
Beet root	857	177	4.57	4.89	79	7	0.005	0.028
Sweet potato	631	252	4.24	5.89	61	40	0.007	0.023
Potato	200	200	23.57	34.42	Nil	46	0.118	0.172
Lady's fingcr	535	86	10.00	11.31	84	13	0.019	0.132
Onion	602	451	9.30	12.20	25	31	0.015	0.027
Radish	464	108	1.05	1.19	77	13	0.002	0.011
Tomato	498	107	6.18	8.87	79	43	0.012	0.083
Chillies	1097	417	4.23	6.09	62	44	0.004	0.015
Ridge gourd	420	172	17.13	20.00	59	17	0.041	0.116
Cabbage	660	267	19.58	20.00	60	2	0.030	0.075
Cauliflower	389	255	8.33	11.59	34	39	0.021	0.045
Fruit crops								
Papaya	2285	734	13.00	23.00	68	77	0.006	0.031
Banana	1760	970	57.50	87.50	45	52	0.033	0.090
Grapcs	532	278	26.40	32.50	48	23	0.050	0.117
Lemon	42	8	1.88	2.52	81	35	0.045	0.315
Watermelon	800	800	29.47	88.23	Nil	179	0.037	0.110
Mosambi*	1660	640	100.00	150.00	61	50	0.060	0.234
Pomegranate*	1440	785	55.00	109.00	45	98	0.038	0.139
Other crops								
Other Croos:								
Sugarcane	2150	940	128.00	170.00	65	33	0.060	0.181
Cotton	856	302	2.60	3.26	60	25	0.003	D.OI I
Coconut	--	--	--	--	60	12	--	--
Groundnut	500	300	1.71	2.84	40	66	0.003	0.009

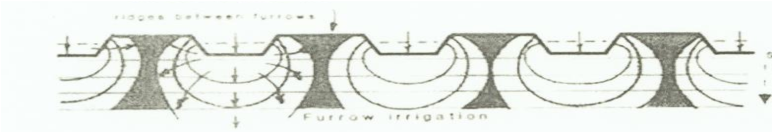
FIM: Flood irrigation method, DIM: Drip irrigation method, Sourc : INCID (1994) and NCPA (1990)

Pressurized Irrigation and Salt Management for Crop Production

There are two ways to manage the salt for crop production in salt affected soils. They are (i) salts can be moved below the root zone (leaching) by applying more water than plant needs (ii) managed accumulation of salt i.e. salts can be moved away from the root zone to location in the soil, other than below the root zoone, where they are not harmful.

Sprinkler or surface irrigation

Border check basin irrigation



Furrow irrigation

Drip irrigation

Fig. 19.1. Salt accumulation pattern in soil under different irrigation systems

The most common remedy used to reduce soil salinity is to increase the quantity of irrigation per application. This approach is effective if the soils are permeable enough to accommodate increased irrigation, and that such a practice will not raise the water table to a risky level. Among the most commonly used methods of irrigation, sprinklers are considered most efficient for leaching salts. The primary reason is that downward movement of soil water flow under sprinklers is unsaturated flow which provides a high level of salt leaching per unit quantity of water applied. This, however, depends on soil profile configuration. For example, stratified soils prevalent in alluvial basins interfere with soil water movement, and creates saturated flow in clay strata present above the sand or sandy layer. Under such situations, sprinklers may not have a distinct advantage. Sprinkler irrigation also has the advantage in high water table areas or uneven grounds, as they provide a high degree of water application control. However, It can induce foliar salt damage.

In addition to leaching the salt below root zone, salts can be managed to move away from the root zone by using pressurized irrigation system. In drip irrigation, the distribution of dissolved salts in the soil profile follows the pattern of the water flux with the tendency for accumulation at the periphery of the wetted soil mass (Fig.19.2). Most of the wetted zone below the emitter, where most of the roots concentrate and function, remains free from salts during the irrigation season with low to medium salinity values. Near the surface, due to evaporation, the salt accumulation is five times greater than in the deeper layers and increases with distance from the emitters. This, in combination with the use of poor quality irrigation water and the application of fertilizers through the system, will cause salinity build-up, which might become a problem in areas where the annual rainfall does not exceed 250 mm. In these cases, it is essential to flood the total area once a year, at the end of the season, with adequate amounts of water in order to leach the salts beyond the rooting depth.

The salinity level in the root zone is related to the water quality, the amount of fertilizers and the irrigation dose (Minhas, 2001). The salt accumulation in the vicinity of the emitters is less than half that between the emitter lines. The EC value of the saturation extract beyond the emitter is 2-3 times the EC_{iw}, and between the lines it is six to ten times higher. This high salt content can be controlled only by leaching or by reducing the amount of fertilizer during the growing season. In no case should the fertilizer concentration in the irrigation water exceed 0.5 dS/m, that is added to the total salinity of the irrigation water.

In drip irrigation, extra leaching with increased quantities of water every application during the irrigation season is not recommended unless salt accumulation reaches hazardous levels. Leaching should take place after the crop harvest, between irrigation seasons, where the salt content is excessive and the rainfall is not sufficient. It is done either by flooding the area or by low precipitation sprinklers with very fine drops.

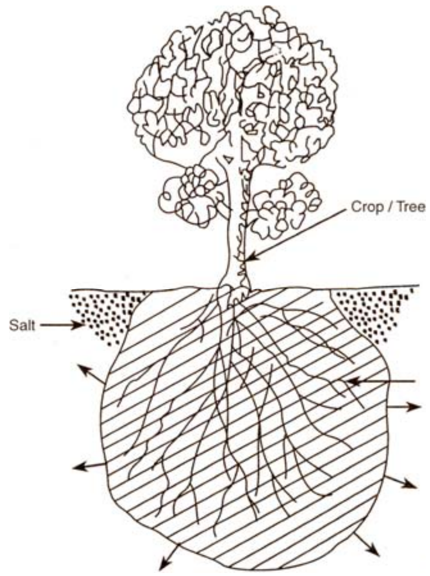


Fig. 19.2. Salt accumulation pattern in soil irrigated with drip system

Control of Secondary Salinization through Pressurized Irrigation Systems

The secondary salinization of soils in irrigated commands is attributed mainly to the disturbance of original salt balances as a consequences of rise in water table or when irrigated with salty waters. The former is the result of replenishment of excessive irrigation water that accelerates the upward movement and evaporation of ground water by capillary action and therefore, promotes the accumulation of salts from ground water and from lower horizon to the surface soil. Saline areas are usually those where a net down flux of water is not possible due to deficit water supplies. Generally there are three ways to control and prevent soil salinization, viz. remove excessive salts from soil, regulate salt distribution in the profile and prevent reaccumulation of salts in soil. Salt leaching after making the provision for artificial drainage and heavy irrigation was once considered to be an effective method for removing excessive salts but it is becoming increasingly unacceptable in the situations of lesser water resources and because of stringent regulations of environmental protection. Thus, only after adapting the appropriate measures for rational use of water and development of water saving agriculture, the occurrence of secondary salinization can be prevented economically and effectively. For reducing ground water recharges, improvements in all the major components of irrigation system, viz., conveyance, distribution and application systems will have to be achieved. Conventional surface irrigation systems have low application efficiency, while efficiency of 90% is achieved with sprinkler and drip systems respectively. Moreover, drip system is more efficient in terms of productivity and water saving. Experiences with different crops in various agroclimatic zones of India show that saving in irrigation water ranges between 10-55 and 50-72% with drip systems over the conventional surface method. Tyagi *et al.,* (1993) developed a framework for planning irrigation system improvement for salinity control. Its applications to Lower Ghaggar Basin showed that occurrence of water logging can be delayed by 10-12 years through efficient irrigation system and canal lining. Thus, the adoption of pressurized irrigation system on a large-scale seems a dire necessity to promote efficient water management for long-term sustainability of irrigated agriculture.

Limitations of Pressurized Irrigation Systems

Economic consideration usually limits the use of pressurized irrigation system despite of several advantages in water management. In addition to that, the main constraint of using saline water in salt affected soils is encountered through clogging of emitting devices. Precipitation of salts may occur on the outlet of emitters especially on drying of waters containing high soluble salts. The main causes of clogging of emitters are suspended matter, chemical precipitation and bacterial growth (Adin and Sacks, 1991). The solution of clogging problems is to prevent entering foreign material in to the system and by chemical treatment. Some methods discussed below canbe adopted for proper functioning of pressurized irrigation systems (Phocaides, 2000).

Flushing: Routine flushing of pipelines is required to prevent emitter plugging from the gradual accumulation of particles which are too small to be filtered, but which settle out or flocculate at the distal ends of pipelines. Flushing velocities must be high enough (at least 0.6 m/sec) to transport and discharge heavy particulate matter from the pipelines. Flushing should be more frequent when large amounts of debris are present, while less frequent flushing may be adequate if only small amounts of debris are flushed. Applying surfactants or dispersing agents such as sodium hexametaphosphate through the micro-irrigation system helps in reducing plugging problems by preventing the accumulation of silts and colloidal clays, allowing them to easily pass through the emitters or flushed from pipelines. Automated flush valves are sometimes used at the ends of the laterals to help flush fine particulates at the start of every irrigation, however, periodic manual flushing is still required. Use of these valves is not recommended since they tend to leak and waste water, requiring extra maintenance.

Chlorination: Chlorine injection is the most common and least expensive method to prevent clogging by biological growth (algae, colonial protozoa, sulfur bacteria, and other mucous organisms). Iron and manganese precipitating bacteria can be controlled by chlorine treatments, aeration or polyphosphates. Chlorine injection will cause oxidation and precipitation of iron and manganese (plus kill any iron and sulfur precipitating bacteria. The general recommendations are to inject 1 ppm of free chlorine/0.7 ppm soluble iron or 1.33 ppm free chlorine per ppm soluble manganese before the filtration system. Calcium and magnesium problems are best addressed by the injection of acids to maintain a water pH between 6.0 and 6.6. Temporary storage or aeration of water is a recommended pretreatment for elevated levels of iron and manganese to facilitate oxidation and precipitation before entering the irrigation system.

Chemigation: Chemigation is required for sustainable operation of micro-irrigation and includes the injection of chlorine, nutrients, pesticides and cleaning agents for pipeline and emitter washing. The use of chemicals through micro-irrigation systems requires an in-depth understanding of the water and soil chemistry of each field and a clear idea of the objectives. Micro-irrigation inherently offers tremendous benefits for chemical injection and applications. Consistent soil water contents and wetted soil volumes tend to increase plant uptake efficacy of many chemicals. Water soluble nutrients can be injected to closely match crop requirements, increase nutrient use efficiencies, and reduce costs.

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Laser Land Leveling

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The uneven fields and poor farm design are responsible for poor crop production and low water productivity. Undulated lands lead to waterlogging conditions in low-lying areas and soil water deficit at higher spots (Fig. 20.1). Significant amount of irrigation water is lost during application due to uneven fields (Kahlown *et al*., 2000). Unevenness of the soil surface has a major impact on germination, stand and yield of crops through nutrient water interaction and salt and soil moisture distribution pattern. Salinity patches in the elevated parts and leaching down of soil nutrients from the root zone in lower spots of undulated fields can be attributed towards low crop production (Landon, 1995). On-farm water management and crop productivity can be improved significantly by leveling the field surface precisely. Precise land leveling involves smoothing and grading the land to provide a suitable surface for efficient application of irrigation water and uniform leaching of salts. It enables efficient utilization of scarce water resources through elimination of necessary depressions and elevated contours. It is a process of ensuring that the depths and discharge variations over the field are relatively uniform and, as a result, water distribution in the root zone are also uniform. Hence, preparation of the field surface for conveyance and distribution of irrigation water is as important to efficient surface irrigation as any other single management practice the farmer employs.

Water distribution in an uneven field

Non-uniform crop stand in an uneven field

Fig. 20.1. Water distribution and crop stand under uneven soil surface

Land leveling always improves water, labour and energy resources utilization. However, sometime, leveling operation could be disruptive to cultural practice and major topographical changes may reduce crop production in the cut areas. Therefore, leveling is usually limited to land, which can be graded economically to slopes, which normally do not exceed 2%. The depth of top soil that can be disturbed without reducing productivity often limits the extent of leveling that is practicable, especially in shallow soils.

Laser Land Leveling

Traditional methods of leveling land are not only more cumbersome and time consuming but expensive also (Table 20.1). Effective land leveling is meant to optimize water-use efficiency, improve crop establishment, reduce the irrigation time and effort required to manage crop (Jat *et al*., 2006). New equipment is continually being introduced which provides the capability for more precise land leveling operations. One of the most significant advances has been the adaptation of laser beam guided land leveling equipment. Laser leveling is a process of smoothening the land surface (± 2 cm) from its average elevation using laser equipped drag buckets to achieve precision in land leveling. Precision land leveling involves altering the fields in such a way so as to maintain a constant slope of 0 to 0.2%. This practice requires large horsepower tractor and soil mover that are equipped with global positioning systems (GPS) and/or laser-guided instrumentation so that the soil can be moved either by cutting or filling to create the desired slope (Walker *et al*., 2003). Laser-controlled land leveling equipment grades fields to contour the land for different irrigation practices. Laser leveling can reduce water use by 20-30% and increase crop yields by 10-20%.

Table 20.1. Time required and suitability of different land leveling techniques

Land leveling techniques	Capacity * (ha/day)	Leveling accuracy (cm)	Suitable for plot area (ha)
Animal	0.08	+/- 4-5 cm	< 0.25
Hand tractor	0.12	+/- 4-5 cm	< 0.25
Blade	0.5-1.0	+/- 4-5 cm	< 0.50
Bucket	0.5-1.0	+/- 4-5 cm	> 0.10
Laser	up to 2 ha	+/- 1 cm	> 0.10

** Capacity depends on farm size and shape, crop residue, soil, type and, moisture conditions and the operator's skills*

The quality of land leveling can be estimated through the standard deviation (SD) of soil surface elevation. A field leveled with conventional equipment can attain a standard deviation of 20-30 mm, while using laser leveling the technical limit extends up to 10 mm. Fig. 20.2 presents the evaluation of the water application efficiency (AE) in a particular case as a function of SD (Playn *et al.*, 1996). The figure reveals that the introduction of laser leveling can result in better water application efficiency (more than 10%), while the cost of the leveling operation is two to three times higher of a standard tillage operation. Before starting the laser land leveling process, the field should be ploughed and a topographic survey be carried out. One of the measures to improve irrigation efficiency is zero-grade leveling for crop production. Zero-slope fields can be flushed or drained more quickly. Level fields allow for a more uniform flood depth, using less water and reducing pumping costs.

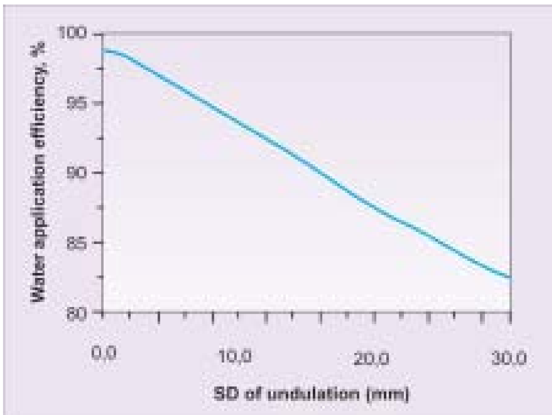

Fig. 20.2. Simulated effect of the quality of land leveling (characterized by the standard deviation of soil surface elevation) on water application efficiency

Benefit of Laser Land Leveling

Laser land leveling provides benefit to the farmers by leveling the farm lands precisely. In brief, laser-controlled land leveling leads to the following benefits:

- Increase in farming area
- Easy land preparation
- Assist top soil management
- Less water requirement for land preparation
- Saves fuel/electricity used in irrigation
- More uniform moisture environment for crops
- Good germination and growth of crop
- Less time and water required in irrigation
- Reduced consumption of seeds, fertilizers, chemicals and fuel

- Better crop establishment
- Less weed problems
- Less effort in crop management
- Optimization of water use efficiency
- Uniformity in crop maturity
- Time efficiency in completion of task

Types of Laser Land Levelers

Manual Leveling Lasers: Set-up of a laser leveling instrument requires the operator to manually level the unit by using the units' screws and bubble vials. These lasers rely on tubular bubbles for leveling. The user needs to level the laser in both the X-axis and Y-axis and rely on the bubbles for accuracy. These lasers can achieve a maximum accuracy of 1 cm in 100 m.

Semi Self-leveling Lasers: These lasers adjust themselves automatically within a range using a compensator. In order to get to a prescribed range, the laser is equipped either with a circular bubble with a bull's eye, or electronic lights that turn green when you reach the self leveling range. These lasers are very accurate and have a shut-off feature if the laser is bumped or goes out of the self-leveling range. They can achieve accuracy of at least 1 cm in 100 m.

Fully Self-leveling Lasers: These lasers automatically find and maintain level within a specified range. These lasers are equipped with an electronic level vial and servomotors. The servo motors level the instrument electronically and when leveled, the laser starts spinning. They are the easiest to use and can achieve accuracy of up to 2.5 mm in 100 m.

Split-beam Lasers: These lasers emit simultaneous horizontal and vertical beams to establish both level and plumb reference lines.

Components of Laser Land Leveling System

A laser-controlled land leveling system has five essential elements (i) laser transmitter (ii) laser receiver (iii) hydraulic control system (iv) control panel and (v) the tractor and grading implement (Rickman, 2002).

Laser Transmitter: The laser transmitter mounted on a tripod allows the laser beam to sweep above the tractor unobstructed. With the plane of light above the field, several tractors can work from one transmitter.

Laser Receiver: The laser receiver is a multi-directional receiver that detects the position of the laser reference plane and transmits this signal to the control box. The receiver is mounted on a manual or electric mast attached to the drag bucket. It is mounted on the scraper. A set of controls allow the laser receiver to control the height of the bucket on the scraper.

Hydraulic Control System: The hydraulic system of the tractor is used to supply oil to raise and lower the leveling bucket. The oil supplied by the tractor's hydraulic pump is normally delivered at 2000-3000 psi pressure. As the hydraulic pump is a positive displacement pump and always pumps more oil than required, a pressure relief valve is needed in the system to return the excess oil to the tractor reservoir. If, this relief valve is not large enough or malfunctions damage can be caused to the tractors hydraulic pump.

Control Panel: The control box accepts and processes signals from the machine mounted receiver. It displays these signals to indicate the drag bucket position relative to the finished grade. When the control box is set to automatic, it provides electrical output for driving the hydraulic valve. The control box is mounted on the tractor within easy reach of the operator.

Tractor and Leveling Equipment: Drag bucket type leveling equipment is commonly used to cut and fill the soil for providing desired grade to the field surface. The leveling bucket can be either 3-point linkage mounted or pulled by the tractor's drawbar. However, pull type systems are preferred as it is easier to connect the tractor's hydraulic system to an external hydraulic ram than connect to the internal control system used by the 3-piont-linkage system. Bucket dimensions and capacity will vary according to the available power source and field conditions. A 60 HP tractor will pull a 2 m wide x 1 m deep bucket in most soil types. Different bucket dimensions from 2 - 5.5 m width with matching requirements of tractors are presented in Table 20.2.

Table 20.2. Selection of tractor and scraper size

Tractor size HP (min-max)	Scapper width meter (min-max)
30-50	2.0
50-100	2.0-3.0
100-125	3.0-3.5
125-150	3.5-4.0
>150	4.0-5.5

How Laser Guided Land Leveling Works

The laser emission device rotates at relatively high speed on an axis normal to the field plane. This rotating beam thereby effectively creates a plane of laser light above the field. Various beam generators are equipped with self-adjustment mechanisms that allow the plane of the beam to be aligned in any longitudinal or latitudinal slope desired. This reference plane of laser light is an advantageous factor in the leveling operation because it is not affected by the earth movement, does not require a field survey to establish the high and low spots, and does not require the operator to judge the magnitude of cuts and fills. The distance between the laser beam and the earth surface is defined such that deviations from this distance become the cuts and fills. With laser systems, there is little or no need for the exhaustive engineering calculations of the conventional approach. The laser emitter is generally located on a tripod or other tower-like structure on or near the field and at an elevation such that the laser beam rotates above any obstructions on the field as well as the leveling equipment itself. The beam is targeted and received by a light sensor mounted on a mast attached to the land grading implement (Fig. 20.3). The sensor is actually a series of detectors situated vertically so that as the grading implement moves up or down, the light is detected above or below the centre detector. This information is transmitted to the control system which actuates the hydraulic system to raise or lower the implement until the light again strikes the centre detector. In this manner, sensor on the mast is continually aligned with the plane on the laser beam and thereby references the moving equipment with the beam. The sensitivity of the laser sensor system is at least 10 to 50 times more precise than the visual judgment and manual hydraulic control of an operator on the tractor. Consequently, the land leveling operation is correspondingly more accurate. The skill of the operator is substantially less critical to the leveling.

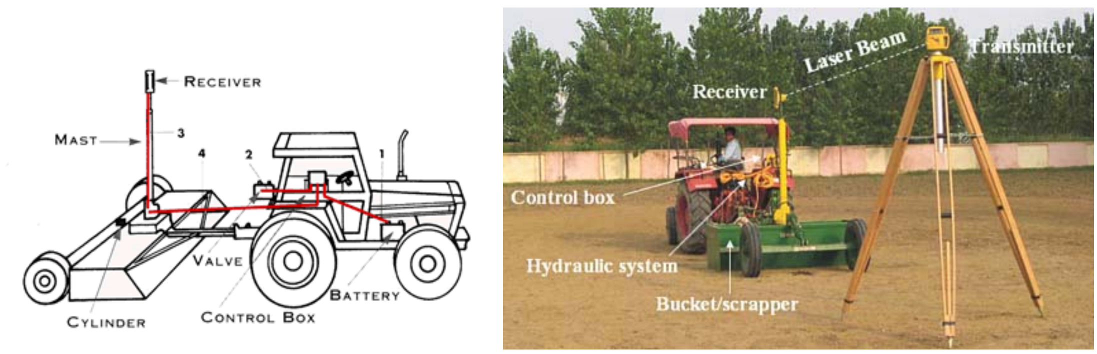

Fig. 20.3. Working of laser land leveler

The electronic and hydraulic control systems generally have two operating modes i.e. i) observation mode and ii) planning mode. In observation mode, the mast itself moves up or down according to the undulations in the field as the operator drives the equipment over the field in a grid-like fashion. The monitor in the tractor yields elevation data from which the operator can determine average field elevations and slopes. In this mode, the blade of the grading implement is fixed in place and only the sensor mast moves. In planning mode, the mast position is fixed relative to the implement blade which is then raised or lowered in response to the land topography. The beam plane is located the appropriate distance above the field centroid and at the desired slopes. By adjusting the height of the mast sensor relative to this plane and the centroid, the cutting and filling is accomplished simply by driving the tractor over the field.

Steps in Laser Land Leveling

- Ploughing should start from the center of the field to outwards. Preferably, plough the field when the soil is slightly moist to prevent formation of large clods. Remove surface residues to aid soil flow from the bucket.
- A topographic survey should be conducted to record the high and low spots in the field.
- Calculate the mean height of the field and by using a field diagram and the mean height of the field, determine how to move soil effectively from the high to low areas.
- Some important facts which should keep in mind while leveling the field are (i) laser-controlled bucket should be positioned at the mean height of the field (ii) cutting blade should be set slightly above ground level (1-2 cm) (iii) tractor should then be driven in a circular direction from the high areas to the lower areas in the field (iv) as soon as the bucket is almost full with soil, turn and drive towards the lower area and once it is empty, drive to the higher area (v) do a final leveling pass in long runs from the high end of the field to the lower end (vi) re-survey to make sure that the desired level of precision has been attained.

Farmer Participatory Appraisal of Laser Land Leveling

Laser-assisted precision land leveling saves irrigation water, nutrients and agro-chemicals. Even then Indian farmers are unable to take full advantage of it and have to rely on traditional methods of land leveling which are labor-intensive and crude, and do not achieve a high level of smoothness of the land surface. In order to evaluate and demonstrate the importance of laser land leveling to the farmers, field trails were conducted by CSSRI, Karnal at 10 farmer's fields in Pundrak and Zarifa villages (Ambast, 2006). Fields were leveled by laser guided land leveler before *rabi* season. The average leveling index (LI) of the selected fields was estimated 1.45 after leveling operation against the average of 2.70 before the operation. The analysis of the individual fields indicated LI of only two fields was more than 1.5 after laser land leveling for the reasons of excessive soil moisture and excessive rice straw. It was further observed that due to precision land leveling, water application time reduced significantly to 3.5-4.5 hours from generally required time of 6 hours for 0.4 ha (1 acre) land. This indicated application of relatively shallow depth (4 cm) of water in the field. The comparison of laser leveled with conventional leveled field indicated relatively better crop performance and yield due to non-stagnation of irrigation/rainwater in the field. 9 more fields were selected in the Kalayat village and leveled by laser leveler before the *kharif* season and their average leveling index after leveling operation was 1.7 cm. On the basis of four closely monitored fields, the average water productivity in the conventional and laser-leveled fields was estimated 1.5 and 2.4 kg/m^3, respectively for wheat crop and 0.37 and 0.47 kg/m^3 for rice crop (Table 20.3). Further, laser leveling intervention was also implemented at 6 farmers' fields in Jaisinghpura village in Haryana and compared with conventionally levelled (CL) adjoining fields (Kamra *et al*., 2010). The field data of year 2009- 2010 indicate that laser leveling reduced irrigation water application in rice and wheat by 18.6 and 21.1 % and increased production by 8.3 and 11.0% respectively (Table 20.4). This meant an additional income of Rs. 10910/ha (Rs. 5040/ha in rice and Rs. 5870/ ha in wheat) due to laser leveling over conventionally leveled fields. The corresponding increase in water productivity (kg/m^3 of applied water) are 34.6% and 37.6% for rice and wheat or Rs. 4.7/m^3 for rice and Rs. 5.9/m^3 of applied water in wheat. Therefore, appraisal of the technology at farmers field clearly indicates that precise land leveling not only saved water and energy but also enhanced crop yield, water productivity and farmers income.

