COASTAL SALINE SOILS OF GUJARAT : PROBLEMS AND THEIR MANAGEMENT

2013

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CONSERVE SOIL & WATER
TO FEED THE FELLOW COUNTRYMEN

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PREFACE

India has agrarian economy and thus a sustained and wide spread agricultural growth is a primary requisite for the development since more than 60 per cent of the population depends on agriculture for their livelihood and thus agricultural development plays a vital role in India's economy. The ever-increasing pressure on land and water resources due to the burgeoning population of people demand their proper conservation and management for sustained crop production. Soil degradation through salinisation has affected about 6.23 million hectares of land in India, of which Gujarat state accounts for 33 per cent amounting to 2.22 million hectares. India has a long coast line of 8100 km of which 1600 km occur in Gujarat state, which thus faces the coastal and inland salinity (secondary salinisation) problems coupled with prevalence of saline ground water.

Deterioration of agricultural lands due to physical and chemical processes necessitate to identify strategies for their reclamation, *in-situ* resource conservation, enhancing water availability through rainwater harvesting, arresting salinity ingress in coastal areas, improving the ground water table situations, searching for stress-tolerant, low water requiring and high yielding crops etc. The problems of environmental degradation in Gujarat state are as diverse and complex as the ecological fabric of the state. While some of the problems are widespread and operate over long term, the others are mainly localised and more intensive in their impacts. Soil and water salinity problems are essentially multi-sartorial and are complex in nature. Vast areas are in imminent danger of turning barren and production and productivity have simply declined due to secondary salinisation. Soil salinity problems are further compounded where the ground water is highly saline and such areas *by and large* remain barren for want of economically feasible technological interventions and thereby affecting the livelihood of the farmers because of low productivity of the existing farming practices. The adverse effects of salinity have put the food and nutritional security at stake while creating environmental pollution and affecting health.

A systematic resource characterization of the coastal saline areas, soil and water resources, cropping pattern, water conservation strategies and identifying and adoption of the economically feasible agro-technological interventions mainly to tackle the issues in the region has been a long felt need. We have made thorough insight in these issues and come out with strategies for bringing coastal saline soils under production based on the technologies evolved, improving the irrigation water scenario by adopting ground water recharge and surface water conservation measures and maximizing crop production through conjunctive mode.

We take this opportunity to express our sincere thanks and gratitude to the Indian Council of Agricultural Research, New Delhi for providing amenities. Thanks are due to the Managing Director, Gujarat State Land Development Corporation, Gandhinagar for providing information on the problems of coastal Saurashtra. To the Coastal Salinity Prevention Cell, Ahmedabad, we woe our thanks for joining our hands in taking on-farm trials in coastal Gujarat. Thanks are due to all the staff of CSSRI Regional Research Station, Bharuch, particularly Shri Indivar Prasad, Shrvan Kumar and Nikam Vinayak, Ramesh Scientists for their help at times of need.

The Bulletin, we sincerely hope, forms a basis for the Government agencies, NGOs, Planners and farming community to tackle salinity issues in the coastal areas in general and Gujarat in particular.

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FOREWORD

Problems of environmental degradation in Gujarat State are as diverse and complex as the ecological fabric of the state itself. Such problems have caused immense loss to agriculture, particularly in the irrigation command areas where soil salinity is important in this respect. Soil salinity problems are further aggravated where the ground water is highly saline and such areas *by and large* remain barren for want of appropriate agro-technological interventions.

Coastal saline soils occur along the 8129 km long coastline of India. Salinity problems in coastal areas can be traced to their marine origin and/or subsequent periodical inundation with tidal water and in case of low lands having proximity to the sea due to high water table with high concentration of salts in it. The coastal soils exhibit a great deal of diversity in physiography and physical characteristics as well as possess rich stock of flora and fauna.

Salt affected soils in the state are more in the Saurashtra and Kutch areas. Salinity and sodicity related reduction in crop yield will be more if the crop/variety grown is not salt tolerant. A perusal of the productivity of horticultural crops indicates clearly that the average productivity is lower in these zones as compared to the state average. Conservation of natural resources and their judicious use have paramount importance in sustaining crop productivity. It has therefore become necessary to frame a long-term policy on conservation, management and sustainable utilization of all natural resources to address the newly emerging challenges. Given the deteriorating natural resource base, it will be utmost important to strengthen research and implement strategies for their conservation, improvement and efficient utilization.

Drs. G. Gururaja Rao, Anil. R. Chinchmaltpure, Sanjay Arora, M.K. Khandelwal and D.K. Sharma of Central Soil Salinity Research Institute have compiled the present Technical Bulletin covering soil and water resources of coastal Gujarat, causes and extent of coastal salt affected soils, soil and water productivity constraints, soil and water conservation measures, agricultural salinity management, conjunctive use strategies for irrigating the crops, agro-technological interventions for maximizing on-farm productivity and recommended agricultural practices for coastal Gujarat conditions. The technologies have been tested in different parts of the coastal Gujarat and found to be cost effective. This will help the farmers of the coastal areas to bring saline lands under cultivation and restore the ecological balance of the state. I congratulate the scientists for bringing out this Technical Bulletin for the benefit of researchers, planners, developmental agencies and farmers of the region.

(Alok K. Sikka)

19 November 2013
New Delhi 110012

EXECUTIVE SUMMARY

Soil salinity is an environmental constraint affecting millions of hectares of once productive land. Besides huge economic losses, rapid salinisation of land and water resources is inflicting severe environmental damages particularly in the irrigation commands of the coastal and inland areas, where salinity increase has chartered a parallel path with the irrigation development. The problem of salinity and alkalinity has affected about 6.73 million hectares of land in India of which 2.22 million hectares are present in Gujarat State. While this problem has already caused immense loss to the agriculture in the state, its further spread poses a grim picture and thus needs a holistic approach for its management. The problems of environmental degradation in Gujarat state are as diverse and complex as the eco-logical fabric of the state. While some of the problems are widespread and operate over long term, the others are mainly localised and more intensive in their impacts. Soil and water salinity problems are essentially multi-sectorial and are complex in nature. Vast areas are in imminent danger of turning barren and production and productivity have simply declined due to secondary salinisation. Soil salinity problems are further compounded where the ground water is highly saline and such areas *by and large* remain barren for want of economically feasible technological interventions and thereby affecting the livelihood of the farmers because of low productivity of the existing farming practices.

Coastal saline soils occur along the 8129 km long coastline of India. The coastal soils exhibit a great deal of diversity in terms of climate, physiography and physical characteristics as well as in terms of rich stock of flora and fauna. Over exploitation of ground water, unscientific management of water resources including use of saline water, inadequate recharge of ground water, deforestation, development of salt and other mining industries are some of the reasons for the development of salinity. But, in the coastal area, the major contributing reason is the ingress of sea water and transportation of saline coastal sands through wind.

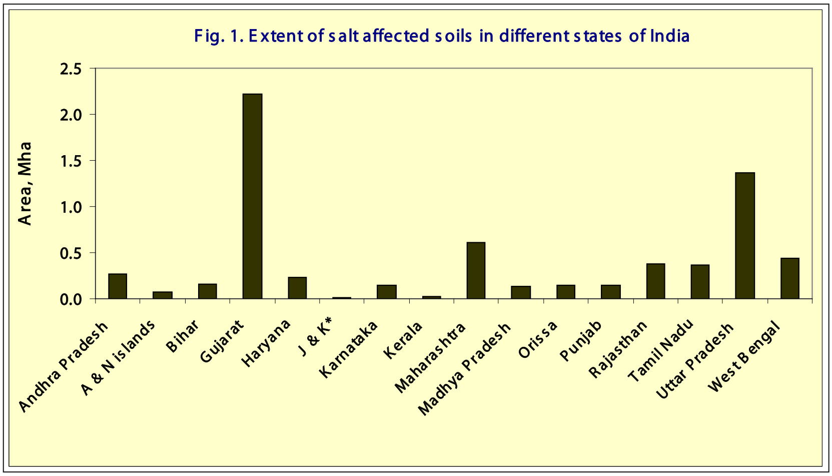
The major causes of soil salinity and lowered productivity of agriculture land in the coastal Gujarat comprise inadequate drainage leading to water logging during monsoon, poor physical condition of soil restricting crop production and nutrient availability, prevalence of poor quality ground waters, high summer temperature resulting in salinization, high soil osmoticum leading to decreased crop production, sea water intrusion making ground water saline and thus affecting soil and crop growth, poor nutrient availability and restriction of crop cultivation to monocropping system. The above features in the coastal saline areas affect the society to a greater extent finally resulting in drop in property values, lowered returns to the farmer, health hazards, lowered crop yields, poor economic status and finally leading to poverty and population movement.

Natural resource management is an important issue that invariably affects all sections of people and sectors of economy. Thus conservation of natural resources and their judicious use have paramount importance. Under such a scenario, it has become necessary to frame a long-term policy on conservation, management and sustainable utilization of all natural resources to address the newly emerging challenges. Since agricultural development with positive growth and long term sustainability cannot thrive on a deteriorating natural resource base, it will be utmost important to strengthen research and strategies for their conservation, improvement and efficient utilization. Keeping this in view and also to bring many saline areas in the coastal Gujarat under production system, a detailed account on resource availability, their characterization, issues pertained to salinity of soils, ground water, their characterisation, diagnosis of salinity of soils and irrigation waters, various management strategies salinity management comprising soil, water and crop interventions with special reference to coastal saline soils of Gujarat in the form of Technical Bulletin has been brought out.

A thorough insight has been made to promote the ideal technological interventions for different situations (low to high saline areas), conjunctive use of saline ground water with surface water for enhancing on-farm productivity, water conservation strategies and ideal packages of practices for the crops grown in the coastal areas with an aim to provide the farmer with technically feasible interventions for obtaining sustainable crop production for the saline wastelands.

1. Soil Salinity

Soil salinity is one of the main environmental problems affecting extensive areas of land in both developed and developing countries. It is the product of complex interaction of many variables, when lessen the current and/or potential capability of soil to produce goods and services. In general, the subsequent changes in land use patterns mainly due to agricultural intensification processes together with many unfavorable natural conditions have accelerated soil salinity problems in many parts of the world. The problem of salinity and alkalinity affected about 6.73 million hectares of land in India. While the problem has caused immense loss to agriculture, particularly in irrigation command areas, its further spread provides a grim picture. Soil salinity problems are further compounded where the ground water is highly saline and such areas *by and large* remain barren for want of economically feasible agro-technological interventions.



It is report-ed that about 6.73 Mha of land is salt affected in India (NRSA and Associates,1996) of which 2.22 Mha is present in Gujarat State (Fig. 1). The problems of environmental degra-dation in Gujarat state are as diverse and complex as the eco-logical fabric of the state. While some of the problems are widespread and operate over long term, the others are mainly localised and more intensive in their impacts. Soil and water salinity problems are essentially multi-sectorial and are complex in nature. Vast areas are in imminent danger of turning barren and production and productivity have simply declined due to secondary salinisation. Soil salinity problems are further compounded where the ground water is highly saline and such areas *by and large* remain barren for want of economically feasible technological interventions and thereby affecting the livelihood of the farmers because of low productivity of the existing farming practices. The adverse effects of salinity have put the food and nutritional security at stake while creating environmental pollution and affecting health.

Since degraded natural resources like soil and water and low soil fertility are the major constraints to increase and stabilize agricultural production, efforts must be made to conserve the vital resources. Rainwater management and the implementation of soil conservation programme hold the key to an ecologically balanced improvement in the

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quality of rain fed agriculture. Over-exploitation of ground water resulting in depletion of ground water table makes the present cropping systems unsustainable. Excessive withdrawal of ground water in coastal region has led to the intrusion of seawater leading to soil salinisation, pollution of drinking water supplies and large-scale migration of people from the affected areas. A detailed account on resource availability, their characterization, issues pertained to salinity of soils, ground water, their characterisation, diagnosis of salinity of soils and irrigation waters, various management strategies for coastal salinity management comprising soil, water and crop interventions with special reference to Gujarat state are described.