Table 20.3. Comparison of conventional and laser guided land leveling

Parameters	Conventional levelling	Laser levelling
Leveling index (cm)	>1.5	<1.5
Irrigation depth (cm)		
Paddy	110-115	90-95
Wheat	30-35	20-25
Pumping requirement (ha/hr/irriation)		
Paddy	25-27	20-22
Wheat	15-17	9-11
Water productivity (kg/m^3)		
Paddy	0.37	0.47
Wheat	1.50	2.44
Profit over conventional (Rs./ha)		
1st year	-	1000-1200
2nd year onwards	-	4000-5000

Table 20.4. Increase in water productivity in laser leveled over conventionally leveled fields

Parameter	Rice	Wheat
Saving in irrigation water (%)	18.6	21.1
Increase in yield (%)	8.3	11.0
Increase in water productivity, kg/ m^3 of applied water (%)	34.6	37.6
Increase in water productivity, Rs./ m^3 of applied water (%)	4.7	5.9
Increase in income (Rs./ha)	5040	5870

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Multi-enterprise Farming System for Livelihood Security in Reclaimed Alkali Soils

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Continuous cultivation of rice-wheat cropping system (RWCS) over four decades in Indo-Gangetic alluvial plains has set in the processes of degradation in the natural resources of water, soil and biodiversity. Sustainability of RWCS is a serious concern due to degrading soil health and shrinking water resources in rapidly changing climatic scenario. Besides these, the profits from these crops have reduced over time and thus causing unsustainability and migration of farmers to urban areas. This calls for an urgent need to reorient the present farming system that can improve land and water productivity, increase use efficiency of nutrients and energy as well as provide regular income to meet farmer's daily needs. A farmer with a family of 5-6 persons and almost equal number of cattle is unable to cope-up with his daily expenditure from RWCS. Increasing income of the farmer per unit land and water by shifting from a crop, commodity and enterprise based agriculture to integrated multienterprise system is called for. Some research efforts made in the country have indicated the superiority of integrated farming system approaches over the single crop and commodity based farming systems (Bahera and Mahapatra, 1998, Channabasavanna *et al*., 2009, Jayanthi *et al*., 2003, Singh *et al*., 2005, Singh, G., 2009, Rathore and Sahu, 2009). The hypothesized mixed farming systems will also provide much needed proofing for climate change related aberrations such as drought, floods, heat and cold waves etc. Integrated farming system with multienterprise may pave the way for realizing increased productivity and profitability through integrated use of water, nutrient and energy in small farms. Diversification of crops and adoption of multienterprise agriculture involving dairying, horticulture, floriculture, bee-keeping, vegetable, fisheries etc holds promise for restoration of soil and water quality, productivity and profitability and livelihood security and sustainability. Apart from this, multienterprise agriculture may have the potential to decrease cultivation cost by synergetic recycling of bi-products/residues of various components within the system and also a regular source of income and employment. The philosophy behind multienterprise agriculture is that a farmer can adopt enterprises such as dairying, horticulture, floriculture, bee keeping, vegetable, poultry, duckery, piggery, mushroom, fisheries, gobar gas plant and solar heater etc. depending upon his resources, marketing and processing options to improve his family income and generate employment for the family at farm level. CSSRI has initiated a multienterprise model in the year 2006 for the small farmers on reclaimed sodic soils on 2 ha land. A farmer can pick enterprises of his choice.

Model Components

The model on 2 ha area consists of crop components such as grain (0.8 ha), fodder (0.4 ha), flower (0.2 ha), vegetable (0.2 ha), fruit+vegetables (0.2 ha). The other subsidiary components such as fish farming (0.2 ha pond area), dairying, bee-keeping, poultry and duckery, mushroom, gobar gas plant and compost pits. Fish pond is surrounded with fruit trees (Guava, Aonla, Karonda) and seasonal vegetables on dykes that ensure additional income and provide aesthetic look to the model. The compost produced in the model is adequate to meet the nutritional requirements of fruits and vegetables being cultivated on the pond dykes. In multienterprise agriculture model, crop components give the income on half yearly basis when the crops are harvested. However, subsidiary components generate income on regular basis to meet out the daily expenditure of the farmer's family. The details of all the components are given below:-

1. Crop Components

A. Grain Production: 0.8 ha cropped area

- (i) Rice - Wheat (0.2 ha)
- (ii) Maize – Wheat - Moong (0.2 ha)
- (iii) Soybean - Winter maize- (0.2 ha)
- (iv) Pigeonpea – Mustard - Fodder maize (0.2 ha)

B. Fodder Production: 0.4 ha cropped area
- (i) Sorghum – Berseem - Oat (0.2 ha)
- (ii) Maize + Pearl millet - Berseem (0.2 ha)

C. Floriculture Production: 0.2 ha cropped area
- (i) Baby corn + Marigold + Gladiolus (0.1 ha)
- (ii) Baby corn + Marigold + Sunflower (0.1 ha)

D. Vegetable Production/ Olericulture: 0.2 ha cropped area
- (i) Cabbage - Tomato-Khira (0.1 ha)
- (ii) Bottle guard - Cauliflower (0.1 ha)

E. Horticulture +Vegetable Production: 0.2 ha cropped area
- (i) Horticulture + Vegetable (tomato and ladies finger)

Note: Intercropping of seasonal vegetables done in between the rows of Guava and banana plantation.

2. Subsidiary Components

An area of 0.2 ha was used for fish cultivation and on the dykes of the pond fruit trees (Guava, Aonla, Karonda) and seasonal vegetables were grown round the year to earn some additional income and to make eco-friendly environment of the system. On one side of the pond dykes other components were undertaken.

- (i) Fishery
- (ii) Dairying (3 Buffaloes and 1 crossbred cows)
- (iii) Poultry (100 birds/ numbers may very)
- (iv) Duckery (10 birds)
- (v) Bee-keeping/ Apiculture
- (vi) Gobar gas plant for cooking purposes
- (vii) Composting

Productivity and Economics of the Cropping Systems

Economics of various components across the enterprises was computed using standard methodology, discounting the labour component (Table 21.1). This is mainly because the model is developed for small and marginal land holders who can deploy 3-4 family members for routine operations. Also the model is closely integrated with domestic activities, so the labour requirement is minimal. The results showed that wheat cultivation was more profitable compared to the rice cultivation. Amongst the different enterprises studied, the fodder crops gave the highest B:C ratio of 5.27 and 3.16 in berseem and oat, respectively. The highest net income was reported under bottle gourd cultivation (Rs. 45,933.88/ha) followed by wheat and berseem (Rs. 42,664.53 and 38,583.00/ha, respectively). The operational cost of fodder crops, in general, and berseem (Rs. 7,313/ha) in particular was much lower than the grain crops. Performance of pigeonpea, soybean, gladiolus and green gram was not satisfactory and proved uneconomical at the existing pattern of resource use. Several factors contribute for variation in economic analysis of each crop each year. Variations in the economics of fruits, vegetables and flower crops due to fluctuating market prices and availability of such produce at different times of the year.

The profitability of different crops under crop components was worked out on the basis of MSP of marketable produce for the year 2008-09 and 2009-10. Horticulture and fodder based production systems were found more remunerative as compared to the other crop production systems. In horticulture production system, the highest net income of Rs. 1,14,857.63/ha was recorded with a B:C ratio of 7.62 and it was followed by vegetable production system (Rs. 94,275.70.10/ha), however, the lowest returns was recorded with floriculture production system (Rs. 50,346.59/ha) with a B:C ratio of 2.48. The comparison between multienterprise agriculture model and crop components was done on the basis of economics (Table 21.2). The results clearly showed that only 13% less income was recorded in horticulture production system as compared to multienterprise agriculture model. With other systems 47, 54, 38, 87 and 71% income of the multienterprise agriculture model was observed with fodder, grain, flower, horticulture and vegetable production systems respectively.

Table 21.1. B:C ratios of individual crops grown in multienterprise model

Crops	Operational cost (Rs./ha)	Gross income (Rs./ha)	Net income (Rs./ha)	B:C ratio
Rice	20623.63	50825.00	30201.38	1.46
Wheat	15485.48	58150.00	42664.53	2.75
Winter maize	15884.75	32345.00	16460.25	1.03
Green gram	10290.13	14897.50	4607.38	0.44
Soybean	14166.30	15632.00	1465.70	0.64
Pigeonpea*	11270.35	750.00	-10520.35	-0.10
Mustard	8106.30	14598.25	6491.95	0.80
Baby corn	19869.90	49975.39	30105.48	1.51
Cabbage	11881.25	20392.50	8511.25	0.71
Cauliflower	20749.63	33500.00	12750.38	0.61
Chillies*	6826.00	10000.00	3174.00	0.46
Bottle gourd	33643.63	79577.50	45933.88	1.36
Gladiolus	42085.00	59080.77	16995.77	0.40
Marigold	14556.09	26446.15	11890.07	0.81
Berseem	7317.00	45900.00	38583.00	5.27
Oat*	8400.50	35000.00	26599.50	3.16
Maize fodder	9707.13	24000.00	14292.88	1.47
Maize+ Cowpea (Fodder)*	10351.50	22500.00	12148.50	1.17
Sorghum+ Cowpea (Fodder)*	8889.95	24000.00	15110.05	1.69

** Represents only 2007-08 data*

Table 21.2. Comparative performance of multienterprise model with other cropping system in 2 ha area

Components	Operational cost (Rs./2 ha)	Gross income (Rs./2 ha)	Net income (Rs./2 ha)	B: C ratio (Rs./2 ha)
Multienterprise model	126683	393931	265248	2.09
Fodder production	22928	146850	123922	5.40
Grain production	39306	181936	142630	3.63
Flower production	40537	141230	100693	2.48
Horticulture	30129	259844	229715	7.62
Vegetable production	43781	232333	188551	4.31

Vegetables and Fruits Production on the Dykes of the Pond

The raised dykes of the pond were effectively utilized for raising vegetables and fruits to meet daily nutritional requirement of 5-6 persons and to generate daily income to meet domestic expenditure. The income from the sale of fruits and vegetable was more than Rs. 50/day. The income from these plants is likely to increase several fold over the years. The fruit plants cultivated on the dykes helped in soil conservation, carbon sequestration and in improving the aesthetic value of model and enhancing the environmental quality. The pH and EC of the pond dykes came down to 9.1 and 1.2 from the initial 9.7 and 4.0 respectively after 4 years.

Soil Health and Quality: Soil bulk density ranged between 1.41 and 1.44 mg/m^3 in various depths across the production components. In general, bulk density was higher in the deeper layers as compared to the surface. Though the variation in bulk density values was not considerable, yet the fodder production component recorded lower bulk density as compared with the other components in all the depths. Saturated hydraulic conductivity varied between 1.4 and 2.0 cm/h among the depths across the production components. Fodder plots recorded 2.0 and 1.8 cm/h saturated hydraulic conductivity values, numerically higher than all the other production components. Water retained at 33 and 1500 kPa soil-water suction also iterated the same trend as that of bulk density and hydraulic conductivity. Fodder production components had higher available water as compared to the other production components in all the depths.

Net increase in available nitrogen and phosphorus was observed in all the cropping systems (Table 21.3). Regular nitrogen build-up was the result of integrated nutrient management in all the cropping systems. Higher nitrogen build-up in fodder production system as compared to others was the result of irrigation with pond water. Nutrient balance in most of the cropping systems was positive, more so in the case of N, P and micronutrients. Recycling of farm wastes and use of pond water helped improving the soil chemical health. The improvement seems to be slow but steady.

Table 21.3. Fertility status of different cropping system under multi enterprise agriculture

Cropping systems	Year	pH	EC (dS/m)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)
Fodder	Initial	8.18	0.35	103.50	26.75	301.50	1.90	13.35	6.15	1.64
	1st yr	8.17	0.37	129.00	27.00	288.00	1.74	11.85	6.45	1.58
	2nd yr	7.91	0.30	216.50	28.90	291.50	1.80	10.44	10.03	1.55
Grain	Initial	8.32	0.28	106.00	24.83	300.00	1.65	14.05	5.88	1.36
	1st yr	8.27	0.28	128.25	24.70	286.25	1.59	12.35	6.07	1.45
	2nd yr	8.05	0.25	180.75	26.38	267.00	1.69	13.43	7.57	1.46
Floriculture	Initial	8.29	0.25	108.00	23.50	388.50	1.78	13.25	6.61	0.81
	1st yr	8.16	0.29	136.50	23.80	377.50	1.79	12.40	6.69	0.84
	2nd yr	8.10	0.29	183.50	27.10	321.00	2.63	10.05	8.12	0.71
Horticulture	Initial	7.70	0.46	123.00	24.20	409.00	2.41	17.80	8.40	7.70
	1st yr	7.74	0.46	131.00	25.10	364.00	1.91	17.50	8.10	7.74
	2nd yr	7.44	0.32	205.00	30.40	345.00	1.21	12.78	11.04	7.44
Vegetable	Initial	7.70	0.46	123.00	24.20	409.00	2.41	17.80	8.40	2.18
	1st yr	7.57	0.31	144.00	30.40	381.00	1.95	15.20	8.31	1.94
	2nd yr	7.44	0.28	201.00	29.40	305.00	1.38	10.20	8.64	1.80

The microbial properties like microbial biomass carbon, microbial nitrogen, dehydrogenase activity and acid phosphatase activity were determined initially and after two years of experimentation using standard methods. After 3 years of cropping greater microbial biomass carbon (mg/kg), microbial nitrogen flush (mg/kg) and dehydrogenase activity (µg TPF/g soil) were observed under sorghum-berseem (268.6, 19.6 and 59.9 respectively) cropping system as compared to all other systems. However, acid phoaphatase activity (µg PNP/g soil) was observed higher (184.5) with rice-wheat cropping system. This indicates that the fodder production component is highly efficient in providing suitable micro climate to microorganisms. The lowest microbial nitrogen (16.5 mg/kg) and dehydrogenase activity (21.2 µg TPF/g soil) was observed under floriculture production system (Baby corn-marigold-gladiolus). However, to come out with definite trend of cropping systems on microbial properties, more observations are to be needed in the coming years when the cropping systems get stabilized.

Subsidiary Components

The size of the subsidiary components depend on resources, marketing and processing options to improve the family income and generate employment for the family at farm level.

Dairy: Combination of crop production and dairy farming is very common and oldest practice in Haryana and Punjab. India has become world leader in milk production with the production of 101 million tonnes of milk. The per capita availability of milk (250 g/day) in Haryana is similar to the minimum requirement. As such milk production unit could be considered as 'core unit' of multienterprise, which could give regular income of >10,000/month and employment to the farmer's family. Average monthly milk productions from animals are presented in Fig 21.1. The variation in milk production was governed by the lactation period of the animals. In the month of December highest milk was produced, whereas lowest milk production was recorded in the month of July. A good volume of milk (>400 liters/ month) was recorded throughout the year. The cow and buffalo milk was sold @ Rs. 24 and 30/kg respectively. The total revenue of Rs. 1,52,306 was generated from the dairy and its by-products (biogas and compost) during the year under report (Table 21.4).

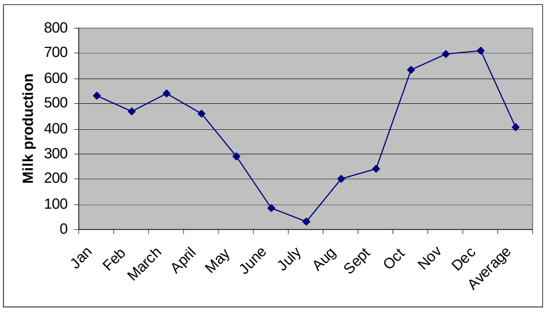

Fig 21.1. Monthly trends of milk production (liters/month) during the year

Fishery: Rearing of different type of fish fingerling viz. *Catla catla* (Catla), *Labeo rohita* (Rohu), *Cirrhinus mrigala* (Mrigal), *Ctenopharyngodon idella* (Grass carp), *Cyprinus carpio* (Common carp) was under taken in the multienterprise agriculture model (0.2 ha). Post stocking management of the pond in relation to multienterprise agriculture is done for natural productivity in terms of pond fertilization mainly with duck droppings and cow shed flush as major component of Integrated farming system. The bottom racking of pond was done at regular interval for nutrient enhancement in water medium for live fish food organism's production. The fresh stocking of pond with different type of carp fish fingerling (10-15 g) at the rate of 10,000 Nos./ha was done. The fish productivity after one year cultivation at the level 750± 250 g mean weight of the overall species from the pond was 3.5 t/ha and finally after eighteen month of culture it has been found at the level of 3.58 t/ha/year with integration of 10-12 duck dropping during day hours and whole day urine production of livestock (4 buffalos and 1 cows). The species recovery from the ponds after harvest were found in order of *Cyprinus carpio* >*Ctenopharyngodon idella* >*Catla catla* >*Labeo rohita* >*Cirrhinus mrigal*. All the physico-chemical and hydrobiological parameters of pond soil and water was observed in permissible limits and found good for fish growth and its productivity. The fish pond water gets enriched in nutrients and its quality can be rated as 'very good'. The total revenue of Rs. 20,383 was generated in the model after expending Rs. 1500 (Table 21.4). Seepage is major component of water balance in the pond affecting quality of pond water and water table around the pond.

Mushroom Production: The culture for raising mushroom as a part of the multi-enterprize agricultural system was prepared in the month of October-November using wheat straw and compost. Ten kg mushroom seed was imported from National Research Centre on Mushroom, Solan and was sown in different trays and was placed in environmental controlled green house made by using local materials available from the residues of the crops, bamboo sticks etc. Per day mushroom production varied from 0.2 to 4.4 kg during the cultivation period. Negligible profit was gained during the study period (Table 21.4). There were many points to be considered for not exploiting potential benefits from mushroom i) poor technical expertise, ii) higher temperature fluctuation during February, iii) no provision of cooling system in thatch, iv) nearness to animal shed results in mortality of spawns and poor growth, v) small size of area under cultivation.

Poultry and duckery: The poultry component was introduced in the last week of August, 2008. The chicks numbering 120 of *desi* mixed breed were purchased for Rs. 3000. In a period of first three months, about 91 chicks died because of some feed related infections. (Singh *et al*., 2009). The poultry component did not prove profitable because majority of chicks died due to diseases in the later year also. Probably smaller population and lack of technical expertise about the poultry production with the team resulted in poor management of poultry. The component of duckery was introduced from September, 2008. Hundred ducks were brought from Bhubneshwar centre of the Central Avian Research Institute. Because of some feed related infections 89 ducks died between September and November, 2008. At present <10 ducks are remaining and are quite healthy. Most of the day, the ducks swim in the fish pond and increase oxygen availability for fish. After the introduction of ducks the mortality of fish in the pond has considerably decreased.

Bee keeping: Bee-keeping refers only to rearing of domesticated honey bee species and their management. Bee-keeping is an economical enterprise that requires less investment and space but provides high return. Investment is required only in the first year when system is established. As a component of the system, 25 boxes were placed in the farming system area. The data calculated from single honey box regarding honey production and income generation and it was found that a gross income of Rs. 2700 was generated from single box with a total production cost of Rs. 1,500. In the year under report only 5-7 boxes were there so we were not able to exploit it with full potential. Total revenue of Rs. 5,040 was obtained from the bees (Table 21.5).

Multienterprise Model

Total revenue generated, expenditure and net income from the crop components and subsidiary components on yearly and per day basis are presented in Table 21.5. The total revenue of Rs. 3,93,931 was generated in the multienterprise model after spending Rs. 128,683. The total net income of Rs. 2,65,248 was achieved in this model. Crop components generated a total net income of Rs. 1,33,732 on half yearly basis, whereas subsidiary components generated Rs. 1,31,516. Subsidiary components generated a daily net income of Rs. 360 with an expenditure of Rs. 266 to meet out the day to day expenditure of the farmer's family.

Table 21.5. Revenue generation, expenditure and net income in multienterprise model (year 2008-10)

Multienterprise components	Revenue generation (Rs.)	Expenditure (Rs.)	Net income (Rs.)
Crop components			
Fodder production - 0.4 ha	29370	4586	24784
Grain production- 0.8 ha	72774	15722	57052
Floriculture production-0.2 ha	14123	4054	10069
Horticulture based-0.2 ha	25984	3013	22972
Vegetable production- 0.2 ha	23233	4378	18855
Sub total	165485 (453)	31753 (87)	133732 (366)
Subsidiary components			
Milk + Compost + Biogas	152306	64662	87644
Fruits & vegetables on pond dykes	27591	2200	25391
Fish	20383	1500	18883
Poultry & ducks	21492	24841	-3350
Mushroom	1635	1600	35
Bee-keeping	5040	2127	2913
Sub total	228446 (626)	96930 (266)	131516 (360)
Total	393931 (1079)	128683 (353)	265248 (726)

* *Figures in parenthesis indicate per day income*

Recycling of Resources

The resources were recycled within the system to increase water, nutrient and energy use efficiency through diversified agriculture options. The animal, fishery, poultry and duckery components are getting the feed and fodder from the crop components (Fig. 21.2). Whatever dung is produced by the animals is used in different ways. About 4.0 tones of cow and buffalo dung is obtained every month from the five to seven animals during the study period. Out of which, 54% was used for generating biogas, 38% for composting, 3% for vermin-composting and 5% was added in the fish pond as fish feed. The biogas slurry from the biogas plant, after production of biogas was also added into the compost pits. A major part of urine of animals was added directly into the fish pond. Gobar gas plant was established in August 2007. The cooking gas production started from September 2007. Bio-gas obtained from the plant is adequate to meet the daily cooking needs of a family of 5-6 people. The cooking gas was available throughout the year to meet energy needs. As an alternate/ supplement to the commercial electricity supply, three electric lamps (40 w) can also be lighted using cooking gas to meet electricity need. Total expenditure on establishment of gobar gas plant was Rs. 12,000. The government provides subsidy to the extent of 50 to 75% to the farmers for establishment of this facility at their farms. Banana leaves, over matured fruits and vegetables are also used as fish feed. Feed Concentrates for the animals also come from the crop component. Animal feed is prepared at site to reduce the cost of inputs and to ensure the quality of the feed.

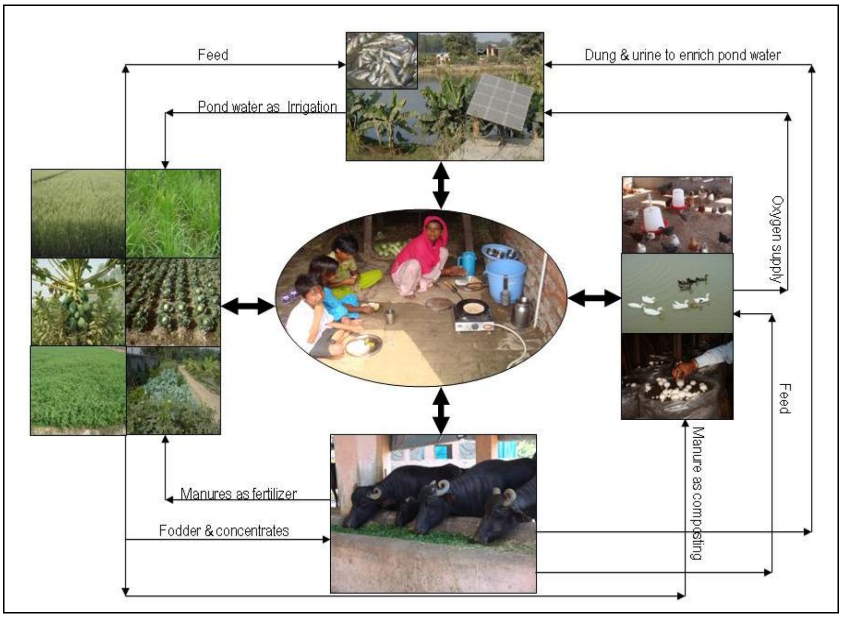

Fig. 21.2. Recycling of resources within the multienterprise model

Resource Conservation and Environmental Quality

Besides a source of regular income to the small and marginal farmers, the multienterprise model acts as the most vital technology in conserving resources and energy and energy at farm level. Recycling of farm wastes and other byproducts of the components ensures environmental quality. Intensive observations are being recorded on the components of water balance in and around the pond as well as irrigation command of the pond. Water balance components will provide precise information on the water requirement of the individual enterprise as well as the components. Future water management strategies will be based on the judicious use of available water resources in the model at farm-level. Electricity generation by harnessing the solar system was also practiced in the Model. The fruit and vegetables crops grown on the dykes were irrigated by drip irrigation system. The drip irrigation system is run on a solar energy system. Resource recycling and physiochemical transformations involve gas exchange within and across the multienterprise components. The above information will provide deep insight into energy balance at farm-level. Conservation and judicious use of farm resources in multienterprise model will ensure environmental quality and help restore the ecosystem for sustainability.

Up-scaling and Commercialization of Model

Success of a technology depends on its adoption by the end-users. Multienterprise model of CSSRI has a great potential for up-scaling and commercialization because of its suitability to small and marginal land holders. As a first step, efforts are being made to demonstrate the model on farmers' fields. Government of India is already providing subsidy on the most of the components of the model, which attracts the attention of resource poor small and marginal farmers. The model can be up-scaled and commercialized by its integration with many of the governmental scheme e.g. RKVY (sub scheme RADP), NREGA, RGKVY, IRDA, and Food Security Mission etc. besides rural developmental schemes, other governmental programmes related to fisheries, poultry, non-conventional energy, rural electrification, rural sanitation etc. can be easily linked with the model. Options and provisions for value addition, processing facilities, good marketing network and integration with other rural enterprises can help attract the attention of rural youth. Special training programmes for skill upgradation among the rural masses in general and youth and women entrepreneurs in particular can help in rapid up-scaling of the model. In its present form, the model has full potential to earn regular livelihood by ensuring food and nutritional security for small and marginal farmers besides its socio-economic and ecological benefits. However, continued research efforts will lead to further improvement of the model, and subsistence farming of today will become prestigious farming of the future.

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Production of Forage and Grasses Using Poor Quality Waters

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It is estimated that the average cultivated area devoted to fodder production is only 4.4% of the total area. Similarly, the area under permanent pastures and cultivable wastelands is approximately 13 and 15 M ha respectively. Likewise, the total area under forests is 25.1 M ha and that open to grazing is 21.0 M ha. All these resources are able to meet the forage requirements of the grazing animals only during the monsoon season. But for the remaining periods of the year, the animals have to be maintained on the crop residues or straws of jowar, bajra, ragi, wheat, barley etc. either in the form of whole straw or a bhusa, supplemented with some green fodder or as sole feed. To meet the ever increasing demand of milk at reasonable prices assured supply of green forage is essential. Looking at the availability of good water for irrigation, such good waters cannot be spared for forage production and thereby will have to depend on poor waters also. It has been observed that crops that can withstand or sustain salty soil conditions can also do well with salty waters.

Forages for Alkali Soil

Volunteer/Naturally occurring Grasses: *Sporobolus marginatus, S. diander, Desmostachya bipinnata, Kochia indica and Suaeda maritima*. However, other species such as *Dicanthium annulatum, Capparis aphylla, Cynodon dactylon, Andropogon squarrosus, Sporobolus coromandelianus* can also be noticed. On low lying areas where water is liable to accumulate for any length of time, *Leptochloa fusca*, commonly called Karnal grass in India is found in abundance.

Most of the volunteer grasses found in alkali soil are very coarse with very little nutritive value excepting a few like Karnal grass, Bermuda grass, *Dicanthium annulatum* etc. As pointed out earlier, Karnal grass grows well where water accumulates, so the land should be shaped in such a way to accumulate maximum rainwater. For this, it is suggested that alkali land should be bunded to make smaller plots. Simple bunding or closure of alkali lands will encourage the palatable grasses to grow and to control the coarse grasses.

Forages in Saline Soils

Plants differ widely in their ability to tolerate salts in the soil. Forage grasses and legumes are generally more tolerant to saline conditions. The plants/crops, which can restrict evaporation, provide better root penetration and enhance organic matter, are more suitable from the reclamation point of view and for better forage production.

Volunteer Grasses: In saline soils , the volunteer grasses like *Cresa cretica, Cyperus rotundus, Chloris pallid, Sporobolus pallidus, Sessuvium portulacastrum, Haloxylon salicorncum*, *Aeluropus lagopoides, Zygophyllum simplex, Dicanthium annulatum, Suaeda fruticosa and Butea monosperma* can be seen growing. Rana (1983) identified four species, *Alhagi pseudealhagi, Salsola baryosma, Suaeda fractiosa and Salvadora oleoides* as indicator plants of saline soils.

Forage Crops: Earlier reports have shown that sorghum (*Sorghum bicolor* L. Moench) as summer (*kharif*) crop is medium tolerant to salinity but Kalippan and Rajgopal (1969) reported it to be fairly tolerant with no significant effects on germination and early vigour up to 6.3 dS/m. However, Mehrotra and Das (1973) exhibited 50% decrease in sorghum at EC_e 8 dS/m. In a sand culture experiment, Kumar and Gill (1994) reported that germination of *Sorghum sudanense* was delayed with the rise of salinity and crop failed to germinate at 18 dS/m but survived at EC_e 6 dS/m.

Amongst the forage crops grown during winter (*rabi*), oats (*Avena sativa* L.) has been found most tolerant to saline conditions. According to Kumar and Sharma (1995) the yields of five forage crops viz., lucerne (*Medicago sativa* L.), berseem (Egyptian clover) (*Trifolium alexandrinum* L.), shaftal (Persian clover) (*Trifolium resupinatum* L.), chinese cabbage (*Brassica pekinensis* (Lour.) Rupr.) and oats are not affected significantly when irrigated with saline water of 5 dS/m but beyond this there could be significant decrease. The yields of berseem, shaftal and Chinese cabbage were significantly reduced at EC_e 7.5 dS/m, however, lucerne showed significant decline only when saline water of 10 dS/m was applied while that of oats was unaffected at this level also.

The order of tolerance of the forage crops to salinity was: oats > chinese cabbage > lucerne > berseem > shaftal. Under field conditions, Yadav and Kumar (1997) recorded observations on sorghum, pearl millet (*Pennisetum americanum* (L)), maize (*Zea mays* (L)), barley (*Hordeum vulgare* (L)), oats and berseem and found that germination of all the crops except barley and oats reduced drastically where soil salinity exceeds EC_2 3.0 dS/m. Berseem, pearl millet and maize recorded decline in tillering/branching and height to a great extent with increase in soil salinity. The results suggested that where soil salinity exceeded EC_2 > 4.5 dS/m, only barley and oats give satisfactory green forage yields (Abhichandani and Bhatt, 1965). The forage crops like berseem, sorghum and pearl millet produced satisfactory yields only up to EC_2 of 4.5 dS/m. Maize failed to produce satisfactory green forage yield beyond a salinity level of 3 dS/m. Yadav *et al.,* (1997) reported that on saline soils (EC_e 3-4 dS/m), the mixtures of berseem with mustard and /or oats outperformed their pure stand in green yield, dry matter yield, protein and mineral matter yield.

Salt Tolerance of Grasses

Grasses tolerate salinity more than forage crops. Bermuda grass, Karnal grass and *Panicum coloratum* can be regarded most tolerant grasses as these show less than 50% yield reduction at EC_e 14-19 dS/m. Malik *et al.,* (1986) reported that karnal grass (*Kallar* grass) can survive up to an EC 40 dS/m but is economical to grow up to EC 22 dS/m. Anjan grass is sensitive to soil salinity.

Forages and Grasses as Affected by Saline Irrigation: Kumar (1988) from field trials at Sampla in Rohtak district inflicted by the problems of high salinity, water table and high salinity of the ground water (EC 22 dS/m) reported that when good water was used for irrigation in saline soils, Para-grass yielded the best, but under saline water irrigation, karnal grass showed best results. When the average yield of 3 years was considered, gatton panic, karnal grass and blue panic were better under saline environment. Kumar and Gill (1994) while examining the effect of high salinity waters under sand culture condition on several forage grasses reported that the grasses, in general, showed poor survival when sown by seeds but established well when transplanted by the rooted slips. *Panicum coloratum,* Karnal grass, Gatton panic and Rhodes grass were relatively less affected owing to irrigation with high saline waters. When the water of 19 dS/m EC was used for irrigation, *Panicum coloratum* showed 50% *Leptochloa fusca* and *Chloris gayana* about 65% Gatton panic 75% while hybrid Napier 100% yield reductions. *Cenchrus ciliaris* and *Panicum antidotale*` could not cope up even with saline water of 12 dS/m.

Under hydroponics conditions, Kumar *et al.,* (1991) found that the salinity levels reducedthe shoot and root weights by 50% were 80 and 92 mol /m^3 for sudan grass; 47 and 65 mol/m^3 for maize; and 29 and 36 mol/m^3 for teosinte thus indicating that sudan grass was more tolerant to salinity. In a sand culture experiment conducted with saline waters viz. BAW (best available water) 2.5, 5.0, 7.5 and 10 dS/m on five *rabi* forage crops namely, berseem, shaftal, lucerne, oats and Chinese cabbage, Kumar and Sharma (1995) reported that oats produced the highest green forage yield among the crops tried and did not show any yield reduction up to saline water of 10 dS/m. Lucerne and chinese cabbage performed better than other crops under saline water conditions.

Yadav *et al.,* (2004) reported that alternate irrigation with saline drainage water increased the yields of all forage crops compared to saline drainage water alone. They further stated that alternate irrigation starting with canal water was superior to alternate irrigation starting with saline drainage water because less salt was added in total. Oat produced the largest green forage yield (32.3 t/ha) in the first year while rye grass gave maximum in the second (34.6 t/ha) and third year (37.0 t/ha). Persian clover performed better than Egyptian clover in all the 3 years. Interaction between species and irrigation treatments was significant. In comparison to canal irrigation water, there were 36.4%, 42.1%, 53.5%, 67.5%, and 85.3% yield reduction in rye grass, oat, Persian clover, Egyptian clover, and senji, respectively when only saline drainage water was used for irrigation purpose. Thus, the tolerance of winter forage crops to salinity was in the order of rye grass > oat > persian clover > egyptian clover > senji.

Cultivated Grasses: Grasses are; in general, more tolerant to alkali soils than the other forage crops (Maas, 1986). Karnal grass can be rated as most tolerant grass to alkali soil conditions as it did not show any yield reduction even at pH of 10.4; rather it gave more yields on alkali soil compared to on normal soil (Kumar and Abrol, 1983, Kumar and Abrol, 1986). This is followed by Rhodes grass that did not show reduction up to a pH of 10.0 and beyond this also there was a small yield reduction. In terms of green forage yield, rhodes grass gave higher yield than karnal grass at all the pH levels including at pH 10.4 because of its greater yield potential. Gatton panic, bermuda grass, coastal bermuda and para grass are also tolerant grasses as these showed less than 50% yield reduction up to a pH of 10. Blue panic, setaria grass and hybrid napier can be regarded as moderately tolerant grasses as these showed good yield up to a pH 9.6, the former two grasses showing less than 50% yield reduction. Guinea grass, anjan grass and deenanath grass are sensitive to soil alkalinity, almost failing even at pH 9.2.

Forage Crops: Amongst the forage crops, *rabi* crops seem to be relatively more tolerant than *kharif* crops. Sorghum, pearl millet and dhaincha (*Sesbania*) are moderately tolerant forage crops as these showed less than 50% yield reduction at pH 9.6; teosinte and maize as moderately sensitive showing less than 50% yield reduction at a pH of 9.2 while cowpea and guar as sensitive. All the *rabi* forage crops are moderately tolerant; oats and shaftal being more tolerant than berseem (Kumar, 1987). All the *rabi* forage crops tested appears to be more tolerant in comparison to wheat (Chhabra and Kumar, 1990-91). Growing of shaftal (*Trifolium resupinatum* Linn.) as a forage crop in *rabi* season has been found more profitable than wheat (*Trifolium aestivum* Linn.) (Sharma *et al.*, 1983).

Kharif Forage Crops during Initial Reclamation

In highly alkali soil, forage crops like sorghum [*Sorghum bicolor* (L.) Moench.], guar [*Cyamopsis tetragonoloba* (L.) Taub.], cowpea [*Vigna unguiculata* (L.) Walp.], Deenanath grass (*Pennisetum pedicellatum* Trin.) and sudan grass [*Sorghum sudanense* (Piper) stapf.] either fail to grow or give very poor yields even after application of 100 per cent of gypsum requirement (Chillar and Bhumbla, 1970). Similar findings were recorded later wherein it was observed that *kharif* forage crops singly or as a cereal-legume combination grown on alkali soils with gypsum at 50% of requirement yielded very low yield than obtained on normal soils. Maize (*Zea mays* L.), guar, and maize + guar failed completely giving no forage yield. These results suggest that *kharif* forage crops should not be grown in the beginning of reclamation of alkali soils.

Kharif Forage Crops After Rice-Wheat Rotation

After following rice-wheat rotation for two years, Chillar (1982) applied gypsum and pyrite at 0, 25, 50, 75 and 100 per cent of their requirements and observed the performance of sorghum, oats and maize. In control plots (pH 9.8), even after two crops of rice and wheat, forage yields of sorghum and maize were extremely low and the yields of both the crops increased with increasing dose of amendments. Sorghum was more tolerant than maize.

Rabi Forage Crops during Initial Reclamation

Among the *rabi* forage crops shaftal has been reported to be relatively more tolerant (Kumar, 1987). From the results of a field experiment, it was evident that the performance of berseem during first year was extremely poor even after application of 25 t/ha gypsum, whereas shaftal gave good yields even with 10 t/ha gypsum application. In the second year, similar results were recorded. However, in the third year berseem showed significant increase in green forage yield with each increasing level of gypsum up to 15 t/ha whereas shaftal gave significantly greater yield at 10 t/ha gypsum. From the same experiment a yield reduction of 25 and 50% in berseem at an ESP of 32 and 41, respectively was recorded while for shaftal such reductions were observed at the ESP of 37 and 53 respectively, indicating higher tolerance of shaftal over berseem. Sharma *et al.* (1983) reported that shaftal was more profitable as fodder crop than wheat in the initial year of reclamation itself. The results of a field experiment conducted at CSSRI on highly alkali soil (pH 10.5) with the application of 50% GR to evaluate the effect of zinc application on rice crop and its residual effect on the yield and chemical composition of following *rabi* forage crops revealed that all the forage crops (berseem, shaftal, oats and barley) were relatively more tolerant than wheat. Amongst *rabi* forage crops, shaftal was found to be most tolerant. Barley produced higher seed yield than oats. Chillar (1982) also noticed that oats for forage grow well after following rice-wheat rotation.

Forage Production with Alkali Irrigation

For reclamation of alkali soils and to mitigate the adverse effect of alkali water irrigation, use of gypsum application is generally recommended. The quantity of gypsum required depends on several factors such as soil characteristics (including initial pH) of the soil, residual sodium carbonate (RSC of water), tolerance of the crop to be grown, climate and water requirement etc. Relatively very small work has been done on the forage production in relation to alkali irrigation. The results of the work done are described below under different heads.

***Rabi* Forages:** On a moderately alkaline soil (pH 9.29), with alkali water irrigation [EC_{iw} 1.8 dS/m, residual sodium carbonate (RSC) 10.5 and sodium adsorption ratio (SAR) 8], oats, shaftal and berseem were more suitable than other crops tested. However, berseem gave comparatively lower yield in the first year of cultivation. Application of gypsum (2 t/ha) increased the yields of forage crops in the second and third year of experimentation. In comparison with their yields in normal soil, oats showed minimum yield reduction under alkali soil irrigated with alkali water, hence was more tolerant among the forage crops studied.

In a separate field experiment with alkali water irrigation it was found that in the first harvest recommended seed rate of berseem at 25 kg/ha + 2 kg/ha mustard gave significantly greater yield than the remaining mixture treatments. Application of gypsum at 2 and 4 t/ha increased the yield of berseem in all the cuts as well as total yield.

***Kharif* forages:** Sudan grass and sorghum were found to be more suitable for situations where soils were moderately alkali and irrigation waters are also alkaline. Maize, teosinte and pearl millet should not be grown with alkali water irrigation. Application of gypsum @ 2 t/ha in the first year improved the yield of kharif forage crops by 15% over the control but during the third year there was 17.5% and 35% improvement in the yield owing to gypsum application at 2 and 4 t/ha, respectively.

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Prospects of Growing Medicinal and Aromatic Plants in Salt Affected Soils

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India is endowed with rich wealth of medicinal plants. The curative properties of drugs are due to the presence of complex chemical substances of varied composition (present as secondary plant metabolites) in one or more parts of these plants. According to their composition, these plant metabolites are grouped as alkaloids, glycosides, corticosteroids, essential oils etc. On the other hand aromatic plants posses odoriferous and volatile substances which occur as essential oils, gum exudates, balsam and oleo-resin in one or more parts viz., root, wood, bark, foliage, flower and fruits.

Ayurveda, the art and science of perfect living is one of the oldest ways of health care in our country. In this system, plants and their extracts are being used to treat the physical and mental sufferings of humanity. Earlier information on medicinal uses of plants was based on folklores but Dr. J. W. Hershberger; an American economic botanist for the first time in 1896 established a distinct field of Ethno-botany. It is a branch of botany which deals in studies on relationship of mankind with plants and their beneficial uses. Recent evidences of side effects of active principal based allopathic drugs therapies have generated renewed global interest in Ayurveda which has five millennia old known history of treating and curing mankind. The herbal active constituents of medicinal and aromatic crops do not have side effects and so has led to increased global and local demand for these plants. Estimates suggest that the present annual world trade in herbal medicinal and aromatic products is about US $ 60 billion and it is expected to grow rapidly. India has annual trade of Rs. 5.5 million with only 0.5% share in world herbal market, but the country has potential to increase this share to a great extent because of suitable geographical location, agro-ecological and edaphic conditions for cultivation of a number of medicinal and aromatic crops. The cultivation of medicinal and aromatic plants therefore is gaining importance for reasons; first, to increase our share in this rapidly growing market, second to take advantage of magical healing power without side effects and third for avoiding extinction of these species. To achieve the above objectives Union Ministry of Health and Family Welfare has constituted a National Medicinal Board for sustainable development and marketing of these crops. Since there is already much pressure on good cultivable lands in over populated countries like ours for production of food, fibre, fodder and other agricultural commodities which allows a very little scope for cultivation of medicinal and aromatic crops on good arable lands.

Salt Tolerance of Medicinal and Aromatic Plants

The indigenous system of using wild plants for treating mental and physical sufferings of humanity thrives on naturally occurring floral diversity referred as medicinal plants. Till now more than 2,50,000 plant species have been identified and of which over 7000 species are used by different ethnic communities in our country. One–third of these are trees and equal numbers are herbs including grasses while remaining one-third are shrubs and climbers. The information on salinity and sodicity tolerance limits of some medicinal and aromatic crops is compiled in Table 23.1. Assessment on salt tolerance of medicinal and aromatic crops by some researchers (Patra and Singh, 1995; Dagar and Dagar, 2004; Tomar and Minhas 2002 a & b) has shown promise for cultivation of some medicinal and aromatic plants on degraded salt affected soils and irrigation with poor quality water.

Observations of different researchers indicated that in general medicinal and aromatic plants are comparatively more tolerant to salinity than sodicity. Very useful information on cultivation of certain medicinal and aromatic crops under saline environment has been compiled by (Patra and Singh, 1995; Patra *et al.,* 1997; Tomar and Minhas, 2002 a). Dagar *et al*., 2005) have demonstrated that medicinal and aromatic crops as Isabgol, Periwinkle, Tulsi, Aloe, Vasaka, *Jatropha* and different aromatic grasses like Palmarosa, Lemon grass and Vetiver can be successfully grown on salt affected soils and irrigation with saline water (10-12 dS/m). Threshold limits of soil salinity for Periwinkle and German chamomile is 10 and 12 dS/m as against the less tolerant medicinal plants like Egyptian henbane, Tulsi and Mentha. Isabgol can tolerate about 8-9 dS/m of salinity. Results from micro-plot studies using irrigation water of salinity 8.0 dS/m did not show any adverse impacts on grain or

Table 23.1. Salinity and sodicity tolerance of different medicinal and aromatic plants

Crop	Salinity tolerance (EC dS/m)		Sodicity tolerance	
Aromatic crops	Soil (EC_e)	Irrigation water	Soil (pH_s)	ESP
Palmarosa	9-12	14-16	9.5	55
Lemon grass	8-10	7-8	9.0	50
Citronella	4-5	5-6	8.5	25
Jamrosa	10-12	9-10	10.0	45
Vetiver	9-10	10-11	9.5	55
Marigold	4-5	5-6	8.8	40
Medicinal plants				
German Chamomile	10-12	8-10	9.5	--
Isabgol	7-8	11-12	9.5	--
Periwinkle	6-8	8-10	10.0	--
Rye for ergot of rye	10-12	12-15	9.6	--
Egyptian Henbane	7-8	8-10	8.9	--
Artemisia	8-10	8-10	8.4	--
Sowa/Dill	8-9	6-8	8.6	--
Vasaka	--	8-10	--	--
Aloe	8-10	10-12	8.4	--
Kair	18-20	15-18	8.6	--
Euphorbia	12-14	10-12	8.8	--
Jamalghota	6-8	6-8	8.7	--
Tulsi	--	8-10	8.6	--
Senna	9-10	10-12	8.7	--
Chanrasura/Halim	10-12	15-17	8.6	--
Satavari	7-8	10-12	8.2	--
Aswagandha	8-10	10-12	8.4	--
Mentha	4-5	4-5	8.6	--

-*Nor reported*

straw yield of this crop. Senna and garden cress have also shown good promise for cultivation under saline conditions. Field studies on salinity tolerance of these crops have indicated that yield and quality of these two species was not affected adversely when irrigated respectively with 10 and 17 dS/m salinity water. Reports also indicated that salinity or sodicity of soils or irrigation water did not have any adverse effect on their oil yield or quality. Moreover, there are reports that quality with respect to active principle components improves under salt stress. Lodha (2005) also reported higher sennosides content in Senna and garden cress oil content and quality under salt stress. A brief account of net return as shown below in Table 23.2 revealed that the vetiver cultivated in alkali (sodic) soils of pH 9.0 and 10.0 gave net return of Rs. 20,480 and Rs. 13,427 /ha, respectively.

Table 23.2. Yield (root and oil) and economic return from vetiver in sodic soil

Soil	pH	EC (dS/m)	Yield (kg/ha)		Net return (Rs./ha)
			Root	Oil	
I	9.0	2.5	27.2	16.3	20,480
II	10.0	2.6	19.9	11.3	13,427

The results from field experiments involving varieties of two aromatic grasses viz. palmarosa and lemongrass grown on sodic soil indicated that in some cases herb yield reduced due to high sodicity but since the oil content under stress condition was higher, the oil yield was not considerably affected as compared to normal soil. It was further observed that active ingredient in palmarosa (geraniol) and lemongrass (citral) also increased under sodic conditions compared to normal soils (Table 23.3).

Table 23.3. Yield (herb and oil) and quality of oil of aromatic grasses under sodic and normal soil

Yield/yield attributes	Palmarosa		Lemongrass	
	PRC-1	RRL B77	Pragati	Jor lab L 2
Herb yield (t/ha) 3 cuts	38.5 (47.4)	39.3 (52.5)	29.0 (35.9)	30.9 (37.6)
Oil content (%)	0.75 (0.63)	0.65 (0.57)	0.65 (0.52)	0.64 (0.52)
Oil yield (kg/ha)	288.8 (298.6)	255.4 (299.2)	188.5 (186.2)	197.8 (195.5)
Geraniol/citral (%)	90.0 (89.2)	88.5 (87.5)	85.0 (76.0)	89.2 (76.2)

Figures in parentheses give the corresponding values under normal soil. Patra et al. (1997)

Kumar *et al.*, (2003) reported that oil yield of aromatic grass palmarosa increased significantly by 24.5 percent at ESP 55 over ESP 16 (control). Further increase in ESP upto 85 decreased the oil yield by 36.5, 57.5 and 71.8 percent, respectively over yield obtained under ESP 55 (Table 23.4).

Table 23.4. Effect of ESP levels on oil yield of palmarosa (sum of 5 cuts)

ESP levels	Oil yield (g/pot)
16 (control)	2.45
55	2.88
65	1.84
75	1.16
85	0.77
CD (5%)	0.025

Aromatic grass vetiver has been reported to withstand soil sodicity (pH 9.0) and periodic water logging without adverse effect on yield and quality of oil (Singh *et al.*, 1987). It is clear from the data in Table 23.5 that significant reduction took place in both root (16.91%) and oil (17.0%) yield at pH 9.5 over control (pH 7.5) although there was no change in oil percent.

Table 23.5. Influence of soil pH on root and oil yield of vetiver

Soil pH	Oil content (%)	Yield	
		Root (g/pot)	Oil (ml/plant)
7.5 (control)	0.045	172.8	0.78
8.0	0.046	181.2	0.85
8.5	0.045	161.3	0.74
9.0	0.045	159.8	0.72
9.5	0.045	143.5	0.63
10.0	0.046	109.1	0.50
10.5	0.046	91.9	0.42
11.0	0.046	66.7	0.31
$LSD_{0.05}$	-	15.3	0.14

Source: Anwar et al., (1996)

It is documented that *Tagetes minuta* (African marigold) was grown on soils of ESP 45 without reduction in yield of herb as well as oil. Moreover the dihydrotagetone content in *Tagetes minuta* oil increased considerably due to sodicity (Table 23.6).

Table 23.6. Effect of ESP on herb and oil yield and dihydrotagetone in essential oil of *Tagetes minuta*

Soil ESP levels	Herb yield (kg/plant)	Oil yield (ml/plant)	Dihydrotagetone (%)
1.2	25.7	0.18	22.1
6	41.6	0.27	24.7
16	34.6	0.25	30.4
24	33.6	0.25	31.5
45	28.8	0.21	33.2
$LSD_{0.05}$	3.6	0.025	-

Source: Prasad et al., (2002)

Similarly Prasad *et al*., (1997) also reported that oil content increased in palmarosa due to sodicity. Sodicity also improved the oil composition as geranyl acetate in the oil of palmarosa increased with increase in soil ESP from 5 to 65 (Table 23.7)

Table 23.7. Effect of ESP on oil content and its composition in *Palmarosa* oil

ESP	Oil content (%)	Oil composition	
		Geraniol	Geranyl acetate (%)
5 (control)	0.4	79.4	10.0
16	0.4	78.5	10.5
35	0.5	76.3	12.2
48	0.6	75.1	13.7
65	0.4	78.1	14.9

Uses of Salt Tolerant Medicinal and Aromatic Crops

The information on drugs or aroma yielding plants and their efficiency in medicines is available and updated regularly in many authentic sources as Indian Pharmaceutical Codex, British Pharmaceutical Codex, United States Pharmaceutical Codex and National Formulary *etc*. The drugs extracted from medicinal and aromatic plants have been found successful in controlling serious diseases as cancerous tumors, HIV, hypertension, rheumatoid arthritis, digestive disorders, used as contraceptives and treatment of many other ailments. Extracts of different medicinal and aromatic crops are used in pharmaceutical, food, flavor and cosmetic industries. However, some of the medicinal and other important specific uses of salt tolerant medicinal and aromatic crop species compiled from literature are presented in Table 23.8. The economics of these crops in comparison to other cultivated conventional crops needs to be assessed in addition to availability of the local market for sale of the produce that can boost their cultivation.