Land degradation due to soil salinity has substantial adverse economic impacts and hence social effects as it causes decline in agricultural productivity. Under natural conditions, salt affected soils support salt tolerant vegetation including trees, shrubs and grasses. Salt problems have also increased where saline ground water is used for irrigation. In many coastal areas, excessive exploitation of ground water has caused sea-water intrusion resulting in worsening of the salinity problems. Due to intensive grazing and anthropogenic activities, many salt affected lands have become denuded. The bare saline soils, resulting from changes in landscape hydrology either due to land development for agriculture or installation of irrigation and drainage schemes are capable of producing forage, fodder or fuel biomass. Farmers, on their lands becoming saline, have historically switched their cropping plan to more salt tolerant traditional crops or employed engineering solutions to remove salts from the soil and prevent their further accumulation. Majority of the traditional crops are not salt-tolerant enough to produce economic yields and engineering solutions are not economically feasible. The loss of productivity is especially crucial where farms are small and land is a scarce commodity. Thus bringing these idled lands into productive culture can be a very important social matter, as well as an economic issue for farmers who have only a few hectares of land.

For developing saline wastelands, the three approaches used by researchers are (i) developing salt tolerant traditional and non-conventional crops, which has met with some success specially with cereals; (ii) breeding of economically important salt sensitive species with wild salt tolerant relatives which showed only limited success; and (iii) evaluation of wild and highly salt tolerant species for their potential agronomic values and finally evolving desirable cultivars through traditional approach and biotechnological interventions. This approach mainly envisages at exploiting the genetic resource of salt tolerant plants which can come from plant communities such as salt deserts, salt marshes and mangrove swamps which were found to have agronomic and horticultural qualities (Gururaja Rao *et al.* 1997).

Salinized farmlands can be used without costly remedial measures and successful rehabilitation of degraded land is usually preferable in terms of resource conservation. Ground water too saline for irrigating conventional crops can be effectively used to grow economically potential salt tolerant plants and halophytes which can be grown using land and water unsuitable for conventional crops. Salt tolerant plants and halophytes can utilize land and water unsuitable for salt sensitive crops (glycophytes) for the economic production of fodder, fuel and other products. The possible domains for the use of salt tolerant plants in this area are (1) farmlands salinized by poor quality irrigation water (inland saline areas); (2) saline areas which overlie brackish groundwater aquifers; and (3) the coastal areas with fragile ecosystem.

1.1. Types and Causes of Salinity

1.1.1. The Issue of Soil Salinity

Concentration of soluble salts in the surface or near-surface soil horizon is a major problem with severe worldwide economical and social consequences. In terms of agricultural consequences, excessive salts in soil accelerate land degradation processes resulting in increased impact on crop yields and agricultural production. (Fig. 2).

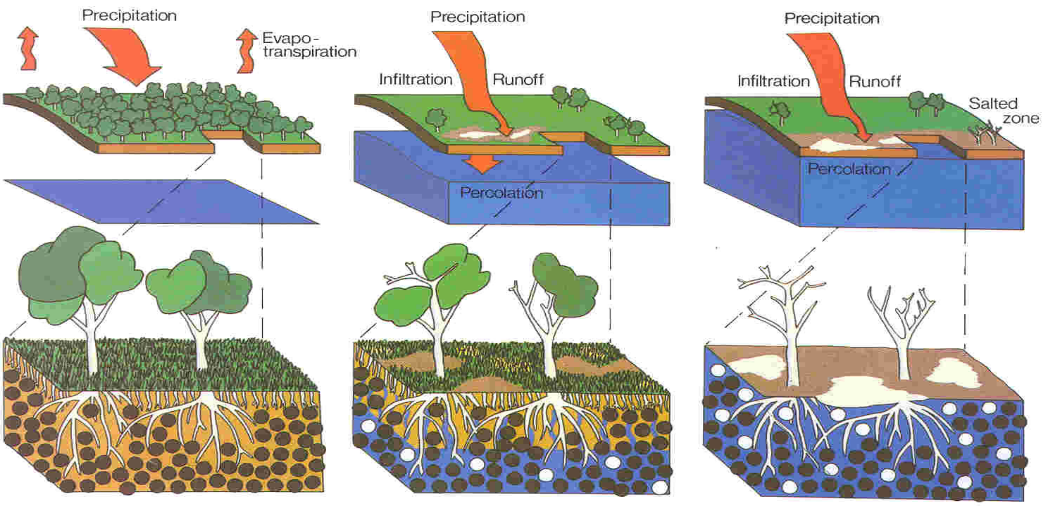

Fig.2. Formation of Salt Affected Soils

Increase in salt concentration in soil also affects some major soil degradation phenomena such as soil dispersion, sealing and crust formation and structural changes resulting in unstable and compacted soils.

Accumulation of soluble salts at the surface or near-surface of soil horizon is called salinization (Szabolcs, 1974). As a consequence, chlorides and sulphates of sodium, calcium and magnesium increase in their concentration resulting in increased electrical conductivity (EC). Further, presence of salt crystals, salt crusts and salic horizons result in presence of loose and quite porous granular structure in the top soil. The top soils become puffy in the presence of large amounts of sodium sulphate and appear moist when soils have calcium chloride and magnesium chloride.

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1.1.2. Natural or Primary Salinity

Salinity, primarily results from the accumulation of salts over long period of time, in the soil or groundwater, which is generally caused by two natural processes.

- The first is the weathering of parent materials containing soluble salts which break down rocks and release soluble salts of various types, mainly chlorides of sodium, calcium and magnesium, and to a lesser extent, sulphates and carbonates. Sodium chloride is the predominant soluble salt.
- The deposition of oceanic salt carried by wind and rain, forms the second cause. 'Cyclic salts' are ocean salts carried inland by wind and deposited by rainfall, and are mainly sodium chloride.

1.1.3. Secondary or human-induced salinity

Salinity occurs through natural or human-induced processes that result in the accumulation of dissolved salts in the soil water to an extent that inhibits plant growth. Secondary salinisation results from human activities (anthropogenic) that change the hydrologic balance of the soil between water applied (irrigation or rainfall) and water used by crops (transpiration).

1.2. Sources and Causes of Accumulation of Salts

The main causes of salt accumulation include:

- Capillary rise from subsoil salt beds or from shallow brackish ground water;
- Indiscriminate use of irrigation waters of different 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 topographical situation, especially in arid and semi-arid conditions.

1.3. Characteristics of Salt Affected Soils

In general, saline and alkali (sodic) soils are the two major groups of salt affected soils (Fig. 3), that can be distinguished on the basis of physico-chemical and biological properties and their geographical and geochemical distribution (Szabolcs, 1979). The above mentioned two categories of salt affected soils account for a very large fraction of salt affected soils in the world-over, there are transitional and borderline formations which are likely to have intermediate properties (FAO, 1988).

Saline and alkali soils are defined and diagnosed on the basis of EC and SAR determination made on soil samples and the information thus generated contributes substantially to the scientific agriculture based on USDA classification given in table 1. In India salt affected soils are mainly confined to the arid and semi-arid and sub humid (dry) regions and also in the coastal areas. The salt deposits are of sodium carbonate, sulphate and chloride with some calcium and magnesium.

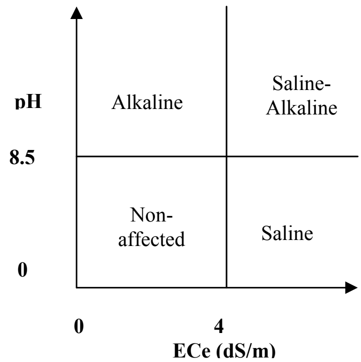

Fig. 3. Classification of soils into saline, alkaline and saline-alkali soils (Richards, 1954).

- These soils vary in nature from saline to non-saline sodic.
- In coastal regions saline soils are most predominant. They have high soluble salts (EC >4 dS/m) of chloride and sulphate of sodium, magnesium and calcium, Low ESP and have pH value less than 8.2.

Table 1. Classification of salt affected soils

Class	ECe, dS/m	pH(s)	ESP	Local Names
Saline	>4	<8.5	<15	Thur, Shora, Khar, Kari, Loma, Pokkati, Soulu
Saline-sodic	>4	>8.5	>15	Usar, Kallar, Karl, Chopan, Reh, Kshar, Bari
Sodic	<4	>8.5	>15	Rakkar, Bara, Usar, Karl, Chopan

1.3.1. Saline soils

These soils have electrical conductivity of the saturation extract more than 4 dS m^{-1}, the exchangeable sodium percentage less than 15 and the pH is less than 8.5. With adequate drainage, the excessive salts present in these soils may be removed by leaching thus bringing them to normalcy. Saline soils are often recognized by the presence of white crusts of salts on the surface. The important soluble salts comprise cations viz., sodium, calcium and magnesium with low amounts of potassium and anions viz., chloride, sulphate and some times nitrate. Owing to the presence of excess salts and the absence of significant amounts of exchangeable sodium, saline soils generally are flocculated and as a consequence the permeability is equal to or higher than that of similar non-saline soils.

1.3.2. Saline–alkali soil

These soils will have electrical conductivity of the saturation extract more than 4 dS m^{-1}, the exchangeable sodium percentage greater than 15 and the pH is seldom higher than 8.5. These soils form as a result of combined process of salinisation and alkalisation. As long as excess soluble salts are present, these soils exhibit the properties of saline soils. Leaching of excess soluble salts downward, the properties of these soils will become like that of nonsaline alkali soils. On leaching of excess soluble salts, the soil may become strongly alkaline (pH reading above 8.5), the particles disperse and the soil becomes unfavourable for the movement of water and for tillage.

1.3.3. `Non-saline alkali soil

Alkali soils which are known as Sodic or Solonetz have their exchangeable sodium percentage greater than 15, the electrical conductivity less than 4 dS m^{-1} and the pH range between 8.5 and 10. The exchangeable sodium content influences significantly the physical and chemical properties of these soils. As the ESP tends to increase, the soil tends to become more dispersed. These soils are also known as sodic soils or solonetz. Some times distinction is made between alkali and sodic soils especially in Vertisols, where the term 'sodic' is preferred as pH of these soils increases slowly with increase in ESP.

In addition to the parameters proposed by the USDA, Indian scientists considered the nature of soluble salts. Further, the pH value of 8.5 is too high, as isoelectric pH for precipitation of $CaCO_3$ at which sodification starts is 8.2 and mostly the pH is associated with the ESP of 15 or more (Abrol et al. 1980). The classification according to the Indian system is presented in Table 3. As there are large Vertisol areas in the country as indicated in the Australian System, the limit for ESP for defining sodic soil can be appropriately lowered (Tables 2 - 4).

Table 2. Properties of Saline, Saline-Alkali and Nonsaline -Alkali Soils

Properties	Saline soils	Saline alkali soils	Nonsaline-alkali soils
Electrical conductivity (dS m^{-1})	> 4.0	> 4.0	< 4.0
pH	< 8.5	> 8.5	> 8.5
Exchangeable Sodium Per cent	< 15	> 15	> 15

Table 3. Indian System of classification

Soil Characteristics	Saline soils	Alkali soils
pH	< 8.2	> 8.2
ESP	< 15	> 15
ECe	> 4 dS m^{-1}	Variable, mostly < 4 dS m^{-1}
Nature of soluble salts	Neutral, mostly Cl^-, SO_4^{2-}, HCO_3^- may be present but CO_3^{2-} is absent.	Capable for alkaline hydrolysis, preponderance of HCO_3^- and CO_3^{2-} of Na^+

Table 4. Australian System of Classification

Soil Type	Category		
Saline soils based on per cent salt content	Non saline <0.1% NaCl	Saline Loam > 0.1% Clay > 0.2% NaCl	Highly saline NaCl > 0.3% NaCl In B horizon
Sodic soils, based on ESP	Non-sodic < 6	Moderately sodic 6 - 14	Highly sodic > 14
Alkaline soils based on pH	Non-alkaline < 8.0	Alkaline 8.0 – 9.5	Strongly alkaline > 9.5

It is inferred from the study that at salinity of $\leq$ 2 dS m^{-1}, the Vertisol can be grouped as sodic if the ESP is > 6 and >10 in clayey and silty clayey soils, respectively. Similarly, at salinity of $\leq$ 4 dS m^{-1}, the Vertisol can be grouped as sodic if the ESP is > 13 and >21 in clayey and silty clayey soils, respectively (Table 5). Whereas at higher salinity ie., > 6 dS m^{-1} even at fairly high ESP also, the soil Ks and dispersion are not affected adversely. It can be fairly concluded that the coupled salinity and ESP values may be considered as the limit for sodic class and needs further attention for deciding minimum data sets for future management of saline Vertisols.