Table 23.8. Medicinal uses of different medicinal and aromatic plants

Crop/species	Medicinal uses
Aromatic crops	
Palmarosa (*Cymbopogon martinii*)	Oil contains geraniol, and emit rose like aroma used in perfumes, tobacco, soaps, medicines
Lemon grass (*Cymbopogon flexuosus*)	Contains citral used in vitamin-A, other edible recepies, perfumery, cosmetics
Citronella ((*Cymbopogon nardus*)	Oil has mosquito repellant characteristics, also used in cosmetics and perfumery
Vetiver (*Vetiveria zizanioides* Linn.)	Oil from roots used in perfumery, cosmetics and flavouring sherbets
Medicinal plants	
German chamomile (*Matricaria chamomilla* L.)	Flowers yield essential oil used as expectorant, sedative, perfumery, gastric stimulant
Isabgol (*Plantago ovata* Forsk.)	Mucilage present in husk helps in cure of various intestinal, blood and cough ailments
Periwinkle (*Catharanthus roseus*)	All parts are used for treatment of tumors, menorrhagia, leukemia and antibacterial uses
Rye for ergot (*Claviceps purpurea*)	Dried *sclerotium* used in contraction of uterus and bladder, controls bleeding. Ergotamine used for migraine
Satavar (*Asparagus racemosus*)	Roots rich source of minerals and other chemicals used for gas and lever, leucoria and as tonic
Aswagandha (*Withania somnifera*)	Alkaloids are anti-cancer, anti-sleeplessness and immune system motivators
E. henbane (*Hyoscyamus muticus*)	Tropane and hyscine are used in treatment of cold, cough, lever pain and apoplexy
Sowa/Dill (*Anethum graveolens*)	Essential oil is given to children for flatulence, seeds are

	used as carminative and stomachic
Vasaka (*Adathoda vasica*)	Bark and leaves extract has antiviral activity, used in cold, cough, bronchitis, rheumatic pain etc.
Aloe (*Aloe barbadensis*)	Extract is cathartic, used in lever, spleen, piles, rectal, menstrual and constipation problems
Kair (*Capparis deciduas*)	Fruit used in cardiac problems, bark used in cough and asthma. Fruits are used as pickles.
Mint (*Mentha citrata*)	Mint oil has great industrial value and also used in flavors of candies, anta-acids and other fresheners
Euphorbia (*Euphorbia antisyphilitica*)	Extract antisyphlatic and is a potential petro-crop
Jamalghota (*Jatropha carcus* Linn.)	Extract used in toothache, diarrhea, skin infections
Tulsi (*Ocimum sanctum* Linn.)	Leaves stimulants, anti-cough, yield essential oil
Senna (*Cassia angustifolia*)	Leaves and fruits laxative, vermifuge, purgative
Chandrasura (*Lepidium sativa*)	Oil is rubifacient/antinflamatory and galactogogic

Reclamation of Salt Affected Soils

Several studies have established that cultivation of medicinal plant such as Isabgol and aromatic grasses like Palmarosa, Lemon grass and Vetiver can reduce pH, EC, ESP and Na of salt affected soils (Table 23.9 and 23.10). In case of aromatic grasses, the reclamation process occurs through improvement of physico-chemical properties of sodic soils due to extensive growth of roots which increase permeability of soil. As a result of decomposition of roots, CO_2 may be evolved which results in solubilisation of native $CaCO_3$. This process takes place much effectively in the fields of vetiver which has the ability to withstand even water logged conditions in sodic soils. A marked decrease in the ESP of soils and changes in their Na and pH after the harvesting of vetiver has proved the ameliorative potential of this crops on such soils (Table 23.10)

German chamomile could also help in ameliorating the sodic soils through higher uptake of sodium an especially harmful cation. It is reported that this crop absorbed sodium to the extent of 66 meq Na/100 g of dry matter and improve alkali soils through ion uptake.

Table 23.9. Ameliorative effects of different aromatic grasses on salt affected soils

Crop	Soil pH (1:2.5)		Soil EC (dS/m)		ESP		Authors
	Initial	Harvest	Initial	Harvest	Initial	Harvest	
Palmarosa (2yrs)	10.62	9.40	4.80	0.64	93.0	43.8	Prasad *et al.,* (1995)
Lemongrass	9.80	8.95	1.25	1.35	60.0	52.8	Patra *et al.,* (2002)
Vetiver	10.50	9.50	--	--	82.0	--	Anwar *et al.,* (1996)
Vetiver	9.50	9.00	--	--	56.5	38.7	Anwar *et al.,* (1996)
Isabgol	10.00	9.70	1.25	0.81	60.0	48.4	Patra *et al.,* (2002)

Table 23.10. ESP and Na of sodic soil before planting and after harvesting of vetiver

Before planting			After harvest of crop		
ESP	pH (1:2.5)	Na (meq/l)	ESP	pH (1:2.5)	Na (meq/l)
10	8.0	87.6	9	7.5	83.6
15	8.5	89.9	14	8.0	86.8
30	9.0	108.9	28	8.3	100.1
50	9.5	122.5	35	9.0	114.1
65	10.0	125.4	42	9.3	118.6
80	10.5	135.9	50	9.5	132.1
85	11.0	152.5	61	9.6	147.6

Quite a significant area of earth surface is affected with excess salts and water logging characterized by poor productivity of crops. The reclamation of these soils is very costly because these require additional inputs as amendments, irrigation and provision of drainage. Growing salt tolerant hardy medicinal and aromatic species is a viable alternate approach for productive utilization of these salt affected and waterlogged soils. Available information indicate that many high value medicinal and aromatic crops have higher tolerance to salinity, sodicity and water logging without any degradation in their quality, rather better quality has been observed under abiotic stress conditions. Immediate gains are quite encouraging in terms of high crop productivity to demands of raw material in national and international market, high economic return, employment generation and agriculture-industry linkage.

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Utilization of Sewage Water in Fruit and Vegetable Production through Drip Irrigation

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The wastewater can be broadly grouped into two major categories – the domestic waste water and the industrial wastewater. In most cities and towns these two waters are disposed off together. If these are disposed off together their 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 general characteristics are better and have no heavy metal contamination. Though the quality of sewage water differs from place to place, season-to-season, on the per capita consumption and the quality of community water supply, but in general these waters are neutral to slightly alkali in reaction, low in salt content and high in pathogenic micro-organism. The water rarely contains heavy metals unless mixed with industrial waste water, which may be toxic to plants and may cause adverse affect to human being by entering into the food chain. It contains nutrients and organic matter, which may increase the soil fertility. The constituents of concern in wastewater treatment and irrigation are listed in Table 24.1.

Different Approaches to Manage 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

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 ground water.

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 to some extent 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 24.2). Thus, to save irrigation water and energy and to enhance productivity, selection of advanced irrigation method would be necessary. The increase in productivity is attributed to conditions of optimum moisture in the root zone resulting 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 24.1. 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	Nitrogen, phosphorus, and potassium 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 resulting in eutrophication of water bodies. When discharged in excessive amounts on land, nitrogen can also lead to the pollution of ground water.
Stable (refractory) organics	Specific compounds (phenols, pesticides, chlorinated hydrocarbons)	These organics tend to resist conventional methods of 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 (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 (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 ground water contamination.

Source: Asano et al., 1986

Table 24.2. Application efficiencies of different irrigation methods

Type of irrigation method	Application efficiency
Flood, border, furrow, check basin, bed and furrow	< 60
Sprinkler	80 – 85
Drip	90 – 95

The evaporation losses are 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 is altogether avoided, which reduces the evaporation losses. Moreover in most cases it would not be necessary to wet the entire field. For example in the case of vegetable crops, only 80% of the wetted area can serve the purpose whereas 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: The area under drip irrigation has increased globally from a mere 40 ha in 1960 to more than 2.7 M ha in 1998. The major countries where it is being adapted are USA, Austerlia, Israil, Mexico, India, and to a lesser extent in Canada, Cyprus, France, Iran, New Zealand, U.K., and Greece (Singh *et al*.,2001). In Russia 2% irrigated area is under drip Irrigation and it has been rising steadily.

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 M ha (Table 24.3). 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 annual compound growth rate of adoption of drip irrigation assessed at present at 12%, it would take about 8 years to bring additional 1 M ha area under drip irrigation.

Table 24.3. Growth of area under 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 24.4, 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 24.4. Area (ha) coverage under drip irrigation for selected crops in India

Crops/fruits	Year	
	1992	1998
Sugarcane	3888	18000
Cotton	383	5462
Vegetable	1537	4515
Fruits	39500	186600
Arecanut	208	5665
Banana	6767	26565
Citrus	3879	22210
Coconut	2596	48361
Grapes	12048	29630
Guava	1543	4930
Mango	4747	21863
Papaya	873	2115
Pomegranate	5437	15250
Sapota	849	5125
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 24.5) reveal that maximum yield increase was in vegetables (60%) followed by fruits (40%), sugarcane (33%) and cotton (27%). Similarly water saving 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 by using drip system were calculated (Table 24.5). Additional returns due to increase in yield ranged from Rs. 16, 767 to 29,568/ha, with maximum in sugarcane and minimum in cotton. The benefit from water saving ranged from Rs. 660 to Rs. 3612/ha (approximate water price Rs. 3/ha-mm, Tiwari *et.al.*, 1998). The benefit from fertilizer saving was estimated at Rs. 450 to Rs. 600/ha for existing rate of fertilizer. The cost of fertilizer is estimated based on the recommended dose for the respective crops.

Table 24.5. Total returns expected from selected crops under drip irrigation system

Input	Cost economics	Sugarcane	Cotton	Fruits	Vegetables
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 returns (Rs./ha)		33780	18700	24030	27510

The cost benefit ratio was calculated for these crops (Table 24.6). 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.

Table 24.6. 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

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 waste water is now being used on a relatively large-scale, mostly in developed countries, for field crops and landscape irrigation, ground water recharge, and storage in recreational centers. In a few cases, tertiary or advanced treatment of the waste water is required (Kirkham 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 of 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).

It is evident from above examples that some degree of treatment was provided to untreated municipal waste water before it could be used for agricultural or landscape irrigation. This is the prevalent norm 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 waste water irrigation system. Pre application treatment of waste water 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 is 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, 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 ground water and surface water contamination and inefficient use of 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 83000 l/day. The quality of the domestic wastewater is given in Table 24.7. Most of the sewage water in the pond is recharging the ground water and a foul smell spreads to areas near the pond. For safe, economical and efficient utilization of sewage water, an experiment was conducted to irrigate ladies 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 sand and screen filters were provided in series, whose description is given in Table 24.8. The ladies finger crop grown during April to September. The amount of domestic wastewater applied was 53 cm whereas total crop water requirement was 89 cm (Table 24.9). 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 24.10).The other part of the crop water requirement was met by rainfall. The yield of ladies finger crop was higher (14.72 t/ha) in the case of subsurface drip irrigation compared to 8.0 t/ha in the case of surface drip irrigation (Table 24.9). 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 24.10). 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 24.7. Composition of domestic wastewater at CSSRI, Karnal

S. No.	Parameter	Values
1	PH	7.93
2.	EC (dS/m)	0.98
3.	BOD_5 (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 (meq /l)	7.89
8.	P (mg/l)	4.06
9.	K (meq/l)	0.29
10.	Na (meq/l)	2.38
11.	Ca (meq/l)	2.19
12.	Mg (meq/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

Table 24.8. Description of sand and screen filters

S.No.	Type of the filter	Capacity, (m^3/hr)	Nominal pressure (kg/m^2)	Pressure difference (kg/m^2)	Nominal size	Mesh size (micron)
1	Sand filter	18	2.50	1.0	-	-
2	Screen filter	25	1.50	0.50	2(6.3)	100

Table 24.9. Water use efficiency in ladies finger during surface and subsurface drip irrigation

Total water requirement (cm)	Sewage water applied	Yield of ladies 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 24.10. Water use efficiency in cabbage 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 the 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 encountered with sewage water may blunt this advantage. During three years of experimentation, the emitters were clogged to some extent resulting in decrease in application efficiency (Table 24.11 and 24.12). 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 .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 a 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 24.11. 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 drip		Subsurface drip	
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 24.12. Estimated application efficiency 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 24.13. Where 48 cm was lost in deep percolation in the case of border irrigation compared to only 20 cm was lost 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 24.13. Estimated deep percolation losses in different irrigation methods

Crop	Surface drip		Subsurface drip		Border
	Initial	After 3 years	Initial	After 3 years	
Ladies 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 Contamination: Soil and plant produce contamination depends to a large extent on the applied effluent quality, soil conditions, and the technology of application. The micro-organism content in the effluent was quite high i.e. around 10^{10}/ 100 ml (Table 24.7) which reduced to 10^{4}/ 100 gm of soil in the case of surface drip irrigation (Table 24.14). In the case of subsurface drip irrigation, soil surface was found free from pathogenic microorganism indicated by *E. coli* (Table 24.14). Plant produces i.e. ladies 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 from diseases during inter culture operation in the case of subsurface drip irrigation.

Table 24.14. 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 required closer spacing of drippers and laterals. To overcome this, experiments are now being conducted on fruit crops. The two fruit crops i.e. Guava and Aonla are 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.

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Integrated Fish Farming in Reclaimed Alkali Soils

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The principle of integrated farming involves farming of fish along with livestock or/and agricultural crops. The rising cost of protein-rich fish food and chemical fertilizer as well as the general concern for energy conservation has created awareness in the utilization of rice and other field crops and livestock wastes for aquaculture (Edward, 1996). Aquaculture in combination with agriculture or livestock is a unique and lucrative venture and provides a 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 feeds for the farm livestock (Abdullah, 2004). The scope of integrated farming is considerably wide. Ducks are raised in pond, and pond dykes are used for horticultural and agricultural crop products and animal addition to fish. Hence this system provides better production, provides more employment, and improves socio-economic status of farmers and betterment of rural economy. In these condition apart from agriculture and livestock/other animal produce, fish production to a level of 3-6 t/ha/year has been achieved depending upon local condition.

Advantage of Integrated Farming System

Integrated farming system is actually a mixed farming system in which fish culture is taken as the main as well as allied activity along with crop production, livestock raising and other allied occupations depending upon land holding. In this system, practically nothing is wasted, ecological balance is beautifully maintained and a variety of products are obtained to meet the farm family need in terms of food and income. Among the different systems integrated fish farming refers to combination of practices incorporating the resources and the recycling of wastes from one farming system to other with a view to optimize the production efficiencies and achieving maximum harvest from a unit area with due environmental considerations.

Types of Integrated Farming System

Depending on availability of different kind of resources in the various agro-climatic conditions different kinds of model have been established, which can be broadly classified as (1) Agri-aquaculture system (2) Aquaculture-livestock integration system (3) Multi-enterprise integrated farming system

Agri-aquaculture System: The aquaculture pond remains the nucleus of the agricultural systems. The agricultural crops are introduced for additional income or *vice- versa*. The main agricultural crops that have been found suitable under this system are paddy, oilseed and pulses, grass and fodder, horticultural/vegetable/floriculture etc.

Paddy-aquaculture System: The sites with high rainfall (above 800 mm) but with poor drainage can be brought under this type of system. Fields having uniform contour and having high water retention are preferred. The paddy plots are re-designed giving provision for trenches or pools with in plot itself. The paddy growing area is either placed at the middle or the fringe with slopes towards the middle or with trenches provided on the lateral flanks of the fields. The capacity of the trenches or pool is determined by taking into consideration the volume of water required for fish culture and irrigation of second crop of paddy during dry month i.e. *rabi* season. Excavated earth from the trench is utilized for constructing a suitable and strong perimeter dyke. The height of the dyke is decided by taking into consideration the inundation level of the area.

Having prepared the plot, deep water paddy variety is selected for direct sowing before the first shower of monsoon. With onset of monsoon, water starts accumulating first in the trenches and then spreads over the paddy plot as the monsoon advance, making the entire area a single sheet of water. With the rising water column, survival is high otherwise in the ordinary paddy fields, it is generally poor. Fish production normally ranges from 700-1000 kg/ha/yr and paddy production around 4-5 t/ha/crop.

Available space on the dyke of renovated plots is used for growing fruit/vegetables etc. so as to generate higher returns.

The yield of paddy can be increasedby 15-20% due to better aeration of water and greater tillering effect caused by the presence of fish. The excreta of fish is useful as additional manure and leftover supplementary feed also helps in creasing soil fertility. The fishes help in controlling weeds which hamper paddy yield. They also control harmful insect and insect larvae. No pesticide is sprayed during paddy cultivation due to the presence of fish in the system. However indigenous methods like neem oilcake/leaf extract can be used as a biological means to control pests.

Grass/fodder based Aquaculture System: Grasses or fodder are usually grown on the pond dykes and serve as feed and to the animal component. They are also grown at the pond bottom during unoccupied season. Aquatic grasses are also utilized for feed of the fishes. In this system herbivorous fishes are cultivated as dominant fish species. The nutrient rich water and silt of pond are used for irrigation and manuring of fodder plots. A system with 50% grasscarp and 10% each of silver carp catla, rohu, mrigal and common carp can yield 3-5 t/ha/yr fish production without any additional expenditure in terms of feed and fertilizer.

Horticultural based Aquaculture System: In the context of nutritional and food security, it is necessary that we increase production of fruits and vegetables through all possible ways. By growing horticulture crops on the embankment of the pond, a farmer will not only do justice to the land but also get the opportunity to have the taste of hygienic fresh fruits and vegetable besides making income from the sale of surplus produce. The added advantage of gardening on pond embankment is that the crops receive the facility of drip irrigation from the pond water and also manure from the pond silt. The most common fruit and vegetable crops for this system are banana, papaya, guava, aonla, bottle gourd, brinjal, cabbage, cauliflower, spinch, raddish, chilli, clusterbean, cowpea, cucumber, pumpkin, tomato, turmeric, zimikand, mushroom etc. The leaf, fruit waste of these commodities is utilized as feed and fodder for herbivorous fishes as well as their decomposed waste as fertilizer for the pond.

Aquaculture-Livestock Integration System

The high fish yields through animal waste recycling in fish ponds can be attributed mainly to the microbial activity through dual food web (i.e.) autotrophic as well as heterotrophic production without denying the importance of direct feeding and interaction between the various components of fish species. Fish-cum-livestock farming is considered as an excellent innovation for judicious recycling of organic wastes and optimum production of high class protein at low cost. This is also one of the most efficient methods of waste disposal and utilization for the production of high quality animal protein.

Aquaculture-Cattle Integration: Use of cattle manure in fish farming is one of the prevailing practices all over the world. Among all the livestock excreta, cow dung is most abundant in terms of availability. Cattle washing are drained directly into the pond. Fertilization of aquaculture nurseries, rearing or stocking ponds with cow/buffalo dung is a widespread practice in India. This dung has a slow rate of inorganic transformation. Therefore, it is desirable to apply the dung in split doses at periodical interval to avoid the ecological imbalance. It has been estimated that the daily output of dung and urine from 2-4 animal is enough to maintain the fertility status of aquaculture in one a pond.

Aquaculture-Pig Integration: The integration of pig with fish culture in India appears to be less obvious than that of the other livestock integration as pig keeping in the country is associated with only the weaker sections of the society. Raising of pig is rather easier than other farming animals as they feed largely on kitchen wastes, aquatic plants and crop wastes. The indigenous breed in general attains 30-45 kg in 1.5 years as compared to the improved exotic varieties which attain 90-95 kg in 5-6 months. However, the indigenous stock is hardy and well adapted to poor rural husbandry practices. Several exotic breeds of pigs have been introduced in India to augment pork production, popular ones being the larger white Yorkshire, Berkshire and Land race. About two months old weaned piglets are grown generally for six months, during which they attain a size of 60-70 kg. Each pig provides about 250-300 kg of dung during six months growth period, thus 500-600 kg in two batches of rearing. It has been estimated that 30-40 pigs are adequate to provide the required amount of 15,000-20,000 kg of pig dung for fertilizing one ha pond. The fishes also feed on the raw and fresh excreta of pigs to a considerable extent, which contains about 70% of digestible food for fish. Production of 6000-7000 kg fish/ha/yr has been achieved along with 4200-4500 kg of pig meat (live weight). The integration is a viable and feasible alternative to argument fish production at low cost.

Aquaculture-Poultry Integration: Fish-poultry farming utilizes poultry droppings or fully built-poultry litter recycled into the fish ponds to attain fish production of 4500-5000 kg/ha/yr. The dosage of application of poultry manure in fish ponds are about one third the rate of cowdung. It is estimated that 500-600 birds would provide the required amount of fertilizers for one ha water area. These birds can also produce more than 7000 eggs and about 1250 kg (live weight) chicken meat. Alternatively, the broiler production may also provide good and immediate returns to the farmers. Success of production depends mainly on the efficiency of the farmers, experience, aptitude and ability in the management of the flocks. This involves procurement of better breeds, brooding equipment, husbandry and management practices including the prevention and control of disease.

Aquaculture-Duck Integration: Duck-fish integration is the most common integration in countries like China, Hungary, Germany, Poland, Russia and some extent in India. A fish pond being a semi-closed biological system with several aquatic animals and plants provide excellent disease free environments for ducks. In turn, ducks consume juvenile frogs, tadpoles, dragonfly etc. thus providing safe environment for fish. Duck droppings go directly into the pond which in turn provides essential nutrients such as carbon, nitrogen and phosphorus which simulates growth of fish. Ducks also help in aerating the pond water, along with pond bottom raking effects. It has been estimated that 200-300 ducks can take care of the fertilization schedule of the water body for an area of one ha. It has been estimated that one duck provides 125-150 g of droppings per day. Thus, about 10,000-15,000 kg of droppings would be recycled in pond. The fish yields from duck-fish farming system ranges from 3500-4000 kg/ha/yr. Further,in addition to the fish 4000-6000 duck eggs and 500-750 kg duck meat are produced from the unit.

Aquaculture-Rabbit Integration: Rabbit excreta is low in moisture and high in nitrogen content and is a quality manure for sustained plankton production for aquaculture ponds. A rabbitary integrated with fish farming practice may prove to be efficient enterprise. Rabbit meat has low fat content in comparison to mutton, pork, chicken and beef.

Aquaculture-Goat Integration: The solid excreta of goat are several times richer in nitrogen and phosphoric acid than excreta of other animals. Goat urine is also equally rich in both nitrogen and potash. Goat dropping has the advantage of direct application into grow out fish ponds as the size of droppings of around 4 mm pellet coated with mucous floats in semi dried state. The droppings have been observed to be consumed by fish. Goat house can be constructed on pond dyke with facility for waste disposal.

Multi-enterprise Integrated Farming System

Integration of more than three farming activities, like aquaculture-crop/plant-livestock practiced together is called the multiple integration or multi-enterprize agriculture e.g. CSSRI model (CSSRI, 2008 and CSSRI, 2009). In this model, both input and output of each activity are closely linked with the other activities through energy flow (Singh and Kumar, 2010). The output of the first farming activity always provide material basis for the second one and in turn the input of second farming activity gives feedback to the first one. So they are vertically and horizontally integrated with each other. In an integrated farm, green fodder are grown not only for feed of herbivorous cultured fishes, but also for raising animal such as pig, cow, duck etc. Therefore, it is important to carry out a special management to enable every production activity to achieve its expected target and ensure a conducive energy flow and high economic return.

Aquaculture for Domestic Sewage Utilization

Studies have shown that higher rates of fish production (3-4 ton/ha/yr) can be achieved by using sewage alone based on ASTP Cuttack model (Ghosh *et al*., 1985; Ayyappan, 2000).

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Multi-tier Cropping System for Higher Productivity in Reclaimed Sodic Soils

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Yield plateau being experienced in 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).

The Concept of 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 and soil resource can be efficiently used. 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.

The 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 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 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 crop. 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.

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.

Benefits of Multi-tier System

- Fruit trees are efficient enough in providing higher economic returns even under stressed growing conditions.
- The approach aims at improving productivity by effective utilization of air space which is not utilized in single tier system.
- 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.
- Higher labour requirement per unit area of multi-tier system contribute towards creation of job opportunities at site.
- High returns per unit area under upland conditions is the ultimate result of fruit based multi-tier cropping system.

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 like mango, litchi, aonla, etc. can be considered. For filler crop, the short stature plants 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 crops. For intercropping during the initial 10 years, different legumes like pegion pea, horse gram, blackgram, cowpea, French bean, millets, oilseeds like niger, ground nut, fodder like *Stylosanthes*, Dinanath grass etc. could be grown as *kharif* crops under rainfed conditions whereas high value crops like vegetables or flowers could be grown under irrigated conditions (Table 26.1). After 10 years, shade tolerant crops like turmeric can be grown as inter crops.

Table 26.1. Suggested models for different agro-climatic conditions

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

Farmers' feedback about multi-tier technology: Farmers feedback about the technology of multi-tier cropping system is as follows:

- 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 under plateau region showed that mango based system resulted in a B:C ratio of 2.40, litchi based system in a ratio of 2.86 and aonla based system in a B:C ratio of 2.51.

Overall results have revealed that fruit based multi-tier cropping systems are effective alternatives to the traditional rice based mon-ocropping system for increasing the profitability under rainfed as well as irrigated upland conditions of the eastern plateau and hill regions. This system may be profitably used in the reclaimed sodic soil also.