Table 5. Grouping of Sodic Vertisols

Texture	**Soil salinity**		
	$\leq$ 2 dS m^{-1}	$\leq$4 dS m^{-1}	$\leq$6 dS m^{-1}
	ESP		
Clay	>6	>13	>18
Silty clay	>10	>21	>32
Overall Vertisols	6-13	13-20	20-32

1.3.4. Constraints

- Excess sodium on the soil exchange complex and/or soluble salts in the soil reduces the productivity of these soils.
- Soil physical condition, particularly soil structure sets posing problem of water and nutrient availability.
- These soils show micronutrient deficiency.

1.4. Soil Salinity Problems in the inland areas

Salts are not alien to the land. They are present since time immemorial as part of weathering of rocks and minerals constituting the soil fabric. Salt lands are formed only when these salts are accumulated beyond a certain proportion. Natural salty lands predate human civilization. The earliest occurrence of salt lands dates back to 2400 BC from the Tigris-Euphrates alluvial plains (Russel et al., 1965). The salt affected soils have always existed on the landscape in India. Their presence was felt only when

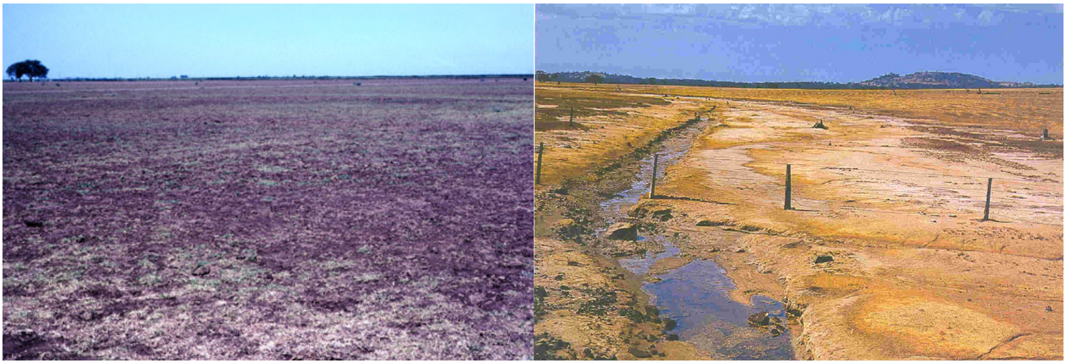

Fig. 3. Salt affected black soil in Gujarat coast (Near Cambay)

pressure on agricultural lands increased. Soil salinity problems in irrigation commands develop whenever soil and hydrological conditions favour the accumula-tion of soluble salts in the root zone. The rise in water table, a common feature in arid and semi-arid regions, once reach between 2-3 m below the soil surface, contributes substantially to evaporation from the soil surface and water uptake resulting in gradual build up of salt, leading to salinisation of the soil (Fig 3-4).

1.4.1. Soil Sodicity and Sub-Soil Salinity

Sodic soils have a low concentration of soluble salts, but a high percent of exchangeable Na^+; i.e. Na^+ forms a high percent of all cations bound to the negative charges on the clay particles that make up the soil complex. The negatively charged clay particles are held together by divalent cations. When monovalent cations such as Na^+ displace the divalent cations on the soil complex, and the concentration of free soluble salts is low, the complex swells and the clay particles separate (*'disperse'*). Dispersion is influenced by mineralogy of the clay, concentration of cations present in the soil solution and/or absorbed on the soil-exchange complex (Shainberg et al. 1997; Agassi et al., 1981). Susceptibility to dispersion also increases with the decrease in concentration of salts in the soil solution (Morin and Van Wimkel, 1996) also as the proportion of monovalent sodium increased relative to the divalent cations i.e. Ca^{++} and Mg^{++} (Levy et al., 1994). As per the USDA Salinity Laboratory, a soil is said to be sodic when its ESP is greater than 15, but in Australia it is considered sodic when the ESP is greater than 6. This lower threshold is due to Australian soils having a low content of other soluble cations, particularly Ca^{2+}, which help to stabilise clay colloids during leaching.

If the concentration of soluble salts is sufficiently low, hydrolysis of the sodic clay will occur, creating a highly alkaline soil. The process of sodicity is complex and occurs over a long period of time. Initially, salts that have accumulated within the soil profile, from either airborne deposition or mineral weathering, cause the clay fraction of the soil to become saturated with sodium. Subsequently, leaching of the profile, either by rainwater over prolonged periods, or by irrigation with fresh water, lowers

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the electrolyte concentration and the clay particles disperse. Further leaching washes the dispersed clay particles deeper into the profile where they block pores and reduce percolation of water. The soil then is very slow to drain, and is readily waterlogged (Fig. 5).

Fig. 5. Highly degraded sodic soil

In semi-arid environments, soil profiles are commonly saline/sodic, where the salts accumulate due to low permeability of the sodic subsoil. In theory, if sufficient salts accumulate, the threshold electrolyte concentration for flocculation will be exceeded and the clay will flocculate and take on pseudo-structure. However, if permeability and leaching increase, the subsequent dilution of salts result in dispersion of the colloids. Consequently, a quasi-steady state between flocculation and dispersion processes is maintained.

In saline/sodic soils water infiltration is slow, and salts derived from rainfall or weathering reactions accumulate in saturated zones in the subsoil. The seasonal and spatial variation of salt accumulation in the root zone not influenced by groundwater processes and rising water table has been denoted as 'transient salinity' (Rengasamy, 2002). This transient salinity fluctuates with depth, mainly due to variations in seasonal rainfall pattern. Transient salinity is extensive in many landscapes dominated by subsoil sodicity.

1.5. Coastal Saline Soils

Coastal saline soils occur along the 8129 km long coastline of India. Salinity problems in coastal areas occurred during the process of their formation under marine influences and subsequent periodical inundation with tidal water, and in case of low lands having proximity to the sea, due to high water table with high concentration of salts in it. The coastal soils exhibit a great deal of diversity in terms of climate, physiography and physical characteristics as well as in terms of rich stock of flora and fauna. These soils comprise deltas, lacustrine fringes, lagoons, coastal marshes and narrow coastal plains or terraces along the creeks. About 3.093 M ha of coastal soils are widely distributed in the coastal belt of West Bengal, Orissa, Andhra Pradesh, Pondicherry, Tamil Nadu, Kerala, Karnataka, Maharashtra, Gujarat, Goa and Andamans and Nicobar Islands. The coastal soils may be either saline or acid sulphate in nature. The saline soils are dominant with NaCl and Na_2SO_4 with abundance of soluble cations in the order of Na>Mg>Ca>K and Chloride as the predominant anion. The major problems encountered in these areas are:

- These lands are subjected to the influence of tidal waves and periodical inundation by tidal water;

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- Shallow water table enriched with salt contributes to increase in soil salinity during winter and summer months;
- Heavy rainfall resulting in excess water during *Kharif* season;
- Poor surface and subsurface drainage conditions;
- Lack of good quality irrigation water and acute salinity during *Rabi*;
- Poor socio-economic conditions of the farming community limiting introduction of high investment technologies.

1.5.1. Characteristics of Coastal Salt Affected Soils of the State

The coastal salt affected soils in Valsad and Surat districts are medium to heavy in texture and greyish to dark brown in colour. Their permeability is low to very low. The pH tends to increase with the depth and alkaline at all the depths. While at some pockets the salt accumulation is found at the surface at some other locations it tends to increase with the depth. The sodicity (ESP)does not show any regular trend with the depth.

In Bharuch district the coastal soils are reported to be heavier and clayin texture throughout the depth. The pH ranges from 8.6 to 9.5 and the EC_2 (1:2) from 0.22 to 8.1 dS m^{-1}. The latter tends to increase with depth. The ESP varies from about 5 to about 53, with an increasing pattern with depth. The permeability of these soils is also very low.

In middle Gujarat coastal area (Gulf of Cambay), the soils are silty loam at the surface and are clay loam to clay at the sub surface. The ECe varies from 9 to 118 dS m^{-1} and ESP from 10-81. The pH and ESP tend to increase with the depth in the soil profile. But the salt accumulation shows a reverse trend indicating its accumulation at the surface through capillary rise. They are moderately calcareous and the hydraulic conductivity ranges from 0.09 to 1.28 cm/h.

The coastal salt affected soils of Saurashtra region are clay in texture with high amount of lime content. The pH ranges from 7.7 to 9.0 without much variation with the depth. The ECe also varies widely from 2 to as high as 20 dS m^{-1} with a tendency of reduction in salinity with depth. The ESP values are also generally high and values of around 50 is not uncommon. But there is no regular trend with depth at different locations.

Soils of Bhal area due to their physiography differ widely in their salinity/ alkalinity problems. While the salinity variations are reported to be from 0.79 to as high as 282.5 dS m^{-1}, the ESP variations are from 11.3 to 30.0. Basically these are clay to clay loam in texture and calcareous in nature with very poor permeability.

In the Rann of Kutch, the surface layer of these soils is blocky with clay or silty clay in texture but, becomes lighter with depth. The pH ranges form 7.8 to 8.4 and the salt does not show any regular pattern with depth. Occurrence of gypsum in the profiles has been reported.

1.6. Causes and Extent of Coastal Salt Affected Soils in the state

The presence of excess salts on the soil surface and in the root zone characterizes all saline soils. The main source of salts in the soil is the primary minerals in the exposed layer of earth's curst. During the process of chemical weathering the salt constituents are gradually released and made soluble. These salts are transported away from their source of origin through surface or groundwater streams. Over exploitation of ground water, unscientific management of water resources including use of saline water, inadequate recharge of ground water, deforestation, development of salt and other mining industries are some of the reasons for the development of salinity. But, in the coastal area, the major contributing reason is the ingress of sea water and transportation of saline coastal sands through wind.

Some of the studies indicated that the sea water intrusion has increased from 2.5 to 4.5 km during 1971 to 5 to 7.5 km during 1977. In the coastal belt from Bhavnagar to Una the sea water intrusion has been reported to be 1.3 to 4 km interior, while in Una to Madhavpur section the figure was 2.4 to 3.2 and Madhavpur to Okha it was 1-2.6 km. On an average, the annual intrusion of sea water has been worked out to be 0.5 km. But this figure is an old one and needs an attempt to update this.

1.7. Soil and Water Related Productivity Constraints

Salinity causes poor and spotty crops, uneven and stunted growth and poor yields. The primary effect of salinity is that it renders less water available to plants although water is still present in the root zone. This is because the osmotic pressure of the soil solution increases as salt concentration increases. Apart from the osmotic effect of salts in the soil solution, excessive concentration and absorption of individual ions may prove toxic to the plants and / or may retard the absorption of other essential plant nutrients. The major causes of soil salinity and lowered productivity of agriculture land in the coastal area mainly attributed by:

- Inadequate drainage, resulting in water logging during monsoon.
- Poor physical condition of soil restricting crop production and nutrient availability.
- Irrigation with poor quality underground water.
- High temperature especially during summer resulting in salinization by capillary river.
- High osmotic potential due to soil salinity, affecting the crop production.