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Health and Quality of Salt Affected Soils of India in Changing Climate Scenario

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The nature has provided the mankind with four basic resources of climate, water, soil and biodiversity to meet its survival needs. Rational use of these natural resources to meet the needs and not the greeds will determine the longevity of civilizations. During last more than three decades, these resources have been stretched and over exploited to meet food, fibre and shelter requirements of burgeoning human and livestock populations. Over exploitation of water, soil and biodiversity has resulted in their degradation in terms of quality and availability. The food grain production in the country is revolving around 210 to 215 million tonnes since 2001-2002 owing to the adverse impact of weather abnormalities despite the advanced technology. Anthropogenic emissions of green house gases have considerably increased due to faulty agricultural practices and have resulted in climate change and global warming of the planet (Swaminathan, 2002; Ramakrishna, 2007). Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluoro-carbons (HFCs), perfluoro-carbons (PFCs) and sulphur hexafluoride (SF5) are the six important gases which are responsible for the current global warming. It has been reported that increase in CO_2 concentration in the atmosphere during last 50 years has almost surpassed the increases reported during the last 1000 years. The mean global annual temperatures increased between 0.4 to 0.7^{o}C during the last century. The year 2005 has been reported to be the warmest year so far. Almost all the years in the current decade recorded extreme weather events, and the year 2007 has also been declared as one of the warmest years. Since last several years the wheat production in the country remained stagnated due to increase in temperature during reproductive phase of the crop across the wheat growing regions. As per FAO records, the wheat stocks have exhausted to its lowest level since 1980. The reasons attributed for such a shortfall include abnormal weather conditions in Australia, Ukraine, Argentina and Russia. Melting of glaciers, sea level rise, submergence of islands/coastal areas and change in rainfall and temperature pattern over the next century are predicted. This change is bound to affect water availability, bio-diversity pattern, demand a new set of land use pattern including enterprises, commodities, crops and varieties. Global warming related ozone depletion has also been reported which may lead to increased UV radiation with far reaching adverse impact on earth's environment and human as well as livestock populations including microbial communities. Such effects of climate change have already started impacting agricultural productivity in several agroclimatic regions and sub-regions of India. The country experienced one of the severest droughts of the last century during 2002 that lowered food grain production by more than 29 million tonnes. The cold waves of 2002-2003, 2005-2006, 2007-2008 caused significant damage to winter crops in the states of Punjab, Haryana and Western UP. The heat wave of March, 2004 in northern states coincided with the reproductive phase of wheat slowed down the translocation of photosynthetic assimilates from vegetative parts to grains and lowered the production by more than 4 million tonnes. Unexpected heavy rainfall (about 20 cm in 48 hours) during February, 2007 caused extensive damage to wheat and other *rabi* crops in Haryana. The monsoon behaviour in 2007 over Kerala was totally different to that of previous years and very heavy rains were observed between June and September leading to severe flooding in low lying areas. Like several past years May, 2008 has also experienced low temperature and monsoon like weather conditions.

Net impact on the productivity will be the resultant of contrasting effects of increased temperature and carbon dioxide concentration depending upon C_3 or C_4 plant and their cultivation in temperate or tropical region. These concerns are likely to provide ample opportunities to the agronomists to plan and execute research to deal with future scenarios of climate to sustain agricultural productivity and food and nutritional security in 21st century.

Impact of Climate Change on Agriculture

The climate change will affect crop yields and cropping pattern due to direct effect of changes in atmospheric concentrations of green house gases in general and CO_2 in particular (Aggarwal and Sinha, 1993). Carbon dioxide is a perfect example of a change that could have both positive and negative effects. Carbon dioxide is expected to have positive physiological effects through increased photosynthesis. This impact should be higher on C_3 crops such as wheat and rice than on C_4 plants like maize and grasses. It has been reported that under optimum conditions of temperature and humidity, the biomass increase could reach nearly 36% for doubling of CO_2. The indirect effects through the increase in temperature will reduce crop duration, increase crop respiration rates, increase evapotranspiration, decrease fertilizer use efficiencies and enhanced pest infestation. Possible impact of climate change on wheat production in India has been worked out by the climate scientists for the period between 2000 to 2070 (Fig. 27.1). There is general consensus that the yield of main season (*kharif*) crop will increase due to the effect of higher carbon dioxide levels (Aggarwal and Mall, 2002). However, large yield decreases are predicted for the *rabi* crops because of increased temperatures. One of the potential effects of climate change on agriculture will be the shifts in the sowing time and length of growing seasons, which would alter sowing and harvesting dates of plants, crops and varieties. High temperature induced higher evapotranspiration would call for much greater efficiency of water and nutrients. Changed weed flora and pests would require special methods of management and control, a challenge for agronomy and plant protection community. There may be a shift in climatic zones due to increased temperatures. In mid-latitudes, the shift is expected to 200-300 kms for every 1°C rise in temperature (IUCC, 1992). Morey and Sadhaphal (1981) reported a decrease in wheat yield by 400 kg/ha for a unit increase of 1°C temperature and 0.5 hour sunshine.

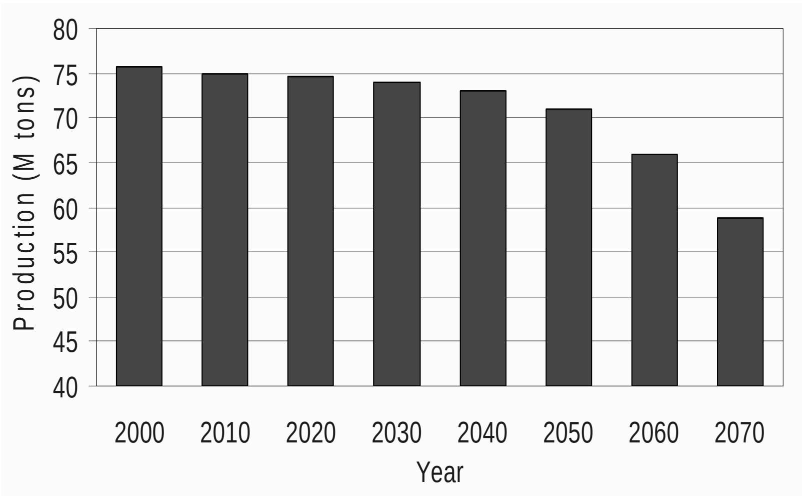

Fig. 27.1. Possible impact of climate change on wheat production in India

Similar observations were also recorded by Hundal and Parabhjot Kaur (2007) under Punjab conditions. Their analysis revealed that an increase of temperature from normal can decrease the wheat yields in the following order:

- Temperature increase in 4th week of January decreased the grain yield by 0.99, 0.66, and 0.70% per degree centigrade for wheat sown in 4th week of October, 1st and 2nd week of November, respectively.
- A decrease in grain yield to the extent of 2.88 and 1.87% per degree increase in temperature occurred when wheat was sown in 4th week of October and 1st week of November, respectively.
- Increased temperature during the second fortnight of February decreased wheat yield by 2.40, 3.30, 2.15, 1.26 and 0.69% per degree increase when wheat was sown in 4th week of October, 1st, 2nd and 4th week of November and 1st week of December, respectively.
- Maximum decrease to the tune of 2.40, 2.10, 2.98, 3.51 and 3.15% occurred when temperature rose during first fortnight of March in case of wheat sown in 4th week of October, 1st, 2nd and 4th week of November and 1st week of December, respectively.
- A yield loss of 1.24, 2.15 and 3.40% occurred in wheat sown in 2nd and 4th week of November and 1st week of December, respectively when temperature increased during 2nd fortnight of March.

Vijay Cuddeford (2002) reported that the area under rice may show a declining trend because several current rice varieties may not set grain under enhanced temperature conditions. There will also be less water for rice cultivation which may necessitate the need of adoption of water saving techniques such as System of Rice Intensification (SRI), arobic and direct seeded rice etc. The effect will be more pronounced in the drought prone areas where rice is cultivated as rainfed crop. Samra and Singh 2002), however, suggested several strategies and contingent crop plans to negate/moderate the impact of sub-dued rainfall/drought in different agro-meterological sub divisions of the country. Large scale impacts of climate change on the oceans will include; increase in sea level, increase in sea surface temperature, decreases in sea-ice cover, changes in salinity/alkalinity, wave climate and ocean circulation. Further, with global warming and associated sea level rise, many coastal systems will experience: increased levels of inundation and storm flooding, accelerated coastal erosion, sea water intrusion into fresh ground water, encroachment of tidal waters into estuaries and river systems, elevated sea surface and ground temperatures. Further, change in climate is expected to increase both the evaporation and precipitation. If rate of evaporation exceeds the rate of precipitation, soil becomes drier, lake levels will drop and rivers will carry less water. Warm water in lakes and reservoirs will likely to increase the blue-green algae and other nuisance lower plants that may reduce the levels of dissolved oxygen and adversely affect the fish productivity. With rise in temperature many fish species will try to shift to find out the cooler regions, either they move upstream of river or in the greater depths. Researchers forecast substantial shift in fish habitats, disrupted pattern of aquatic plants and animal distribution and alter the fundamental eco-system process that will result in major ecological change. Kumar and Parikh (1998) worked out economic loss between 9 to 25% for a temperature rise of 2 to 3.5^{o}C. Similarly, Sanghi *et al*., (1998) predicted a loss of about 12.3% in net revenues for a rise of 2^{o}C in temperature and 7% increase in rainfall. Coastal regions of Gujarat, Maharashtra and Karnataka are predicted to be most negatively affected. On the other hand, West Bengal, Orissa and Andhra Pradesh are predicted to benefit (to a small extent) from global warming.

Health and Quality of Salt Affected Soils

High concentration of salts in the root zone soil reduces the productivity of nearly 6.73 M ha of otherwise productive lands in India. Similarly, 25% of the ground water resources in the country are saline and brackish. Certain states like Rajasthan and Haryana located in the western part of the country are endowned with 84 and 62% of poor quality ground waters, respectively. Continuous use of such waters for irrigation to agricultural crops is bound to increase the problem of salinity and sodicity in India. The projections are that the country will have 11.7 M ha area affected by salinity and sodicity by 2025.

Strategies to Moderate the Adverse Effects of Climate Change

Some of the strategies to negate/moderate the impacts of climate change on health and quality of soils are summarised below:

- Developing new plant genotypes for drought, heat and cold tolerance adapted to climatic variability and ranges. There is a strong case to screen and document the already existing germplasm of crops, trees, animals and even microbes about their location specific response to such changes. Based upon this screening, location specific crop/variety calendars for application according to changed situation needs to be developed.
- Devising agronomic practices which may moderate/negate the impact of predicted climate changes and promotion of conservation agriculture practices such as zero tillage, bed planting, residue management and crop rotation.
- There is a need to develop contingency plans to cope-up with weather related abrasions such as cold and heat wave and drought. These contingent plans should be such that these can be practically implemented on a short notice/warning.
- Developing precision and accurate forewarning mechanisms to reduce production risks and for undertaking preventive measures. There is a strong case now to go for developing and upgrading medium and long range forecasting systems (15-20 days in advance) so that farmers have reasonable time to respond to risks.

- Identification of genes for tolerance to moisture, heat and cold stresses and developing a canvas of transgenics having tolerances to abiotic stresses. Biotechnological approaches such as pyramiding of genes should be a priority area of future research in climate change.
- Reducing green house gas emissions through carbon sequestration in different land use systems with major emphasis on raising tree plantations on degraded soils. Research on bio-diesel /petro-crops such as *Jatropha* and *Pongamia* which have potential to substitute fossil fuels needs strengthening. Since India cannot afford to divert cultivable area from grain crops to ethanol/bio-diesel production, our priority should be to extend cultivation of such plants on degraded lands which constitute an area of about 107 M ha.
- Curtailing losses of methane and nitrous oxide from cultivated fields by increasing use efficiency of water, nutrients, energy and other agronomic manipulations.
- Manipulation of crop micro climate by means such as use of wind breaks, tunnels or green houses to reduce the effects of climate change.
- Genetic engineering/biotechnological tools which can convert C_3 plants into C_4 mode of photosynthesis to tap the increased CO_2 in the environment for higher biomass production. .
- Develop knowledge based decision support systems for translating weather information into operational management practices at district, block and village Panchayat level.
- Benchmarking of areas prone to climate change impacts on agriculture and livestock and periodic monitoring to initiate timely preventive action.
- Establishment of automatic weather stations in all the 127 NARP zones to provide value added agromet advisory service to the farmers. There is also a need to establish climate monitoring towers/climatic control facilities at select places in the country for periodic monitoring of water, energy, gases and salt fluxes. These facilities should be used for designing location specific cropping/farming systems
- Promoting multi-enterprise agriculture to reduce risk and for assured livelihood security in areas prone to weather/climate abrasions. Nearly 50% of the farmers in India cultivate less than one ha land. Integrated farming system is a promising proposition for such small holding
- Improved management of livestock populations including poultry through better management of feeding and livestock housing. Animal sector is the major contributor for methane to the environment.
- Improving the efficiency of energy use in agriculture by using better designed efficient machinery and implements.
- There is a need to develop crop insurance and early warning systems to reduce/negate the impact of climate change and achieving stability in production. There is also a need to develop weather-crop-livestock relationships and weather-crop modelling for forecasting pest infestations.
- There is a strong case to intensify efforts for increasing climate literacy among all stakeholders of agriculture and allied sectors, students, researchers, policy planners, science managers, industry and farmers.

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Socio-Economic Impact of Saline and Sodic Soil Reclamation

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The consequences of degrading land resources due to salinity and sodicity are witnessed at farm level, regional level and national level. At the farm level adverse effects are (i) threat to the sustainability of land resources and (ii) decrease farm production by (a) decline in resource productivity, (b) abandon crop production and (c) cut-back in resource use. Soil salinity and sodicity have direct impact on growth and development of agricultural economy. Studies have shown that the yield and income effects of salt affected soils are quite high. The land degradation severely affects the production of important crops like rice, wheat, cotton, sugarcane, groundnut, etc. At the regional level, consequences are (i) displacement of labour from agriculture, (ii) widen income disparities and (iii) affect the sustainability of secondary and tertiary sectors. At the national level, consequences are (i) decline in agricultural production, (ii) affect gross domestic product, (iii) bring down export potential of important crops and (iv) increase import bill.

The brief description of agro-physical, socio-economical and environmental impact of soil salinity and sodicity are as follows.

Impact on Crop Production

- Various degrees of salinity and sodicity can cause serious and severe decline in soil productivity and crop yields (Table 28.1).
- To overcome reduction in yield farmers increase inputs such as seeds, fertilizers, etc.
- In salt-affected soils, response to any input is low: e.g., crop yield response to fertilizer application is less as salinity is a limiting factor.
- Less possibility for alternative land use: e.g., farmers are forced to cultivate only salt tolerant crops, which might not always be high-income cash crops.
- Salinity and sodicity reduce efficient use of water (i.e. crop yield per unit water) causing reduction in return from capital investment and labour inputs.
- Salt affected soils are more fragile with greater risk and always subjected to other forms of degradation: e.g., salinity and sodicity reduce land green cover and soil becoming subject to other degradation processes such as wind and water erosion.
- In salt-affected soil environment, saline water table can enhance salinity of fresh waters in rivers and other water sources through seepage.
- The rehabilitation programmes require high investment cost in reclamation of salt-affected soils as compared to other types of degraded lands, in general.

Table 28.1. Grain yield of major crops under various environments (t/ha)

Crop	Normal soils	Salt affected soils	Waterlogged soils
Rice	3.99	2.18 (45)	2.30 (42)
Wheat	2.59	1.57 (40)	1.85 (38)
Cotton	1.63	0.61 (63)	0.37 (77)
Sugarcane	63.68	33.02 (48)	24.74 (61)

Figures in parentheses indicate percentage loss over normal soils

Impact on Socio-Economic Conditions

- Abandonment of the land where severe salinity and sodicity degradation occurred which increased the number of landless farmers.
- Low food security due to low food production and supply.
- Reduced labour use efficiency: e.g., reclamation of salt affected soils needs more labour, crop yield declines and input requirement reduces which ultimately would reduce labour use

efficiency in these soils. Reclamation programmes and improved farming systems often involve high costs being capital investment of the Government.

- Lower farm income of resource poor small farmers: e.g., as a consequence of salinity and sodicity farmers are forced to work on land of others or migrate to outside the area in search of other sources of livelihood.

Impact Assessment

The impact of salinity and sodicity can be assessed with the help of Spider diagram based on economic, social and ecological parameters, which is generally used for impact assessment of technologies (Fig. 28.1). It is obvious from the diagram that impact is assessed in five categories - very bad, bad, moderate, good and very good depending on combined score of the impact indicators. The salinity or sodicity impact are usually assessed first before reclamation and again after reclamation when the soils are improved to some extent.

Fig. 28.1. Spider diagram for impact assessment of salinity and sodicity

Impact Indicators		Rating				
		1 Very bad	2 Bad	3 Moderate	4 Good	5 Very good
Economic	Crop yield		* *		@ @	
	Household income		* *		@ @	
	Family labour income		* * *		@ @ @	
Social / Institutional	% of farmers adopting land reclamation technologies without incentives	* * * * * *		@ @ @	@ @ @	
	% of farmers adopting recommended package of practices	* * * *		@ @ @ @		
	Children having technical education	* * * *			@ @ @ @	
	Household decision making		* * * *		@ @ @ @	
Ecological	Soil pH & EC		* *		@ @	
	Soil fertility		* * *		@ @ @	
	Occurrence of crop failure	* *			@ @	

*Initial scoring: **********; Scoring after 3 years: @@@@@@*

Financial Appraisal of Land Reclamation Projects

The financial appraisal of salinity and sodicity management projects is aimed at finding out whether the project is economically viable and able to provide justified return on the investment made on it. The financial feasibility involves detail analysis of the capital requirement for installation of the system, annual operational and maintenance cost of the project and benefits generated by the project. In the land reclamation projects, the initial investment is made once whereas the returns obtained from the project are spread over several years in future.

The financial appraisal of project mainly includes costs and benefits analyses for estimation of economic parameters. The cost-benefit analysis is a decision-making tool for investment choice in respect of total costs and total benefits. It helps in comparing the cost and benefit of alternative technologies. Generally, for the financial feasibility we consider only tangible direct benefits and costs viewing the simplicity of estimation procedure.Nevertheless, all the costs and benefits are difficult to quantify in financial terms because a new technology may have negative and positive side effects on the society. When both direct and indirect benefits and costs are accounted, it is called social cost-benefit analysis.

There are many tools and measures to evaluate the feasibility of the land reclamation technologies. Some important cost-benefit analysis measures are described here:

- Pay Back Period
- Simple Rate of Return
- Net Present Worth
- Present Worth of Benefit-Cost Ratio
- Internal Rate of Return

Pay Back Period (PBP)

The pay back period measures the number 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
E = Annual net earning (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 projects. 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
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 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 cannot 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. 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 also 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. General formula used for estimation of NWP is as follows:

$$NPW = \sum_{t=1}^{n} \frac{Bt - Ct}{(1+i)^t}$$

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
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. In other words, it is return to one rupee invested on the project. The BCR can be calculated with the help of the following formula:

$$BCR = \frac{\sum_{t=1}^{n} \frac{Bt}{(1+i)^t}}{\sum_{t=1}^{n} \frac{Ct}{(1+i)^t}}$$

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. When the internal rate of return is used in economic analysis, it is called internal economic rate of return (ERR) whereas in 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 find the differences between discounted benefits and costs. The IRR calculation is just reverse of the procedure we adopt for 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 IRR can be expressed in algebraic form as:

$$IRR = \sum_{t=1}^{n} \frac{Bt - Ct}{(1+i)^t} = 0$$

Choose a discount rate (lower rate), which will give a positive NPW. If in the first step, NPW is positive one 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:

$$IRR = \text{Lower discount rate} + \text{Difference between the two discount rates} \times \frac{\text{NPW at lower discount rate}}{\text{Difference between NPW's at the two discount rates}}$$

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).

Socio-Economic Benefits of the Reclamation

There are numbers of socio-economic and environmental benefits of the sodic land reclamation. The sodic land reclamation has direct influence on poverty and livelihood of the rural poor. The impact of sodic land reclamation is quite visible in terms of additional food production, employment, farm income, resource-use, farm assets, capital formation, land value, soil health and quality of life and environment. It helps in eliminating poverty and inequity amongst the rural society. The social impact can also be seen as increased literacy level, declined birth and death rates and high life expectancy of the affected people. The major socio- environmental impacts of sodic land reclamation are discussed in the following paragraphs.

Food Production

A rapid increase in food grains production was witnessed in the northern states of India during sixties and seventies mainly due to introduction of high yielding verities of rice and wheat, on one hand and acreage expansion under these crops through crop diversification and by reclamation of sodic lands, on the other. The additional annual production of rice and wheat on sodic lands after reclamation is estimated to be 5 and 3 t/ha, respectively, after 3rd year of reclamation under farmer's resource endowment. It is reported that the sodic land reclamation has contributed 27% to the total increase in rice and wheat production in Punjab, 14% in Haryana and 12% in Uttar Pradesh. It clearly highlights the importance of sodic land reclamation in food grains production of the country (Table 28.2).

Table 28.2. Yield obtained in reclaimed sodic land during first 3 years of reclamation

Reclamation year	Rice yield (t/ha)	Wheat yield (t/ha)	Total yield (t/ha)
1st year	4.0	2.0	6.0
2nd year	5.0	2.5	7.5
3rd year	5.0	3.0	8.0

Employment Generation

One of the important benefits from the sodic land reclamation is employment opportunity to the marginal farmers and landless labourers in rural sector. Roughly 165 man-days/ha employment is generated in the first year of reclamation. The employment potential through reclamation of sodic lands is estimated to 30 man-days/ha in bunding, levelling and gypsum application and 94 and 41 days/ha in rice and wheat cultivation, respectively. In subsequent years, nearly 135 man-days/ha would be employed for rice-wheat cropping system at farmer's field. The potential and achieved labour employment due to reclamation of sodic land in Haryana farming situation is shown in Table 28.3. The total employment potential in the 1st year of reclamation at full-fledged level of technology is estimated to 214 man-days/ha whereas 160 man-days/ha employment could be generated during the subsequent years in areas with high degree of mechanization of agricultural operations. It ranges between 207 and 237 man-days/ha in areas with low degree of mechanization as in Uttar Pradesh. The rough estimates revealed that reclamation of alkali lands is annually generating jobs for about 181,000 farmers and landless labourers in Punjab and Haryana whereas nearly 78,000 people are getting employment per annum in Uttar Pradesh because of sodic land reclamation. In case of afforestation of alkali lands, roughly 213 man-days/ha employment can be generated in the form of initial establishment work. It is indeed encouraging that the land once characterized as barren and lying uncultivated because of sodicity would generate remarkable productive employment after reclamation.

Table 28.3. Potential and achieved labour employment due to reclamation of sodic land

Particulars	Estimated man-days ha^{-1})	
	Potential at full-fledged level of technology	Achieved at farmer's field
Labour demand for reclamation	54	30
Labour demand for rice cultivation	99	94
Labour demand for wheat cultivation	61	41
Toal employment in 1st year	214	165
Employment in subsequent years	160	135

Family Income

The progressive improvement of salt affected lands has contributed significantly to the agricultural development. Among the multiple benefits of land reclamation, one of the important social benefits is a continuous income generation and war against poverty in rural areas. It has been reported in a sample survey that before adopting the reclamation technology, the bottom 50% farmers had only 30% share of the total income, which rose to 36% after land reclamation. It indicates the fact that dissemination of such programmes in a state like Uttar Pradesh is important for raising income and purchasing power of the rural poor who own salt affected lands and lives in abject poverty. Post-project changes triggered significant increase in family income. Annual household income of erstwhile landless households (now marginal farmers) increased more than 100%. Income from reclaimed land constitutes about 44% of incremental income for those households who did not have access to a productive land before reclamation. Due to project intervention, barren lands have come under double crop from no-crop level. The erstwhile landless labourers are enable to earn on an average Rs 17,600 per annum from their own land because of sodic land reclamation programme. Their non-farm income confined mostly to wages, which has also gone up due to combined effect of rise in employment days and wage rate. The impact studies showed that after the land reclamation, sizable growth has been noticed in many agro-based and auxiliary industries such as poultry, dairying, farm machinery workshops, etc. these rural industries are providing a good amount of income to those who are associated with these units directly or indirectly.

Farm Assets and Capital Formation

The farm assets and capital formation increased remarkably even on partial adoption of the reclamation technology. The studies show that farm assets and gross capital formation at different levels of technology adoption in Haryana are quite encouraging (Table 28.4). The total capital formation on technology adopter farms, on an average, was Rs 4,71,000 per farm, out of which 48% was on farm building, 28% on farm machinery, 14% on irrigation structures and rest on livestock. The gross capital formation showed an increasing trend with increase in the level of technology adoption. The farm machinery got maximum emphasis at high-level technology adoption.

Table 28.4. Capital formation at different levels of reclamation on selected farms of Haryana

Technology Levels (Based on gypsum use)	Gross capital (Rs. /farm)	Percentage of total capital			
		Building	Machinery	Irrigation	Livestock
Very low (<5.75 t/ha)	3,52,000	49	25	15	11
Low (5.75-9.50 t/ha)	4,73,000	47	28	15	10
Medium (9.5-13.25 t/ha)	4,94,000	47	28	14	11
High (>13.25 t/ha)	5,03,000	48	31	13	08
Overall average	4,71,000	48	28	14	10

Resource Use

The use of input resources increased tremendously in the sodic lands after reclamation. The time series analysis showed that the use of all the crucial farm inputs such as labour, machine, irrigation, fertilizers, etc. increased significantly (Table 28.5). The consumption of nitrogenous fertilizer increased between 77 to 88%, irrigation hours 88% in rice and 12% in wheat cultivation after land reclamation. Machine power increased between 92 to 117% whereas human labour use rose to 19% in rice cultivation. It could be attributed to anticipated higher productivity and profitability of the crops despite high input costs in the later period. Farm production and profitability of the crops could be increased further through reallocation of the resources particularly fertilizer and machine use in rice and wheat crops.

Table 28.5. Changes in resource use on rice and wheat after sodic land reclamation (per ha)

Input resources	Rice		Wheat	
	Initial reclamation stage	After 5 years of reclamation	Initial reclamation stage	After 5 years of reclamation
Labour (days)	69	82	45	44
Machine (hours)	6	13	12	23
Irrigation (hours)	101	190	67	75
Nitrogen (kg)	64	113	52	98
Zinc (kg)	-	24	-	4

Land Value

The value of land is a symbol of prestige in the society to the owner, decides credit worthiness of the farmer and plays an important role in decision making processes at the farm. The reclamation of sodic lands substantially increased the value of the land due to increased production potential. It is estimated that the average value of sodic land increased from Rs. 10,000 to Rs 2,00,000/ha depending on the location and availability of infrastructure in and around the area. The U.P. Sodic Lands Reclamation Project showed tremendous increment in value of land over a period of 7 years. The value of B+ class land increased from Rs. 1,15,000/ha before reclamation to Rs. 1,70,00/ha after reclamation whereas value of B and C class lands increased from Rs. 55,000 and Rs 30,000/ha to Rs 1,55,000 and Rs. 1,25,00/ha after reclamation, respectively. It showed that value of reclaimed land has gone up by about 48% in case of B+ class land, 108% in B class and 317% in C class land.

Poverty Alleviation

The sodic land reclamation programme provides unique opportunity to the rural people for alleviation of poverty, particularly for marginal and small farmers, who are bound to struggle for their livelihood. Project intervention in Uttar Pradesh resulted in decline of participant households below poverty line from 80% to 55% during a short period of 7 years (Table 28.6). Thus, the sodic land reclamation programme proved exemplary model for poverty alleviation in the sodicity-affected areas.

Table 28.6. Status of households before and after sodic land reclamation

Households	Pre – project status	Post – project status
	Below poverty line (%)	Above poverty line (%)
Landless labourers	88	76
Marginal farmers	84	67
Small farmers	72	33
Large farmers	69	26
Overall average	80	55

Adopted from U.P. Sodic Lands Reclamation Project

Quality of Life and Literacy

The interventions through land reclamation have positive impact on household economy and quality of life of the beneficiaries. The literacy improved remarkably over the years in the areas where sodic land reclamation took place. The male literacy was invariably more than female literacy in the project area irrespective of the category of households. The project provided maximum benefits to schedule costs and erstwhile landless labourers. Male literacy improved by 7% and female literacy by 9%. It is attributed to the increased awareness among people about education. The number of children enrolled at school registered remarkable increase as compared to the number registered before reclamation. These facts reflect impact of land reclamation on various important aspects of daily life and decision-making capabilities of the rural people, which have direct positive correlation with the standard of living.

Empowering Women Folk

The sodic land reclamation contributes to women empowerment through Woman Self Help Groups (WSHGs). It provides a boost to the socio-economic upliftment of women. Women in rural areas, who don't have savings earlier, have their own savings after getting reclaimed their problematic lands. Besides, the groups are helpful in enabling their members to support the agriculture and allied activities by the way of micro financing. It is obvious from these facts that the sodic land reclamation has strong and favourable correlation with the women empowerment.

Environmental Impact

The important social impact of the sodic land reclamation is improved quality of environment. Utilization of rainwater by reducing surface runoff and soil erosion during rainy season are the brighter aspect of reclamation as about 40% of the total irrigation requirement of the newly reclaimed areas of rice and wheat is met from the rainwater conservation. It is ultimately resulting to increase in ground water recharge and improvement in the soil quality. It further helps in controlling flood hazards by reducing peak runoff during the heavy rainstorms. Thus by adoption of the sodic land reclamation technology, the flood hazards minimize, recharge to ground water increases and waterlogging reduces. The combined effect of all these are resulting to considerable environmental improvement in the area. There has been reduced incidence of malaria, filaria and other water borne diseases to a large extent. Another important environmental benefit is the change in landscape after reclamation of unproductive barren, undulated and unmanaged lands. The properly managed soil, water, road, path, vegetation and landscape improve the overall microclimate of the area.

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Physiological Mechanisms of Tolerance to Salinity and Sodicity Stresses

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Salinity and sodicity stresses are ever-present threats to crop yields, especially in countries where irrigation is an essential aid to agriculture. Plants growing under saline and sodic environment are invariably faced with the increased concentrations of toxic ions in their tissues resulting from increased uptake of ions mainly Na and Cl under salinity, and Na under sodicity. Although the tolerance of saline conditions by plants is variable, crop species are generally intolerant of one-third of the concentration of salts found in seawater. Salt tolerance is complex genetically and physiologically with glycophytes and halophytes and relatively less tolerant crop plants showing a wide range of adaptations.

Glycophytes and Halophytes

Majority of plants are unable to tolerate saline and sodic conditions permanently. Depending upon their response to these stresses, plants have been 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 may be 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. Almost all the crop species are glycophytes. Glycophytes have a selective advantage in non-saline soils over halophytes, because their growth rates are generally faster. The level of salinity, nature of salt responsible for salinization also has an important role to play in the growth and development of plants.

Effect of Salinity on Plants

Salts in the soil water may inhibit plant growth for the three reasons. First, the presence of salt in the soil solution reduces the ability of the plant to take up water, and this leads to reduction in the growth rate. This is referred to as the osmotic or water-deficit effect of salinity. Second, if the excessive amounts of salt enter the plant in the transpiration stream there will be injury to cells in the transpiring leaves and this may cause further reductions in growth. This is called the salt-specific or ion-toxicity effect of salinity (Greenway and Munns, 1980, Sharma and Gupta, 1986). Thirdly, it could be due to nutritional imbalance that may be caused by selective higher uptake of few elements while there may be depressed uptake of the others. Since the ions that are nutritionally important, affected in this way, this effect is usually described as nutritional imbalance effect. As salinity is often caused by rising water tables, it can be accompanied by waterlogging. Waterlogging itself inhibits plant growth and also reduces the ability of the roots to exclude salt, thus increasing the uptake rate of salt and its accumulation in shoots. The definition of salt tolerance is usually the percent 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.

Variability in Salinity and Sodicity Tolerance in Crops and Species

The criterion of relative yield in saline and non-saline conditions has been widely used to describe salt tolerance or relative salt tolerance of crops. Evaluation of salt tolerance of crops, vegetables and fruit trees have been made by the US Salinity Laboratory (Fig. 30.1) and Central Soil Salinity Research Institute, Karnal. If 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, windspeed, etc.) and the water-supplying potential of the rootzone, and increases as salinity increases until the plant dies. The curve in Fig. 30.1 shows that the salt tolerances of various crops could be 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) as follows:

$$Y_r = 100 - b\,(EC_e - a) \qquad (29.1)$$

where Y_r is the percentage of the yield of the 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 the osmotic potential of the soil.

Cultivated crops can be categorized into sensitive, moderately-tolerant and tolerant species according to their specific salt tolerance (Fig. 29.1) 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. 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 slightly in saline environments.

Within crop species great variation exists regarding their ability to grow and yield under salinity or sodicity in soil and poor quality waters. Even within a crop, different varieties or cultivars may differ widely in their tolerance to salinity or sodicity stress. Crop species like lentil, moong, gram and other pulses are very sensitive to these stresses. Their growth is affected even at soil salinity of EC 4 dS/m 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.

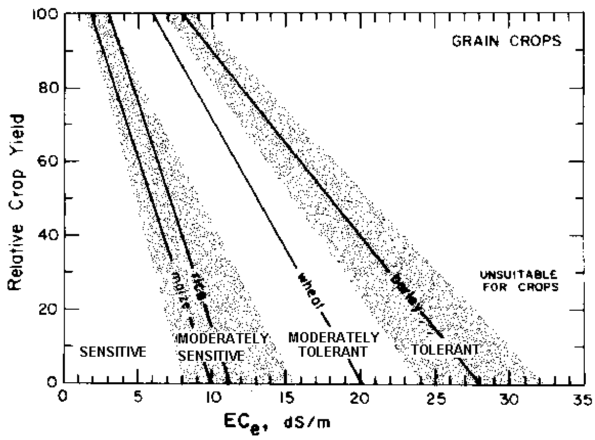

Fig. 29.1. Salt tolerance of grain crops
(Source: Maas and Hoffman, 1977)

Assessment of Tolerance

Evaluating field performance of crops under saline conditions is notoriously difficult because of the variability of salinity within fields and the 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 the salinity of the medium can be readily adjusted to required values (Maas and Hoffmann, 1977). Estimates of tolerance obtained from such experiments may not always be borne out by the response of plants in the field. Evaluating tolerance is made more complex by variation in sensitivity to salt during the life cycle. In tomato, for example, tolerance at germination is not correlated with the ability to grow under salt stress: both are controlled by different mechanisms, although some genotypes have similar tolerance at germination and during vegetative growth. The example suggests 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 exercized 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, intraspecific variation in tolerance is also associated with variation in a wide variety of physiological traits.

Causes of the Growth Reduction under Saline Conditions

The effects of a saline soil are two-fold: there are effects of the salt outside the roots, and there are effects of the salt taken up by plants.

The salt in the soil solution (the "osmotic stress") reduces leaf growth and to a lesser extent root growth, and decreases stomatal conductance and thereby photosynthesis (Munns, 1993). The rate at which new leaves are produced depends largely on the water potential of the soil solution, in the same way as for a drought-stressed plant. Salts themselves do not build-up in the growing tissues at concentrations that inhibit growth: meristematic tissues are fed largely by the 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 the growth of new leaves.

The 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 the 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 photosynthesising 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 the necessary photosynthate. For perennial species, there is an opportunity to enter a state of dormancy, and thus survive the stress.

The 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. The two-phase growth response is illustrated in Fig. 29.2. The experiment was conducted with two genotypes with contrasting rates of Na^+ uptake, and known differences in salt tolerance. Fig. 29.2 shows that during the first 3-4 weeks after the soil was salinised, there was a large growth reduction in both genotypes. This is called the 'Phase 1' response, and is due to the osmotic effect of the salt. Then after 4 weeks, the genotypes separated; the one with the low Na^+ uptake rate continued to grow, although still at a reduced rate compared to the controls in non-saline solution, but the one with the high Na^+ uptake rate produced little biomass and many individuals died. This is the 'Phase 2' response, and is due to genotypic differences in coping with the Na^+ or Cl^- ions in the soil, as distinct from the osmotic stress.

Physiological Mechanisms of Plant Injury 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 and 'physiological drought
- Injury to cell membranes
- Na^+-K^+ selectivity
- Ca^{2+}- Na^+ selectivity, transport and leakage, osmotic adjustment through solute accumulation in the symplast
- Salt accumulation in the apoplast (cell wall) resulting in cell dehydration
- Damage to developed tissue, resulting in decreased photosynthetic surface and lack of sufficient metabolites for growing tissue
- The cost of osmotic adjustment, compartmentation and exclusion
- Hormonal balance in the plant and
- Nutrient deficiencies, especially N and K

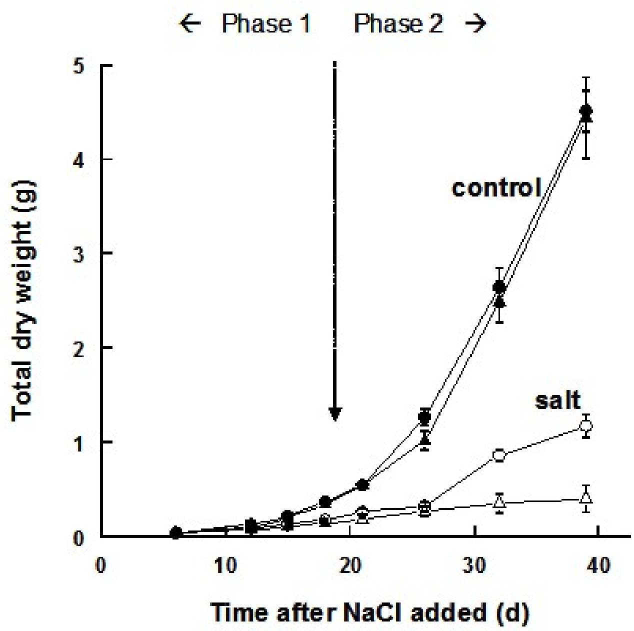

Fig. 29.2. Two accessions of the diploid wheat progenitor *Ae. tauschii* grown in hydroponics in control solution (closed symbols) and in 150 mM NaCl (open symbols). Circles denote the tolerant accession, triangles the sensitive one. The arrow marks the time at which symptoms of salt injury could be seen on the sensitive accession; at that time the proportion of dead leaves was 10% for the sensitive and 1% for the tolerant accession (Source: Munns *et al.*, 1995)

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. The concentration of salts is higher in the sensitive crops than the resistant ones. In chickpea, salt tolerance depends upon exclusion of Na^+ and Cl^- from the 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 in the top than Cl and was more in the shoots of sensitive than the resistant genotype (Sharma, 1996) indicating that the concentrations of Na^+ and Cl^- determine their relative salt resistance. It is also true about a number of other crops like rice, wheat, barley and many other crops. There is a lot of evidence correlating reduced Na with salt tolerance (Greenway and Munns, 1980; Jeschke, 1984; Schachtman *et al.,* 1991; Sharma, 1996).

In wheat, ion exclusion preferentially maintained lower Na^+ and Cl^- levels in the apical tissue, as the leaf to leaf gradient in Na^+ and Cl^- became steeper as the external salinity increased, although there were significant differences between sensitive and tolerant cultivars (Sharma, 1996). Correlation analysis on individual plants indicated that excluding Na^+ at low salinity, and Na^+ and Cl^- at high salinity, were correlated significantly with growth performance, although it was clear that some other factors were also involved.

Although it is difficult to distinguish clearly whether the toxic effects are due to Na^+ or Cl^-, the data for chickpea indicated that injury was more due to Cl^- than Na^+. Chloride accumulation increased with longer duration of salt exposure as evidenced by the increased concentrations of Na^+ and Cl^- at the second and third sampling stages in the older plants. Decreasing rates of plant growth and increasing concentrations of ions with prolonged exposure to salinity suggested the failure of plants 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^+. Only a small number of experiments have attempted to determine the direct toxicity of Cl^-, and their interpretation is not straightforward.

There is sufficient evidence to be confident that salt tolerance is a multi-genic trait. Research on the physiology of salt tolerance also suggests that the overall trait is determined by a number of sub-traits any of which might, in turn, be determined by any number of genes. These sub-traits generally include an ability to minimize the net accumulation of sodium and/or chloride ions and to select potassium from a background of high sodium concentration.

Plant Injury under Salt and Water Stress

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. The impact on yield depends on the timing, speed of onset, intensity and duration of the stress and stage of the crop. These deleterious effects may cause 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). 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 29.1). Plants may suffer severe injury and mortality if the stress is of a higher level. 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.

Table 29.1. Changes in plant fresh, dry weights, leaf diffusive resistance (LDR), transpiration rates and leaf water potential (LWP) of third fully expanded leave

Days after salinization	Fresh weight (g)	Dry weight (g)	LDR (s/cm)	Transpiration (g/cm²/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

Long -term Growth Responses: In the longer- term, being weeks for a short-lived annual to months or years for 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. 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 (Greenway and Munns, 1980) or at least partly from an exclusion of specific ions from the xylem vessels supplying the 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. The concentrations at which this occurs will depend upon the ability of the species to compartment the salts in the vacuole, and the time it takes to happen will depend mainly on the salinity level, the ability of the roots to exclude the salt, and the ambient conditions affecting the 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.

These processes are not mutually exclusive, and may act separately or combined. Some may operate over a short term and others over a long term. Some play a more important role on certain crops, some on others.

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.

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Radiation Induced Salinity Tolerance in Crops

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The pioneering discoveries by Roentgen of X-rays in 1895; Beaquerel's discovery of radioactivity in 1896; and Marie and Pierre Curie's of radiaoactive elements in 1898 led eneventually to the report in the 1920's of the effects of radiation on genes. Discovery of induced mutations in fruit fly Drosophila melanogaster in 1927 and in barley (Stadler, 1930) by X-rays initiated a new area of induced mutagenesis as a tool in crop improvement strategies. Soon after this discovery many plant breeders started investigating the use of radiation induced mutations for changing different characters in plant architecture. During the past 75 years, more than 2500 varieties have been officially released as listed in the IAEA/FAO mutant varieties database, including 534 rice lines, 205 wheat lines and 71 maize lines (http://www-infocris.iaea.org/MVD/). Of these, 60% were released from 1985 onwards. Mutant varieties have been released in more than 50 countries. Top six countries in which most mutant varieties were released are China (27%), India (12%), USSR and Russia (10%), Netherlands (8%), USA (6%) and Japan (5%). From these officially released varieties, approximately 70% are in agricultural crops and remaining mutant varieties in ornamental and decorative plants including mutants of Chrysanthemum, dahlia etc. Since the effects of mutations on ornamental plants are clearly visible and selection for altered flower colour, shape or size is relatively easy, the application of mutation techniques in the breeding of these crops has a high success rate.

Conventional Mutagenesis of Seed Propagated Crops

Seeds are the most commonly used materials for induced mutation. Mutagenic treatments fall into two main classes: physical (ionizing radiation, UV) and chemical (mostly alkylating agents). Fig. 30.1 gives a general scheme for conventional mutagenesis. Once seed of a parental line has been treated with a mutagen, it is referred to as M0 seed and on germination produces M1 plant. Some rare dominant mutants can be detected among the M1 population, but since M1 plants exhibit chimeras and physiological disorders (as a carryover from the mutagenic treatment) selection is not normally practiced until later generations. Since plant selections can be made in M2 population for the most obvious phenotypic mutants, but more subtle quantitative effects are best screened at M3 and validated in subsequent generations. Once a mutant has been selected, it is normally multiplied from a single source and tested for homozygosity. Since mutant traits of interest to plant breeders are quantitative (e.g. yield, quality, stress tolerance), the process of mutation detection and evaluation is time consuming, upto four generations can elapse before mutant lines are entered into crossing programmes.

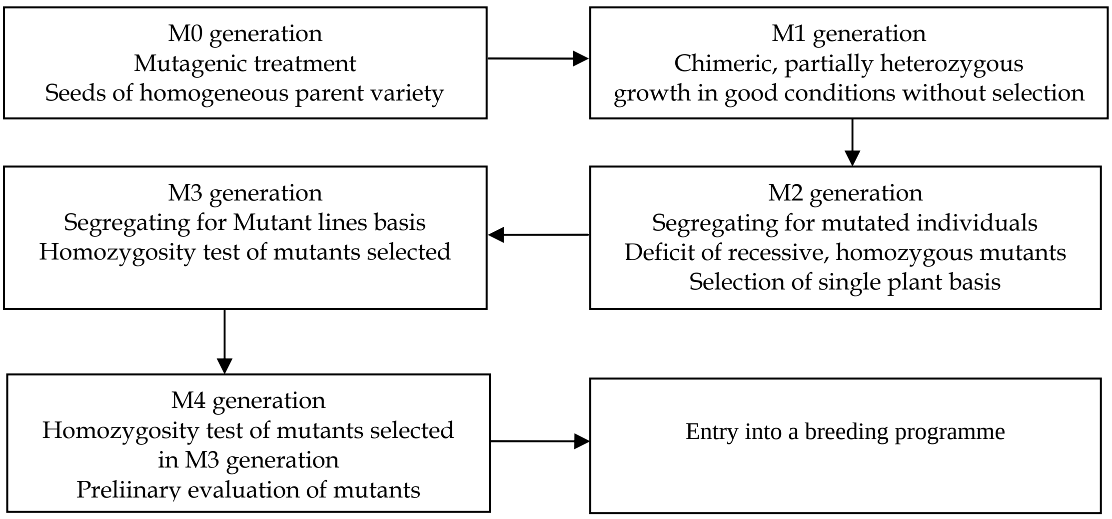

Fig. 30.1. Development of mutant lines using conventional mutagenesis

General Procedures for Using Induced Mutations

The general procedures for using induced mutations are rather simple and have a strong basis in the laws of genetics. Dormant seeds of the so called parent variety are irradiated or treated with a chemical mutagen. Mutagenic treatments can cause chromosomal rearrangements or change some genes to some other allelic forms. Plants grown from mutagenised seeds are called M1 plants. When a multicellular tissue like the seed embryo is treated with a mutagen, the plant developing from treated seed has a chimeric structure from genetic point of view. After meiosis, the seeds developed on M1 plants are already the M2 generation. The seeds are sown in experimental plots and a segregating M2 population is subjected to various screening procedures for desired characters. Screening for quantitatively inherited characters is usually done in M3 generation where selection on a line, rather than on a single plant basis can be initiated. Selected mutants from the M2 or M3 generation are usually checked by homozygosity in the M3 or M4 generations respectively. Promising homozygotic mutants can be used directly for multiplication, this will lead to the development of so called direct mutant variety (e.g. barley cv. Diamant in CSSR; rice cv. Calrose 76 in USA) or they can be used in a cross breeding programme (e.g. linseed mutants M1589 and M1722).

Procedure for Optimally Inducing Mutations in Rice

- Select disease free seeds with uniform size and shape. Viable seeds with high germination rates must be used.
- Choose a wide range of the concentration of the chemical for use in the induction treatments with varying time durations in order to determine the optimum concentration-by-time for mutation induction. A minimum of three hours duration is usually required for EMS treatments.
- Use 40-50 seeds per treatment with a minimum of three replications
- Put the seeds in a polyethylene mesh bag, fold the bag and hold in place with plastic clip.
- Label the bag appropriately (e.g. indicating the variety name, date and treatments carried out)
- A control, i.e. non-treated with EMS should be included.
- EMS is carcinogenic. It should be labeled properly as carcinogen.
- Wear gloves during the above procedures.
- Use disposable pipette and balloon for pipetting.
- Work should be done in confined area and under hood. If hood is not available, use face mask.
- Dispose off the unused EMS solution and all the liquid waste by adding 4% NaOH and excess water.

Current Status and Significant Achievements

In the group of crop species, around 70% of the varieties have been released as direct mutant varieties and rest 30% were obtained from crosses with mutated parents (Maluszynski *et al*., 2000). Among the agricultural crops, mutant varieties involving cereals dominate with 64%. Rice is in the first place (25%) followed by barley, wheat, maize, durum wheat and others (oat, millet, sorghum, raya etc.). Most of the rice mutant varieties were released as direct mutants means direct seed multiplication from selected mutants. Nevertheless some mutants such as 'Reimei' (Japan) and 'Calrose 76' (USA) were successfully used in extensive cross breeding prgrammes. Semi dwarfness and earliness were the often selected characters in treated populations. On the list of improved characters are also traits desired for increasing sustainability in rice production, such as cold and salt tolerance or photoperiod insensitivity. In rice, as in other crops, radiation was more often used to generate desirable traits (190 varieties) while some (923) were induced by chemical mutagenesis. Some mutant varieties have high economic impact. Rutger (1992) discussed that 11 mutant rice varieties were grown on an annual area of over one lakh hectares each. Among them are the Chinese varieties Zhefu 802 and Yuanfengzao on more than one million hectares. The successful development and release of cotton variety NIAB 78 in Pakistanin 1983 is another example. It was developed by crossing a US and a local variety by irradiating with gamma rays, which led to doubling of the production of cotton in Pakistan. In central European country, malting barley is an important crop. It is generally grown on more than 25% of cereal acreage. Dry seeds of variety Valticky were irradiated with 10 Kr of X rays. Selection for improved characters was initiated in M2 generation. A selected mutant designated as X2-228 became the progenitor of new variety 'Diamant' released in 1965. The mutant differed from the parent variety 'Valticky', a relatively tall variety (92 cm) which is highly susceptible to lodging under increased levels of nitrogen fertilizer in such important agronomic traits as reduction of culm length (15 cm), resistance to lodging, semi-prostate growth habit, higher tillering ability, 12% increase in grain yield. It also showed slow initial development. This character lead to prolonged period of organogenesis during tillering and as a consequence, to a greater number of spike bearing tillers. Resistance to lodging and high tillering resulted in substantially increased productivity of the mutant. Later more than 85 varieties developed from the mutant 'Diamant' were released in various European countries.

The Case of Golden Promise

Mutant cultivars or mutant lines have usually been investigated only for a character or characters directly related to solving a particular breeding program. Mutants kept in collections are very seldom investigated for other characters not related to an already described mutated trait. This was the case in rice mutant variety 'Atomita 2' released in Indonesia in 1983, selected for earliness and brown plant hopper resistance and later discovered to carry a mutated gene for slat tolerance in Vietnam.

'Golden Promise' is a direct mutant variety developed by gamma ray treatment of the barley cultivar Maythorpe' in UK in 1966. This variety was extremely important in UK barley industry, and dominated the Scottish barley acreage in 1970's to mid 1980's. It is still a standard for malt quality in Scotland. Mutated genes from 'Golden Promise' were transferred to other genetic backgrounds, leading to the release of 17 other barley mutant cultivars in UK. In salt tolerance tests at Scottish Crop Research Institute, a significant difference (50%) has been detected between shoot Na accumulation of 'Golden Promise' plants and its parent variety 'Maythorpe' under slat stress conditions. The results imply that the mutational difference between a mutant variety and its parent is also responsible for increased tolerance to salt.

Mutational Analysis of the *Arabidopsis* Genome

In barley, maize, pea and tomato, large mutant germplasm collections have been established and used for genetic analysis and plant breeding. Recently, due to intensive mutation efforts, *Arabidopsis* has become, most probably, the genus with the highest number of induced mutants. *Arabidopsis* mutants have been characterized as mutations affecting basic metabolism and been obtained following seed treatment with EMS. Chemical and physical mutagens have also been widely used to induce mutations in this model plant. Using EMS mutagenesis, oil composition was genetically modified by increasing oleic acid content from 15 to 86% with parallel reduction in linoleic acid from 18 to below 2%. The use of shuttle mutagenesis in crop improvement with induced mutations in *Arabidopsis* was also demonstrated, where, genes for herbicide resistance obtained through microspore mutagenesis in *Brassica napus*, have been cloned and transferred into canola and tobacco to elevate levels of herbicide tolerance. Many studies have demonstrated that the steps leading to successful gene transfer such as gene identification, characterization and cloning and to gene expression in transgenic plants can be more easily achieved in this model plant *Arabidopsis*.

Mutation Techniques Crop Improvement Programmes

Generation of Desired Variability: Exploiting natural or induced genetic diversity is a proven strategy in the improvement of all major food crops, and the use of mutagenesis to create novel variation is particularly valuable in those crops with restricted genetic variability. Historically the use of mutagenesis in breeding has involved forward genetic screens and the selection of individual mutants with improved traits and their incorporation into breeding programmes. Although this approach has clearly proved very successful, there are limitations imposed by, for example, the difficulty of identifying a small number of individuals with novel phenotypes within a large population, or by the genetic redundancy present in many plant species as a result of gene duplication and polyploidy, such that many mutations have no detectable effect on the plant. Recently, reverse genetic approaches have permitted the silencing or interruption of individual candidate genes. Whilst mutations occur spontaneously in nature, the frequency of such mutations is too low to rely on alone for accelerated plant breeding. The degree of mutation is dependent on the tissue and degree of exposure (dosage×time). Mutations at single nucleotide pairs are generally of the most interest to breeders because large-scale changes to chromosome structures usually have severely negative results. However, the use of mutagens that alter chromosome structure to increase the number of recombination events and break undesirable linkages is also extremely valuable. Critically, mutations in important traits or genes (e.g. in nutritional quality, resource use efficiency, architecture or phenology) can be readily exploited by plant breeders without the legislative restrictions, licensing costs, and societal opposition applied to GM approaches. This is despite the fact that transcriptomic analyses have shown that large-scale plant mutagenesis may induce greater changes in gene expression patterns than transgene insertion (Batista *et al.*, 2008).