- High water table conditions, developing into secondary salinization, affecting soil health and crop productivity.
- Sea water intrusion through high tides and black flow in river estuaries, affecting soil and crop growth.
- Poor nutrients availabilities including micro nutrients with special reference to zinc, in Saurashtra region lime induced iron chlorosis is also observed.
- Cultivation restricted to mainly mono cropping system.

1.7. The Repercussions of Salinity

The soil water relations are governed primarily by soil texture, structure, nature of clay minerals and the nature and extent of ions on the exchange complex. The salty soils having high exchangeable sodium are highly dispersed in nature and show poor soil-water relations. The replacement of sodium with favourable cations like calcium improves the soil-water relations of salty soils. The hydraulic conductivity of these soils is several times less than that of normal soils of identical textural and mineralogical make-up. The soil moisture content particularly in alkali soils decreases rapidly due to evaporation at the surface, but layers below the surface depth continue to remain wet, as the lower depth due to poor hydraulic conductivity does not replenish moisture at the surface. Salinity build-up in the soil makes the land with vegetation gradually barren (Fig. 6)

Fig. 6. Agricultural fields turning barren due to salinity

1.8. Soil salting costs to the earth

- Soil salting leads to deterioration of farms' natural features – **Property values drop**;
- Reduced workable land results in decreased productivity **– Less returns to the farmer** ;

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- The quality of farm water supplies is reduced **– Lower crop yields**
- Time and money are lost in reclamation **– Poor economic status**
- The prosperity of the community suffers – Results in poverty
- The effects of soil salting on a community can be drastic. As land produces less, farm incomes drop and spending within community decreases – **Population movement**
- The quality of water supplies for towns, livestock and domestic purposes deteriorates – **Health hazards.**
- The physical environment changes too. Rivers and streams receive salt-laden run-off and silt as soil structure changes and erosion occurs – **Affects life processes**

1.9. Impact of Salinity/ Sodicity on Crop Productivity

The salinity/sodicity of the soil adversely affects the crop productivity. The reduction in the crop yield will be more if the crop/variety grown is not tolerant to salinity/ sodicity. The salt affected soils in the state are more in the Saurashtra and Kutch areas. A perusal of the productivity of horticultural crops indicates clearly that the average productivities are lower in these zones as compared to the state average. Regarding the productivities of vegetable crops and spices and condiments, in 5 out of the 8 districts they are lower than the state average.

2. Soil and Water Resources

Soil, water, vegetation and the weather form the very essence of all kinds of life and provide support to its varied activities. Natural resource management is an important issue that invariably affects all sections of people and sectors of economy. Thus conservation of natural resources and their judicious use have paramount importance. These resources are subjected to various kinds of deterioration and indiscriminate exploitation. Under such a scenario, it has become necessary to frame a long-term policy on conservation, management and sustainable utilization of all natural resources to address the newly emerging challenges. Since agricultural development with positive growth and long term sustainability cannot thrive on a deteriorating natural resource base, it will be utmost important to strengthen research and strategies for their conservation, improvement and efficient utilization.

2.1. Soil Resources

Soil, an important natural resource on which the edifice of life exists consists of inorganic and organic (living and non-living) material whose characteristics depend on the five soil forming factors: parent material, topography, climate, vegetation and time. The land surface of the country is spread over an area of 328.73 Mha and represented by red and laterite soils (117.2 Mha), black soils (73.5 Mha), alluvial soil (58.4 Mha), desert soils (30 Mha) etc. About 57 per cent of the total geographic area of the country is suffering from various forms of degradation – water erosion, wind erosion, chemical and physical deterioration. Over 5.3 billion tonnes of top soil alone is lost every year through erosion resulting in a loss of around 8 M tonnes of plant nutrients and 3 M tonnes of food grains. In addition, about 9.4 M ha of land is suffering from water logging and soil salinity in varying degrees. Soil resources are also shrinking at an alarming rate of 0.25 M ha/annum due to rapid industrialization and urbanization. India's share in land resources is only 2%, on which 18% of the world's population and over 15% of the world's livestock survive.

2.1.1. Threats to Soil Resources

The massive post-independence development of irrigation has brought sufficient water for crops in millions of farms in India. Irrigation development, though a major factor in India's ability to enhance food production in irrigated areas and attain self-sufficiency in cereal grain production, in many canal commands, a rise in water table has been noticed consequent leading to the degradation of soils through water logging and secondary salinisation.

2.1.2. Soil degradation

The primary cause of degradation is the demographic pressure on land, resulting in loss of vegetative cover through deforestation (Fig. 7). The land degradation occurs mainly due to uncontrolled deforestation followed by agricultural/farm activities. Hence, planning for productive land use is necessary to meet the growing challenges of food security since the land resource is not expandable physically. It is estimated that in India, about 174.4 M ha of land is potentially exposed to various degradation forces like Water (153.2 Mha) and wind erosion (15.0 Mha). About 40.0 M ha is subjected to floods and 22.0 Mha is not reclaimable for agri-cultural use. Loss of vegetative cover results in huge run-off, lower-ed recharge of ground water and subsequently development of salinity**.** Salt affected soils occur at a tune of 6.73 Mha in our country. Salinisation or soil degradation caused by increase of salt in the soil is caused by incorrect irrigation management or intrusion of sea water into coastal

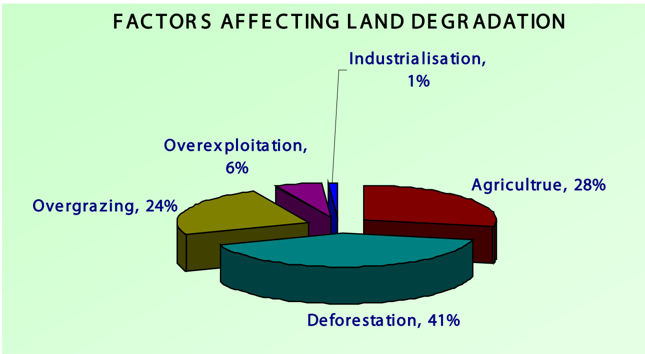

Fig. 7. Factors influencing land degradation

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soils arising from over-abstraction of ground-water. It is severe on irrigated lands of the dry zone. It reduces crop yield and in severe cases causes complete abandonment of agriculture.