The creation of mutagenized populations forms the foundations of the reverse genetic approaches, although collections of accessions containing natural polymorphisms can also be used. To ensure that any gene of interest carries sufficient significant mutations, the populations of induced mutations may need to be very large; the size required is dependent on the dosage of mutagen and the level of gene duplication created by recent or ancient polyploidization events. Mutant populations have now been created for many cereal crops, including rice (Suzuki *et al.*, 2008), maize (Till *et al.*, 2004), sorghum (Xin *et al.*, 2008), barley and both hexaploid bread wheat (Slade *et al.*, 2005) and durum wheat, mostly created by treating seeds or pollen with chemical mutagens. To increase the efficiency of mutation detection it is advisable to optimize mutagen dose to achieve a high mutation rate while avoiding serious effects on germination and plant development. In diploid species this can be difficult as even relatively low levels of mutation can result in the almost complete loss of male or female fertility, resulting in a need for very large populations if saturated coverage is required. By contrast, polyploid species such as wheat have a very high tolerance of mutations due to the complementation of essential genes by homeologous copies and thus populations saturated with mutations can be much smaller, resulting in more cost-effective screening for mutations. However, a consequence of this genetic buffering is that recessive mutations in single homeologues of genes in polyploid species are less likely to show a phenotype, and it becomes necessary to identify mutations in each homeologous copy of the target gene and bring these together by crossing. The choice of chemical mutagen will also influence the maximum permissible mutation rate achievable: EMS creates a larger proportion of non-sense mutations, involving the introduction of novel stop codons, than a mutagen such as MNU, due to the specificity of EMS in creating mainly G–A and C–T transitions, and any individual mutations is therefore more likely to have a phenotypic effect. This may partly explain the high mutation frequency achieved in rice using MNU, although the mutation rate in this population was also enhanced by the selection of M1 plants with reduced fertility, which had previously been shown to be associated with higher rates of visible phenotypes in the M2.

Use of *i- vitro* Haploid Technology: The mutant production cycle can be significantly shortened by the application of doubled haploid (DH) techniques. Beversdorf and Kott (1987) developed a mutagenesis and *in vitro* selection system using microspore cultures in rapeseed. This system involved gamma rays or chemical mutagen treatment of uninucleate, potentially embryogenic microspores followed by a selection of developing embryo like structures or plantlets on a medium with a selecting factor (Swanson *et al.*, 1989). Further, in barley, anther culture, bulbosum method or microspore culture can be used for rapid production of true to type mutants. The use of a mutagen in various *in vitro* systems usually significantly decreases their regeneration ability. Using a M1 plant as a donor of anthers or microspores for production of DH, almost all problems relating to the somatic effects of mutagen on tissue could be avoided. In the DH2 generation from mutated barley plants, more than 25% of true to type mutants were observed, among them with some mutants with useful characters such as semi dwarfness or uniculm plant type.

Mutation Techniques in Heterosis: It is well known that radiation and chemical mutagenesis can induce male sterility in plants (Rutger 1992). Chaudhary *et al.*, (1994) have clearly demonstrated the potential of mutagenesis for induction of male sterile mutants. A large M2 population (more than 2 lakh seeds) of *Arabidopsis* was developed from EMS mutagenized seeds and screened for male sterile plants. Nineteen putative mutants were selected. Among the few of them genetically analyzed, 4 non-allelic mutants with different blocks of pollen development were found. It is important to note that in these mutants the vegetative growth and female fertility was not altered. The mutant heterosis has also been confirmed in maize and barley.

***In-vitro* Culture, Mutagenesis and Somaclonal Variation:** The technique of mutation induction and in vitro culture seem to be ideally suited for the improvement of vegetatively propagated plants. Food crops, such as cassava, banana, sweet potato, potato and sugarcane are vegetatively propagated and are a staple diet in many countries. Large number of plants can't be used for mutagenesis due to the large size of conventional propagule, hence *in-vitro* culture is used for mutagenesis. This also provides relatively uniform and large population of cells and tissues in disease free situations for irradiation. It can be achieved by successive culture of buds or regeneration of shoots and somatic embryos from cell suspension and callus cultures derived from irradiated tissues and explants. Irradiation in combination with *in-vitro* culture has proved to be a valuable method of producing desired variation and rapid propagation.

Both somaclonal variation and mutations result in the production of new genotypes with a limited change in the original genome. As a source of variation, somaclonal variation mimics induced mutations. Somaclonal variation has been associated with changes in chromosome number and structure, point mutations, DNA methylation, changes in cytoplasm and plastids, activation of transposons etc. For selection of mutagenised cells or tissues, selection pressure can be applied either at the cell population level or on the plant regenerated from cell cultures and followed by selection in conventional field plots. The potential high efficiency of *in-vitro* selection system is based on the fact that it is possible to grow millions of cells in a petri dish or in a flask and achieve rapid multiplication of cell populations on a defined media. Addition of sodium chloride, fungal toxin, herbicides, antibiotics to the medium or exposure of cell to heat, cold and freezing is used for selection of desired variants. While a great number of radiation induced mutants have been released as new cultivars, somclonal variants have been so far of limited value in plant improvement. Both somaclonal variation and conventional mutagenesis are complementary to and not a replacement for conventional plant breeding.

Use of Mutations for Enhancing Salinity Tolerance: Salinity is a major environmental stress limiting plant growth and productivity. Further salt tolerance is known to e multigenic character controlled by large number of genes. Accordingly, it is often concluded that mutation induction has no role to play in enhancing salinity tolerance of crop plants. However, examples from literature reveals otherwise. Both gain of function as well as loss of function has been reported in different crops with respect to salinity tolerance. Examples of rice and Indian mustard are discussed here. Lee *et al*., (2003) have reported radiation induced salinity tolerant lines in rice. Many scientists have followed the approach of inducing mutations in cells or tissues and then selecting for salinity tolerant lines.

Rice: Rice is a major staple food and is consumed by more than half of the world's population. Rice is sensitive to salinity (Mass and Hoffman, 1977), hence salinity tolerant lines are urgently required. Success in obtaining abiotic tolerant lines using an *in vitro* culture in combination with radiation techniques has been attained in several crop plants including rice (Shehata *et al*., 2009). The successful identification of salt tolerant lines obtained from *in vitro* mutagenesis was carried out at germination, seedling stage and the maturation period on a medium (solution or saline field) (Sathish *et al*., 1997). NaCl tolerant cell lines were selected from irradiated calluses (Lee *et al*., 2003). M1 regenerates were obtained from the salt tolerant callus cultured on the auxin free medium for 30 days. Some regenerates were more tolerant than the parent variety on a medium containing 0.75% NaCl. Seeds (M3, 5000 lines) derived from M2 lines were grown to the three leaf stage. M3 lines were soaked with 0.75% salt solution for 3 weeks and 350 salt tolerant genotypes were selected. Among the M3 350 lines, 40 tolerant lines were selected from a saline field (EC 10-14 dS/m) near the sea coast. Of the 40 lines, two (18-1 and 50-1) showed more improved plant height, panicle length, tillering number, spikelet number and yield than those of the original variety. They also screened 30 RAPD primers and two RAPD markers were identified, which appeared in both salt tolerant lines. From DNA hybridization experiments, it appeared that the fragment arose from the middle repetitive copy sequences. The transcript involved in the marker showed a higher expression in the salt tolerant lines than the sensitive lines. These salt tolerant were further used as a resource in salt tolerant breeding. Shehata *et al*., (2009) have also reported the development of four mutant rice lines with early maturity, non-lodging and higher salinity tolerance, employing gamma rays mutation induction. These mutant lines Sakha 101-M30, Sakha 102-M20, AC-M50 and Egyptian Jasmine M30 were selected in M6 generation and evaluated for two years under saline conditions (EC 6-6.5 dS/m).

Indian Mustard: Oilseed crops are important to Indian economy and *Brassica juncea* is being grown in areas having saline underground waters for irrigation. Experiments were initiated at CSSRI Karnal for inducing variability in high yielding and improved lines of *B. juncea* by the use of radiation and chemical mutagenesis, five genotypes were selected viz. Rohini and Varuna (high yielding genotypes) in one group and CS 614-4-1-4, CS 245-2 and CS 33-4-9, which were improved for salt tolerance and developed at CSSRI, Karnal as another group. These were radiated with 20, 40, 60, 80, 100 and 120 kR doses. Approx. 1200 seeds each, from the seven radiation treatments from each of the five genotypes were selected in each generation for advancing the generation upto M5. Variability was recorded in growth and yield parameters. All the radiation treatments showed increase in main shoot length in all the genotypes compared to controls. The increase in main shoot length with increase in radiation treatment varied from 6% (40, 60 and 100 Kr) through 10% (20 and 80 Kr) to 13% (120 Kr). Further in Varuna, main shoot length increased by 22% at 120 Kr treatments compared to controls. This is an important character to be observed for higher yield under salt affected soils. Significant differences in seed yield were recorded in different radiation treatments. Amongst different genotypes, seed yield declined by 18% in CS 614-4-1-4 to an increase of 10% in CS 245-2 compared to controls. Seed yield increased by 63% in 100 Kr plants in CS 245-2 and by 19% in 40 Kr plants in CS 33-4-9 respectively.

The mutant germplasm was also characterized for salinity tolerance at germination and seedling emergence stage. Radiation treatments also showed positive effects on seedling emergence under salinity stress with 32% increase in CS 614-4-1-4 (20 Kr), 27% increase in CS 245-2 (80 Kr) and 25% increase in CS 33-4-9 (40 Kr) respectively. At the highest salinity level of EC 22 dS/m, seedling emergence ranged from nil to around 20% in different genotypes. Maximum seedling emergence was noticed at 60 and 80 Kr radiation treatments at EC 22 dS/m. Mutant plants have been selected recording highest seedling emergence at salinity level of EC 22 dS/m. In general, radiation showed positive effects with respect to toxic ion accumulations as lesser Na ions were accumulated in radiation treatments plants compared to control values. The mutant plants selected showed lesser accumulation of Na/K showing higher salt tolerance compared to control plants. Maximum Na/K (1.75) was observed in Rohini (20 Kr) whereas minimum Na/K (0.95) accumulation was seen in Varuna (60 Kr) plants. The seeds obtained in M4 and M5 generations were evaluated for their salt tolerance potential at germination and seedling emergence stages to select tolerant as well as sensitive mutants for initial development stages. These seeds were also evaluated under field conditions for their whole plant tolerance to salinity and alkalinity. A total of 752 mutant plants (approx 150 plants from each variety, total 752 plants) from each of the radiation treatments from five varieties were evaluated under two types of stresses.

Further, segregants of interest were also selected by imposing selection pressure for salt tolerance at seedling and flowering stages in M4 generation by exposing the plants to salinity stress in field. Main shoot length differed significantly under salinity stress and under increasing radiation treatments. The percentage decline in main shoot length was lesser in radiation plants compared in controls in all the genotypes evaluated. Overall, the main shoot length increased by 8% to 12% in radiation treated plants. The longest main shoot length (104.5) was recorded in CS 33-4-9 at 40 Kr (104.5), whereas maximum percentage increase (34%) in main shoot length was observed in CS 33-4-9 followed by 10% in CS 245-2 on mean basis. In general, mean seed yield declined with increase in salinity stress, except in CS 33-4-9 and Varuna where it showed an increase of 11% and 3% respectively under salinity stress compared to controls. However, it increased with increase in radiation treatments. Overall, seed yield increased by 12% (20 Kr) to 25% (80 Kr) under radiation treatments.

Further, 10 best performing mutants from each of the radiation treatment were evaluated under alkalinity stress (pH 9.2) besides control conditions (pH 8.5) in field. For main shoot length, significant differences were recorded amongst varieties, radiation treatments and alkalinity stress and their interactions. Overall, 7% (40 Kr) to 15% (20 Kr) increase in main shoot length was observed under various radiation treatment plants, compared to non-radiated control plants. The percentage decline in main shoot length was lesser in radiation plants compared in controls in all the genotypes evaluated. Maximum percentage increase (42%) in main shoot length was observed in Rohini (80 Kr) followed by 21% increase in Rohini (40 Kr) under alkalinity compared to controls. In general, mean seed yield declined with increase in alkalinity stress, except in Rohini, where it showed an increase of 9% under alkalinity stress compared to controls. Genotypes CS 614-4-1-4 showed maximum decline of 31% in mean seed yield with minimum decline of 17% in mean seed yield in CS 245-2 under alkalinity stress compared to controls. Under various radiation treatment plants, seed yield increased by 56% in Rohini (40 Kr) plants under alkalinity stress compared to controls followed by 14% increase in seed yield under stress in CS 245-2 (40 Kr) plants.

Based on their performance at seedling emergence stages under varying salinity stress levels and under field conditions, two tolerant (R20-4, R80-4, Cs614-60-3, CS614-60-1, CS245-20-3, CS245-80-2, CS33-60-2, CS33-120-2, V40-1 and V100-4) and sensitive (R20-2, R120-2, 614-20-3, 614-80-1, 245-80-4, 245-120-4, 33-60-4, 33-80-2, V40-3 and V20-4) mutant plants were selected from each radiation treatments from five genotypes. Crosses were attempted amongst different tolerant and sensitive mutant plants and F1 seeds have been obtained.

Groundnut: Salinity tolerant lines have also been reported in groundnut (*Arachis hypogea*) through induced mutation by Ahmad and Mohammed (2009). They evaluated 77 groundnut variants for selecting for salt tolerant lines. These were isolated in M2 generation after seed treatment to 4 groundnut varieties, Giza 5 and Giza 6 (erect types) and NC 9 and Gregory (runner type) with different doses of gamma rays and various concentrations of sodium azide. In M3 and M4 generations, selection was practised based on high yield and low variances compared to parent varieties. In M4 generation, 9 mutants were obtained, out of which three mutants (M6-13, M6-18 and M6-30) produced higher pod and seed yield per plant under salinity stress.

Prospects for Crop Improvement

The last few years have seen the release of the first genome sequences for model plant species and the more genetically simple crops (Arabidopsis Genome Initiative, 2000; International Rice Genome Sequencing Project, 2005). Exploitation of these sequence data and associated tools for functional genomics has led to rapid progress in understanding the roles of individual genes, particularly in plant development and defence against pathogens. However, utilization of this knowledge for genetic improvement of more complex crops has been variable due to a combination of factors including lack of complete genome sequences, lack of genomic resources such as insertional knockout libraries and, for some species, the absence of high throughput transformation systems. However, the mutation screening technologies described above should make much more rapid progress by facilitating both the deployment of candidate genes identified in model species and also increasing available variation in genes of known agronomic value. This will be further enhanced by the explosion in sequence data for crop species that will undoubtedly follow the development of next generation sequencing technologies, enabling facile identification of genes for modification. One negative factor is that random mutagenesis is much more likely to generate loss of function mutations rather than conferring improved or new properties on the targeted gene, and thus will only be an appropriate strategy in a proportion of cases. Furthermore, in contrast to technologies such as RNAi which, in principle, can target multiple genes simultaneously, point mutagenesis can only target a single copy of a group of related genes, whether paralogues or homeologues, and mutations in different gene copies may have to be brought together by crossing in order to achieve the desired effect.

Mutagenesis is currently not regarded as genetic manipulation, as the random base changes involved are identical to those occurring naturally; indeed, as described above, many current crop varieties contain genetic material with origins in mutagenesis programmes. It seems likely, therefore, that reverse genetic selection of beneficial mutations through the screening approaches outlined above will have a major impact on crop breeding in the near future. TILLING (Targeting Induced Local Lesions IN Genomes) and similar techniques have reawakened interest in random mutagenesis for crop improvement, as illustrated by the rapid development of mutagenized populations and reverse genetic screening platforms in many crop species. An equally rapid deployment of novel alleles for crop improvement is certain to follow. A major obstacle in many crop species is the lack of complete genome sequence information, which slows the development of suitable TILLING targets. However, advances in sequencing technology are also likely to relieve this bottleneck within the relatively near future, as sequencing even very complex crop genomes such as wheat becomes practicable.

Mutagenized populations can be created at relatively low cost, although diploid species that are intolerant of high mutation frequencies require much larger populations for full coverage. Conversely, highly mutagenized lines of polyploid species may require significant backcrossing to remove extraneous mutations before they can be assessed for phenotypes or used in plant breeding. Importantly, the use of such novel alleles in crops will not be impeded by the tough regulatory regimes that cover GM crops; this alone should assure the rapid deployment of this technology in plant breeding.

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Development of Salt Tolerance Varieties of Wheat

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In India 6.73 M ha area is salt affected out of which 3.77 and 2.96 M ha are sodic and saline respectively. Wheat is one of the major crops grown in these soils. 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 as these require 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 challenge to breed wheat varieties for salt affected soils, which may help to stabilize production for the rapidly growing population of the country. Since, 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 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).

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 always be rewarding. 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. Therefore there is need to select genotypes under artificially created environments along with target sites. For an effective and efficient selection under stress environments, following point must be considered:

- Selection in the target site itself (field)
- Proper designing in the field to reduce the error due to soil heterogeneity
- Knowledge and use of threshold stress level, slope and tolerance indices
- Duplication of salt stress in lab, pots or microplots
- Identification of precise growth stage that limit productivity
- Selection under different stress levels
- Involvement of physiological parameters
- Selection based upon multiple salt tolerance indices
- Knowledge of yield components correlated with tolerance and yield
- Determination of genetic variance for desired characteristics
- Knowledge of heritability, variability and nature of gene action of different yield attributes
- Use of stability parameters

Artificial Environments

Microplots: Soil heterogeneity and spatial variability hinders the reliability of the response of the genotypes in true and dependable way. At CSSRI, mini field 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.

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.

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 studies give indications about relative germination and survival rates. These trays are used for seedling stage studies only.

In-situ Field Evaluation

The field gradient of soil salinity is determined by the soil tests 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, 20-30 m 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 plots basis to evaluate their yield potential.

Estimation of Salt Tolerance

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.

Threshold EC or pH and Salt Tolerance Index

Crop yields are not generally decreased significantly until the EC_e 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 dS/m and 50% yield reduction is observed at 14.0 dS/m as per the following equation:

$$Y = 100 - s(EC_s - EC_t) \quad (31.1)$$

Where: EC_t is the salinity threshold and s is slope that gives per cent yield reduction for each unit of added salinity above the threshold value.

The salt tolerance Index

$$S = Y_s/Y_c \quad (31.2)$$

$$S = (1-(Y_s/Y_c))/(1-D) \quad (31.3)$$

Where Y_s is the yield under salinity, Y_c is the yield under non saline conditions and D is the mean of all genotypes under stress/mean of all genotypes under normal

Germination as a Selection Criterion

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 suitably 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. 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 are 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:

$$\frac{\text{Percentage of emerged seedlings}}{\text{days to first count}} + \frac{\text{\% of additional emerged seedlings}}{\text{days to second count}} + \frac{\text{\% of additional emerged seedlings}}{\text{days to final count}}$$

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. Faster germination is considered to be better under salt stress conditions.

Physiological Parameters for Salt Tolerance

The concentration of toxic ions increases in the saline solution. 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 kind of uptake specifically for K is present in wide range of plants. Higher K^+/Na^+ (or lower Na^+/K^+) 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 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 (Table 31.1).

Table 31.1. Relative tolerance of wheat varieties

Tolerant[1]	Medium Tolerant[2]	Medium Sensitive[3]	Sensitive[4]
Kharchia 65	KRL 1-4	HD 2009	HD 4502
KRL 3-4	KRL 19	HD 2285	HD 4530
KRL 99	KRL 210	HD 2851	Raj 911
	KRL 213	HD 2329	Moti
	KRL 35	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 EC_e 8.5 dS/m
2. Grows well and sets viable seed upto soil pH_2 9.3 or EC_e 6.5 dS/m
3. Grows well and sets viable seed upto soil pH_2 9.1 or EC_e 5.5 dS/m
4. Grows well and sets viable seed upto soil pH_2 8.5 or EC_e 5.0 dS/m

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 semiarid 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 population 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.

Use of Wild Relatives to Improve Salt Tolerance in Wheat

There is considerable variability in salt tolerance amongst members of the *Triticeae*, with the tribe even containing a number of halophytes. The halophytes display a capacity of Na^+ exclusion and in some cases Cl^- exclusion even at relatively high salinity. Some of the halophytic members of the tribe *Triticeae* such as tall wheatgrass spp. (*Thinopyrum* spp.), *Eltrygia elongata* and sea barleygrass (*Hordeum marinum*), are more salt tolerant than wheat. It is possible to hybridize several wild species in the *Triticeae* with the durum and bread wheat using cytogenetic techniques.

Aegilops tauschii (*Ae. squarrosa*) is the progenitor of the D genome of wheat. D genome has been reported to have imparted the Na^+ exclusion and K^+/Na^+ discrimination to bread wheat. The best sources of *Ae. squarrosa* might be used in the breeding program by making synthetic hexaploids, to further improve this trait in bread wheat.

Wide hybridization of tall wheat grass species with wheat appears a promising avenue to improve salt tolerance. Some of these halophytic species such as *Eltrygia elongata* (EE genome) and *Thinopyrum bessarabicum* (JJ genome) have shown better yields under saline field conditions (13.9 to 15.6 dS/m). The genes and their mechanism of Na^+ exclusion in these species might differ from *Kna1* locus in bread wheat on chromosome 4D (Dubcovsky *et al*., 1996) and *Nax1* locus in durum wheat on chromosome 2A (Lindsay *et al*., 2004). To make use of amphiploids as new salt tolerant wheat, the most tolerant accessions of wild relatives should be used to make amphiploids with a range of modern high yielding, salt tolerant, and locally adapted varieties.

Bread wheat (*Triticum aestivum*) is in general better Na^+ excluder than durum (*Triticum durum*) wheat. Attempts have been made to transfer *Kna1* locus of K^+/Na^+ discrimination from D genome of hexaploid wheat into teteaploid wheat (Dvorak *et al*., 1994). Using the pairing mutant *phe1* in the background of durum cultivar capelli, homeologous recombination of the distal part of the long arm of chromosome 4D with chromosome 4B was obtained. However, in this attempt durum genotype obtained with higher K^+/Na^+ ratio were not agronomically superior to the parental lines.

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, four salt tolerant wheat varieties, KRL 1-4, KRL 19, KRL 210 and KRL 213 have been developed by Pedigree method of selection and released through CVRC (Table 31.2).

Table 31.2. Characteristics of CSSRI salt tolerant wheat varieties

Name of the variety	KRL 1-4	KRL 19	KRL 210	KRL 213
Year of release	1990	2000	2010	2010
Plant height (cm)	89 (84-91)	85 (82-90)	99 (97-100)	97 (95-99)
Days to maturity	132 (130-137)	132 (128-136)	143 (137-146)	145 (138-149)
Tolerance limits				
Salinity (EC_e)	7.0 dS/m	7.3 dS/m	6.6 dS/m	6.4 dS/m
Sodicity (pH_2)	9.3	9.3	9.3	9.2
Grain yield (t/ha)				
Non stress	4.5	4.0	5.2	5.1
Stress	3.0 (2.5-3.4)	3.0 (2.5-3.5)	3.5 (2.7-3.7)	3.3(2.5-3.5)
Grain type	Medium	Medium	Bold	Medium
Recommended ecology	NWPZ, NEPZ	NWPZ, NEPZ	NWPZ, NEPZ	NWPZ, NEPZ
Date of sowing	Normal	Normal	Normal	Normal

NWPZ: North west plain zone, NEPZ: North east plain zone

These salt tolerant varieties 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 q of breeder/labeled seed has been distributed to seed agencies and farmers. Farmers can grow these varieties under salt stress and can generate additional yields up to 7.0-8.0 q/ha which may fetch higher economic returns in comparison to traditional wheat varieties.

Three salt tolerant genetic stocks KRL 35, KRL 99 and KRL 3-4 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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Characterization of Wastewater for Irrigation

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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 m^3 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 (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 is a direct source of surface waterlogging, ground water 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 big cities. In fact all the rivers have become big open sewer drains and lakes and ponds as sewage dumps. On the other hand, 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.

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). In India, production worth US $ 670 million and employment equivalent to 130 million mandays 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 wastewaters often have 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 and ground water. Thus, before resorting to the use of wastewater in agriculture; its characterization for suitability for irrigation is very essential.

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 22,900 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 water allowance per head in each district. Quantity of total sewage generated and projections for the year 2025 for Haryana state are presented in Table 32.1.

Table 32.1. Distrisct wise sewage generation in Haryana

District	Sewage generation (MLD)		District	Sewage generation (MLD)	
	Present	Projections for 2025		Present	Projections for 2025
Ambala	25.7	38.6	Kurukshetra	20.8	31.2
Bhiwani	17.5	26.3	Mahendergarh	6.2	9.3
Faridabad	104.1	156.2	Panchkula	19.3	29.0
Fatehabad	9.8	14.7	Panipat	28.4	42.6
Gurgaon	20.2	30.3	Rewari	8.2	12.3
Hisar	33.2	49.8	Rohtak	28.1	42.2
Jhajjar	15.3	23.0	Sirsa	21.1	31.7
Jind	19.9	29.9	Sonepat	30.4	45.6
Kaithal	17.9	26.9	Yamunanagar	28.3	42.5
Karnal	30.8	46.2	Total	485.2	728.3

The total quantum of current 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 considering average irrigation interval of 20 days, the wastewater would have the potential of supplying supplemental irrigation to about 11,700 ha are 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

Composition of Wastewater

Though actual composition of wastewater may differ from community to community but all municipal wastewater contain; organic matter, nutrients (NPK and micronutrients), dissolved inorganic minerals, toxic chemicals and pathogens (Table 32.2).

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.

Table 32.2. Chemical characteristics of some industrial wastewater

Industry	pH	EC (dS/m)	SS (mg/l)	BOD (mg/l)	COD (mg/l)	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
Fertilizer	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
Electroplate	6-8.9	2.4	0.06-0.38	--	--	--	--	--

SS:Suspended soilds , BOD: Biological oxygen demand, COD: Chemical oxygen demand

The major contributors of pollution in terms of BOD are distilleries followed by paper mills. Distillery effluents are very concentrated and 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 having 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 32.3).

Table 32.3. Average irrigation characteristics of sewage generated in Haryana

Parameters	Untreated		Treated	
	Range	Average	Range	Average
EC (dS/m)	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 (meq/l)	-- 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

The cationic and anionic constituents in 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 meq/l while Ca:Mg ratio > 1. All these parameters indicate that these waters could be exploited for irrigation purpose without any adverse effect on soils. Sewage from Mahendergarh, Kaithal and Rewari districts had RSC >6 meq/l mainly because of ground water quality. Contents of trace and heavy metals were within permissible limits. But wastewater fromsome of industrial townships like Ambala, Panipat, Sonepat and Faridabad had higher metal contents.

Pollution and Public Health Parameters

TDS in sewage ranged between 0.6 – 3.3 g/l and is on higher side than permissible levels. BOD and COD of wastewater ranged from 176 to 345 ppm and 233 to 457 ppm, respectively. Ambala sewage had maximum BOD and 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.

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 season 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 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 rainy seasons, while the values were 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 increased markedly in summer while CO_3 and HCO_3 were 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 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 was 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 increased with treatment but pathogen loads reduced slightly. The major advantage of conventional STPs seems to be reduction in organic loads while these remain ineffective in reducing the levels of soluble metals and other ions.

Nutrient Potential

Sewage from different districts in general are rated high in terms of plant nutrient contents. Additions of macro and micronutrients and organic matter for conditioning of soils are inseparable from sewage irrigation and thus their use can diminish the requirement for fertilizers, 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 in addition to 130, 760 and 20 g of Zn, Fe and Cu, respectively (Table 32.4).

The nutrients supplied would 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. It is estimated that these effluents have the potential to contribute about 56.4 t/day or 20,872 t/year when all the nutrients are taken into account. Since these effluents contain appreciable amounts of organic matter, it improves soil conditions.

Table 32.4. Nutrient potential of sewage in Haryana

Nutrients	Contents (ppm)	Nutrient added (kg/irrigation)	Contribution (t/year)	Price (Rs/t)	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		

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Safe Conjunctive Use of Sewage Water for Crop Production

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Sustainable management of soil and water resources is the key and most essential parameter for the livelihood security of the farmers. However, these natural resources are being gradually contaminated because of use of large quantities of wastewater produced from continually expanding population along with an exponential industrial growth and urbanization. Wastewater in the context of this paper is the water that has been used in domestic or industrial processes and during the utilization process its quality deteriorates because of excessive soluble salts, metals, metalloids, pathogens, other organic and inorganic pollutants. Due to resource constraints and prohibitive costs of conventional treatment, in developing countries larger portions of wastewater are disposed off either raw or after partial treatment. Urban drainage systems in developing countries mix domestic and industrial wastewater and stormwater, often discharging the wastewater into natural waterways, polluting water used by the farmers and other downstream users in peri-urban agriculture. In India, the Ganges River receives about 120,000 cubic meters of sewage effluent per day, affecting downstream domestic and agricultural use and threatening human health.

Land is the most logical sink for wastewater disposal, particularly in land locked areas as irrigation. Around cities in developing countries, farmers use wastewater from residential, commercial, and industrial sources, sometimes diluted but often without treatment for irrigating high value crops like vegetables and food grains. Wastewater use is prevalent because of scarcity of fresh water and added advantages of wastewater viz: a source of plant nutrients, assured irrigation, and lack of alternate water sources resulting in higher crop yields and improvement in soil fertility. The practice of wastewater irrigation is widely adopted by resource poor farmers overlooking the potential health and environmental risks in the form of pathogens causing diseases, heavy metal accumulation and soil salinization. Farmers suffer due to contact with wastewater, while consumers are at risk from eating vegetables and cereals irrigated with wastewater. Wastewater will be increasingly used in coming years also because of higher fresh water allocation to more remunerative sectors like industry and municipalities. Agriculture is the single largest user which consumes about 70% of the total fresh water abstraction. Therefore, under the fresh water scarcity for agriculture, even the wastewater will be used for irrigation causing the pollution of natural resources. To contain the ill effects, sound management strategies are to be devised to protect these resources from further degradation. For planned strategic wastewater use, a coherent programme involving government policies, 'polluter pays' principle, awareness, regular health check up of the irrigators, forest establishment, efficient microbial strains, wet lands, cultivation of remunerative non-edible crops, application of organic and inorganic amendments, bio-filters is to be framed and implemented. Conjunctive and regulated water use both in cyclic and mixing mode may be one of the important strategies to mitigate or reduce the adverse impacts of wastewater irrigation.

Rationale behind the Conjunctive Wastewater Use

Large volumes of wastewater are returned to the hydrologic system in urban areas, where only 15–25% of water diverted or withdrawn is consumed. Worldwide, marginal-quality water will become an increasingly important component of agricultural water supplies, particularly in water-scarce countries. At least 2 M ha are irrigated with untreated, partly treated, diluted, or treated wastewater. The estimated area would be larger if the land irrigated from rivers and canals that receive wastewater were considered. Wastewater use will increase in India, as the proportion of freshwater in agricultural deliveries declines from 85% today to 77% by 2025, reflecting rising demand for freshwater in cities. Many of the small-scale farmers in developing countries using untreated or diluted wastewater for irrigation likely feel fortunate to have any water supply, given their inability to purchase higher quality surface water or to pump groundwater. Public makers should consider wastewater and saline or sodic water when evaluating national water management strategies to optimize the use of limited water resources.

Nutrient Supply by Wastewater Irrigation

The amount of nutrients in 1,000 cubic meters of wastewater irrigation per hectare can vary considerably, 16–62 kg total nitrogen, 4–24 kg phosphorus, 2–69 kg potassium, 18–208 kg calcium, 9–110 kg magnesium, and 27–182 kg sodium (Yadav *et al*., 2003). The farm level nutrient value of wastewater will vary with constituent loads, soil conditions, crop choices, and the cost and availability of inorganic fertilizers. The nutrients in municipal wastewater can contribute to crop growth, but periodic monitoring is needed to avoid imbalanced nutrient supply. Excessive nutrients can cause undesirable vegetative growth and delayed or uneven maturity and pollute groundwater and surface water.

Water Quality Irrigation Concerns

The feasibility of using treated municipal wastewater as a source of irrigation water depends upon its quality. As long as treated municipal wastewaters meet irrigation water quality criteria and state regulations governing disease-causing organisms in the water, they should be considered safe for agricultural use. This in turn depends upon the quality of the municipal water supply, the nature of the constituents added during water use, and the kind and degree of wastewater treatment. Wastewater constituents that can degrade water quality for irrigation include salts, nutrients and trace contaminants. The Biochemical Oxygen demand (BOD), one of the most important indicators of pollution, was observed highest in Amlakhadi at Ankleshwar (714 mg/l) followed by Ghaggar at Moonak, Punjab (626 mg/l), Khari at Lali village, Ahmedabad (320 mg/l); Musi at Hyderabad (225 mg/l). Due to high BOD dissolved oxygen in these stretches was observed most of the time either nil or very low. The results indicate that the organic and bacterial contamination continued to be critical in water bodies because of discharges of domestic wastewater mostly in untreated form from the urban centres of the country. The municipal corporations of various urban coglomerations are not able to treat sewage thereby increasing the untreated sewage load. This is further aggravated as the receiving water bodies also do not have adequate water for dilution. *Faecal coliform* another important indicator of pollution was found highest in Yamuna river at Agra, Nizamuddin, Mazawali and Okhla (MPN 5.2×10^6 to 3.7×10^6) followed by Hindon after confluence with Krishni (1.1×10^6 to 4.6×10^5), Ganga at Dakshineshwar and Uluberia (1.1×10^6 to 2.8×10^5).

Heavy Metals Estimation in Ground Water

Through cation exchange, chemical exchange, chemical sorption, precipitation, and complexation reactions, metallic ions are readily removed from wastewater and are concentrated in sludges. Soil particles act to further sequester most heavy metals, and this preference of metals for particulates has been observed often in agricultural soils. Therefore, heavy metal cations would not be expected to leach out of the unsaturated soil zone into ground water. In fact, the risk of ground water contamination is used only to determine the heavy metal standard for hexavalent chromium. Hexavalent chromium is an unstable and rare form of chromium, and is rapidly reduced in most environmental conditions to its trivalent form, which is quite immobile in soils and not expected to leach to ground water.

Effects of Conjunctive Use of Wastewater in Crops

Vegetables

The use of sewage water alone or its use with tube well water (1:1) under varying levels of fertilizer application (50, 75 and 100% of fertilizer recommended dose) in sweet corn (*kharif*) – cabbage/ cauliflower (*rabi)* – okra (summer) crops in Gujarat improved the crop yields over only tube well water. The maximum improvement in crop yields due to sewage irrigation was 30.4 q and 8.5 q/ha equivalents to about 8 to 9 per cent in cauliflower and sweet corn, respectively. The results of the pooled analysis indicated that the sewage application was significantly superior over tube well irrigation in increasing crop yields which was at par with combined use of sewage and tube well water (1:1) (Table 33.1). The beneficial effect of the sewage could be ascribed to the addition of nutrients as well as organic matter to the soil. Sewage use showed the saving of Nitrogen by 25 per cent in the crops viz., cabbage / cauliflower and okra which received direct sewage irrigation as well as in sweet corn (*kharif*) due to cumulative residual effect of sewage irrigation. Where municipal wastewaters are used to irrigate crops, users must take into account nutrients (nitrogen and phosphorous) accompanying the water and adjust fertilizer practices accordingly. Under certain soil-plant systems, it is recommended that soil phosphorus levels be monitored so that the accumulation of soil phosphorus does not exceed crop requirement (usually about 150 kg/ha).

Table 33.1. Effect of sewage water with graded levels of fertilizer on crop yields (q/ha)

Treatments	Fertilizer level (%)	Cauliflower – Okra –Sweet corn		
		Cauliflower head	Okra fruit	Sweet corn cobs
Tube well water (T)	50	255.4	62.6	95.2
	75	260.9	72.7	99.5
	100	267.4	64.8	103.0
	Mean	261.3	66.7	99.2
Sewage water (S)	50	273.8	63.0	110.5
	75	281.7	76.6	103.9
	100	289.7	78.9	108.0
	Mean	281.7	72.9	107.7
T: S (1: 1)	50	259.1	64.1	103.0
	75	268.5	77.6	105.5
	100	272.7	71.5	107.4
	Mean	266.8	71.0	105.3

However, the quality of the sewage with respect to presence of heavy metals should be looked into as it contained average heavy metals viz., Co (0.08 ppm), Cd (0.03 ppm), Cr (0.06 ppm), Ni (0.18 ppm) and Pb (0.11 ppm) which caused an increase in the DTPA- extractable heavy metals status after four years as compared to tube well alone or tube well water and sewage (1:1) irrigation. Thus, use of sewage and tube well water in 1:1 cyclic mode has been found advantageous to minimize the load of heavy metals in the soil over the years.

The partitioning of absorbed heavy metals in different plant parts like fruit, leaves and root indicated that the heavy metals *viz*., Cr was accumulated in both roots and leaves almost equally whereas Co, Ni, Cd and Pb were found more concentrated in leaves followed by roots of okra and cauliflower (Minhas and Samra, 2004). Only a small fraction of the absorbed heavy metals was translocated to fruits. However, consumption of leaves by animals may be a matter of concern from animal health point of view. Thus, the plant itself has build the internal mechanism of preventing the accumulation of heavy metals in edible parts but needs monitoring for heavy metal contents in other plant parts and soil. Contamination of edible parts with pathogens would be a matter of concern, for human health if the vegetables are consumed in raw form.

The Cd contents found in soil and different vegetable irrigated with sewage water are given in Table 33.2. Soil Cd was significantly correlated with clay content, pH, EC and CEC. Cadmium availability index decreased with increase in soil depth. Leafy tissue accumulated Cd about twice that of fruit portion. The results suggested that prolonged ingestion of sewage irrigated leafy vegetables can develop such Cd levels in human body that may cause a number of ailments.

Use of Treated and Untreated Industrial Effluents for Irrigation in Coarse Millets

In general the industrial effluent have high salt concentration, oxygen demand (BOD and COD) as well as heavy metal load but with the treatment of the effluents in sewage treatment plant, the organic load can be reduced to a significant extent. In a field experiment on sorghum and pearl millet crops conducted at Umaraya during 2001-04, sole use of untreated effluent generated from dyes, organic and inorganic chemicals and pharmaceuticals industries was the most harmful than the treated one or the conjunctive use of treated and untreated effluents with tube well water in 1:1 ratio.

Table 33.2. Cadmium concentration in urban agricultural soils used for growing vegetables with untreated municipal sewage as in irrigation source in Faislabad, Pakistan

Soil under vegetable	Cd concentration (mg/kg)				
	Soil depth (cm)			Plant	
	0-15	15-30	30-60	Leaf	Fruit
Bitter gourd	0.29	0.24	0.16	0.18	0.08
Cauliflower	0.27	0.26	0.19	0.19	0.07
Eggplant	0.25	0.28	0.26	0.17	0.10
Fenugreek	0.33	0.27	0.17	0.24	--
Okra	0.29	0.24	0.27	0.16	0.10
Onion	0.28	0.26	0.18	0.17	0.18
Pumpkin	0.30	0.22	0.17	0.18	0.11
Spinach	0.34	0.30	0.26	0.23	--
Mean	0.29	0.26	0.15	0.19	0.08

The better crop yields were recorded with treated effluent irrigation than the untreated when both were applied in conjunction with tube well water in 1:1 ratio. Accumulation of different heavy metals (Cd, Cr, Ni, and Co) showed no particular increasing or decreasing trend with irrigation by treated and untreated effluents applied alone or in conjunction with tube well water. However, in case of lead the build-up was higher when the fields were irrigated with untreated effluents compared to its application after treatment. Further, the soil contamination due to heavy metals loading was also remarkably less under alternate use of effluents with tube well water (1:1). The soil irrigated with untreated wastewater had more salinity and organic carbon content.

Conjunctive use wastewater with tube well water seems to be better compared to sole use of wastewater in controlling the heavy metal build-up in soil and crops. Under water scarcity conditions, those crops in which heavy metals are not translocated to the edible part could be irrigated up to some extent with treated industrial effluents in conjunction with fresh water. However, the soil health and crop quality should be regularly monitored for possible build-up of heavy metals as well as salinity.

Health Hazards with Wastewater Use

Human health risks from wastewater include exposure to pathogens, helminth infections, and heavy metals. Leafy vegetables, eaten raw, can transmit contamination from farm fields to consumers. Hookworm infections are transmitted by direct exposure to contaminated water and soils. A survey along the Musi River in India revealed the transfer of metal ions from wastewater to cow's milk through fodder (para grass) irrigated with wastewater. About 4% of grass samples showed excessive amounts of cadmium, and all samples showed excessive lead. Milk samples were contaminated with metal ions ranging from 1.2 to 40 times permissible levels. Leafy vegetables accumulate greater amounts of certain metals like cadmium than do nonleafy species. Generally, metal concentrations in plant tissue increase with metal concentrations in irrigation water, and concentrations in roots usually are higher than concentrations in leaves. Globally the diseases caused by wastewater are responsible for the loss of a large number of human lives (Table 33.3).

Strategies and Future Plans

- Water quality can be improved by storing reclaimed water in reservoirs that provide peak-equalization capacity, which increases the reliability of supply and improves the rate of reuse and can even reduce fecal coliform levels in water.
- Drip irrigation can protect farmers and consumers by minimizing crop and human exposure, but pretreatment of wastewater is needed to avoid clogging of emitters.

Table 33.3. Annual global mortality and disability adjusted life years lost due to some diseases of relevance to wastewater use in agriculture disease

Disease	Number of deaths	DALYs[a]	Comments
Diarrhea	1,798,000	61,966,000	Almost all (99.8%) deaths occur in developing countries, most (90%) of them among children
Typhoid fever	600,000	-	Estimated 16 million cases a year
Ascariasis	3,000	1,817,000	Estimated 1.45 billion infections; 350 million suffer adverse health effects
Hookworm disease	3,000	59,000	Estimated 1.3 billion infections; 150 million suffer adverse health effects
Lymphatic filariasis	0	5,777,000	Mosquito vectors of filariasis breed in contaminated water; does not cause death but leads to severe disability
Hepatitis A	-	-	Estimated 1.4 million cases a year; serological evidence of prior infection ranges from 15% to nearly 100%

DALYs[a]: Disability-adjusted life years lost due to disease, reflect the time lost due to disability or death from a disease, compared with a long life free of disability in the absence of the disease. DALYs describe the health of a population or burden of disease due to a specific disease or risk factor.

- A combination of farm-level and post-harvest measures can be used to protect consumers, such as producing industrial or nonedible crops or products that require cooking before consumption.
- Farmers also can stop applying wastewater long before harvest, to reduce potential harm to consumers.
- Vegetables can be washed before sale or consumption, and storage methods can be improved.
- Public agencies can implement child immunization campaigns against diseases that can be transmitted through wastewater use and target selected populations for periodic antihelminthic campaigns.
- The nutrients in municipal wastewater can contribute to crop growth, but periodic monitoring is needed to avoid imbalanced nutrient supply.
- Untreated wastewater should not be used on crops that are likely to transmit contaminants or pathogens to consumers.
- Building of large-scale conventional treatment systems is financially not viable. Therefore, alternate technical low cost options like cultivation of crops on raised beds should be followed.
- The sources, from where discharged effluent has no or little treatments, are to be delineated and need to be addressed separately.
- The wastewaters produced from different sources (domestic, urban and industries) must be assessed separately for their nutrient content, effects on crop yield and quality and possible harmful environmental effects on soil.
- Though the use of wastewater is an old age practice but the information on cost benefit ratio under different situation in different crops including fodder is not available which need to be clearly understood before making the policies for its use in agriculture.
- Management options for the use of industrial effluents in terms of low cost chemical treatments, agronomic, cultural practices, oxidation ponds, dilution either in mixing or cyclic mode are to be devised for sustainable application under different agro-climatic conditions to minimize the degradation of our valuable natural resources.
- Estimation and isolation of microbial population not limited only to faecal coliforms but also the other organisms like nematodes, protozoa etc thriving under the situations where domestic and industrial effluents have been added on long-term basis should also be made to predict the impacts of wastewater use on biological properties and health of soil.
- For the cases where the effluents with no or little treatment options are to be applied, sinking capacity of soil, performance and carrying capacity of different remunerative crop species having non-edible economic parts but producing large biomass including trees which are known

to sequester, tolerate and accumulate higher levels of heavy metals must be studied for phytoremediation of contaminated soils.

- Keeping these in view a wastewater should be seen in totality and treated like a commodity, which can be a resource for agriculture if used properly but could prove to be a disaster if applied indiscriminately in an unscientific manner.

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Irrigation Induced Soil Degradation in Command Areas

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India has made significant investments in creating irrigation potential of more than 50 M ha. However, the irrigated areas, which have contributed significantly in increasing food grain production are now facing serious problem of rise in ground water table and soil salinization. Such problems are more serious in areas that have received canal irrigation. The impact of soil degradation in irrigated areas due to soil salinization and waterlogging has not been evaluated adequately. In the Nagarajunasagar project command area, nearly 25,000 ha of 140,000 ha under irrigation have been affected by salinity and waterlogging in a period of 14 years. Extent of human induced soil degradation in India is presented in Table 34.1.

Table 34.1. 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
• Loss of topsoil	27.3	99.8	5.4	-	132.5	40.3
• Terrain deformation	-	11.8	-	4.6	16.4	5.0
Wind erosion	0.3	10.1	3.1	-	13.5	4.1
• Loss of topsoil	0.3	5.5	0.4	-	6.2	1.9
• Loss of topsoil/terrain deformation	-	4.6	-	-	4.6	1.4
• Terrain deformation/over blowing	-	-	2.7	-	2.7	0.8
Chemical deterioration	6.5	7.3	-	-	13.8	4.2
• Loss of nutrients	3.7	-	-	-	3.7	1.1
• Salinization	2.8	7.3	-	-	10.1	3.1
Physical deterioration	6.4	5.2	-	-	11.6	3.5
• Waterlogging	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					32.2	9.8
Total geographical area of India					328.7	100.0

Source:

Irrigated Soils: Changes in Physico-chemical Properties

It is clear that non-judicious use of irrigation water, irrespective of its quality lead to soil salinisation and sodification. Continuous accumulation of salts in root zone results into soil salinisation. 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. 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 salinisation 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 (Chaudhari and Somawanshi, 2002, Chaudhari *et al*., 2010).

Rising and Depleting Water Table

The increased irrigation by tubewells, supplemented by canal irrigation, has resulted in depletion and lowering of underground water at the rate of almost 1 meter/annum in the central Punjab causing concern of depleting groundwater resource for the posterity and increasing the groundwater table in the southwestern sectors resulting in the problem of salinization and changes in land use. Effect of irrigation on soil degradation due to waterlogging and accumulation of salts in soils of Punjab revealed that in the Sangrur and Kapurthala districts, the 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/annum, the ground water table in the Sangrur and Kapurthala districts receded at the rate of about 0.2 meter/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 change the land use pattern in favour of wheat-paddy rotation at the cost of maize, cotton or citrus cultivation. The Faridkot areas, once known for cotton production in the state, are now being increasingly used for paddy production where irrigation water is available and thus aggravating the problem of waterlogging and salinity due to the addition of large quantities of salts through tube well waters of marginal quality for irrigation. On the other hand, the Sangrur and Kapurthala areas which were previously abandoned for cultivation because of sodicity problem, have now been reclaimed and brought under paddy-wheat rotation after rectifying 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 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 affecting adversely 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 Indian, the total carbon stock of the Indo-Gangetic Plains of India, and while estimating the formation of secondary carbonates in Indian soils.

Irrigation Induced Land Degradation in Mula Command of Maharashtra: A Case Study

Irrigation induced salinisation and alkalisation has emerged as twin problems in the command areas under different agro-ecological situations in general and under arid and semiarid ecosystems in particular. In order to understand the menace of irrigation induced land degradation, results of a case study carried out in Mula Command Area of Maharashtra is presented here. The study was carried-out with the following objectives.

- To study the changes in hydro-physical behaviour of dominant soil series with change in irrigation intensity and irrigation induced salinisation and alkalisation.
- To study the effect of irrigation induced salinisation and alkalisation 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 (Chaudhari *et al.*, 2006).

In the whole command area, 40 soil profiles were selected in head, middle and tail reaches. Soil profiles, 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. 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.

Most of the soils in the command area are 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 MRBC. If the same soils are brought under frequent irrigation, as at middle end, soils become saline in reaction with EC >8.0 dS/m. However, under intense and heavy irrigation situations at head end, soils turn 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 salinisation and alkalisation starts simultaneously but the hazard of salinisation appears much earlier than alkalisation.

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/hr, 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 a 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. 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. 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 revealed that Otur soil 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 waterlogging. 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 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 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 and provision of drainage. 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 and pressmud etc.

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Laboratory Exercise: Determination of Gypsum Requirement

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Sodic soils were characterized by the presence of "Exchangeable Sodium Percentage" (ESP) that resulted in high pH, poor physical condition and nutritional imbalances which adversely affects the plant growth. The addition of gypsum ($CaSO_4$, $2H_2O$) followed by flushing is recommended to replace the exchangeable sodium by calcium and leaching of excess soluble salts. Due to its easy availability, safe to handle and relatively low cost, gypsum is preferably used as an amendment for reclamation of sodic 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 selecting the gypsum requirement of a soil. In general, calcium ions in gypsum replace sodium from the mineral 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 al*., 1973). Khosla and Abrol (1972) observed maximum reactivity of gypsum at 0.59 mm (30 mesh) particle size, while further increase in particle sized 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 10cm 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 help 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).

Gypsum is used for improving the quality of irrigation water having high RSC or SAR for crop production in the arid and semiarid areas in Haryana and 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.

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 favors 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 : 250 ml
2. Burette : 50 ml
3. Pipette : 5 ml

Reagents

1. Gypsum saturated solution: Take 5 gm 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 litre.
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 0.5 gm EBT with 100 gm NaCl to prepare the standard Erichrome Black T (EBT) indicator.
5. Buffer Mixture: Mix 67.5 gm NH_4Cl with 570 ml NH_4OH and make the volume to 1 litre and adjust the pH to 9.5 with NH_4OH.

Procedure

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

Calculations

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

$$\text{Milliequivalent per litre of Ca in gypsum} = \frac{\text{X x strength of EDTA x 1000}}{\text{Aliquot taken (5 ml)}} = S$$

$$\text{Milliequivalent per litre of Ca in filtrate} = \frac{\text{Y x strength of EDTA x 1000}}{\text{Aliquot taken (5 ml)}} = T$$

Gypsum requirement (meq /100 gm) = 2 (S -T)

Now, 1 meq of gypsum per 100 gm soil is equivalent to 860 ppm of gypsum and one hectare soil to a depth of 15 cm may be taken to weigh 2 x 10^6 kg (approx.). Therefore, the quantity of gypsum required to reclaim one hectare of top (0-15 cm) soil is as follows:

GR (tons/ha) = GR (meq/100 gm) x 860 x 10^{-6} x 2 x 10^6 kg
= GR (meq/100 gm) x 1720 kg
= GR (meq/100 gm) x 1.72 tons

Thus, 1720 kg or 1.72 tons of 100% gypsum is required for each meq/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.

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