2.1.3. Erosion

Among various soil degradation processes, soil erosion is the most serious degradation problems in the Indian sub-continent. When it rains so hard that the water cannot infiltrate into the soil fast enough, runoff occurs. Runoff picks up soil particles and carries them off the field and this is called erosion. The loss of top soil results in reduced productivity.

2.1.4. Water erosion

Water erosion, the most serious degradation problem in India, results in loss of top soil in about 130.5 Mha and terrain deformation in 16.4 Mha. About 29% of eroded soil is permanently lost to the sea and 61% transferred from place to place and about 10% is deposited in reservoirs leading the low storage capacity.

2.1.5. Wind erosion

This is a serious problem in the arid and semi-arid regions, particularly in the states of Rajasthan, Haryana, Gujarat and Punjab. In India wind erosion is moderate to severe in arid and semi-arid regions of the north-west, covering an area of 86000 km^2. It has been estimated that the soil moves at the rate of 222 kg hr^{-1} at a wind speed of 29 km hr^{-1} over a strip of 300 m width and one meter high from the ground.

2.1.6. Chemical deterioration

Loss of nutrients or organic matter and accumulation of salt or pollutants are the main causative factors in chemical deterioration. Nutrient depletion and loss of organic matter lead to decline in soil fertility and microbial biomass. Besides, excessive leaching of basic cations cause reduction in base saturation resulting in soil acidification.

2.1.7. Land – Weathering

Physical process of breaking up of rocks is called land-weathering. Physical elements such as annual change in temperature, humidity, and rainfall are responsible for it. In addition, plants and trees also contribute in this process through the expansion of their roots.

2.1.8. Land degradation by human activity

Human beings are engaged in making land useless and degraded by their activities. These (activities) include deforestation, large-scale land mining, mismanagement of urban waste and effluents of factories etc. that give open invitation to land erosion. Deep ditches, heaps of soil, stones and waste destroy the usefulness and natural beauty of land. The effluents and polluted water of factories, urban sewage and waste make land unsuitable for agriculture and other uses.

3. Physiography of Gujarat State

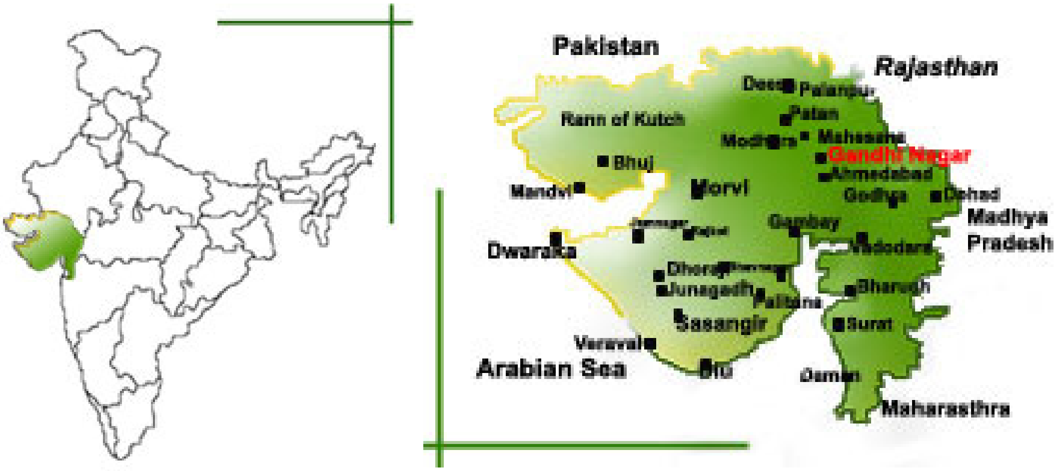

Fig. 8. Physiography of Gujarat State

Gujarat is situated between 20°1' and 24°7' north latitudes and 68°4' and 74°4'east longitudes on the west coast of India (Fig. 8). Gujarat state, a Western province in India covers an area of 1,96,024 km² with a population density of 210 km^{-2} is bounded on the west by the A*rabi*an sea, the North-West by Pakistan, the North by Rajasthan, the East by Madhya Pradesh, on the South and South - East by Maharashtra.

It comprises the Peninsula known as Saurashtra, the barren, rocky North-East containing the Rann of Kutch, and the mainland from the Rann of Kutch and Aravali hills to the river Damanganga. The main rivers flowing in Gujarat are Sabarmati, Mahi, Narmada and Tapti. The Tropic of Cancer passes through the Northern border of Gujarat.

3.1. The Scenario in Gujarat

While deep black and coastal alluvial soils are predominant in South Gujarat, Middle Gujarat and the Saurashtra peninsula has medium black soils and calcareous medium black soil, respectively. The Bhal region has a type of soil that is clay in texture, which prevents percolation of water making large parts marshy during monsoons and extremely saline. Gujarat state is endowed with great diversity of ecosystems ranging from deserts,

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scrublands, grasslands, deciduous forests, wetlands, mangroves, coral reefs, estuaries and gulfs. About 33.5% of the State's geographical area is already subjected to varying degrees of soil erosion. The main causative factors for this are high intensity rainfall over short duration and in some places hilly terrains. Salinity ingress, sub-surface intrusion of sea water in regions of high ground water discharge affects about 13524 sq. km area. Over-extraction of ground water for highly intensive cropping practices also resulted in soil salinity.

The heavy industrialization along the "Golden Corridor" i.e., Vapi to Mehsana belt and the concomitant release of effluents also affected the natural resources particularly, ground water, flora and fauna. Industrial discharges into Gulf of Kutch affected the fish and coral reef production. Similarly, salt manufacturing in the Little Rann coupled with heavy vehicular movement pose serious threat to the wild ass population, which eventually migrated to Great Rann of Kutch, North Gujarat, and Bhal areas. Expansion of saltpans also affected the population of flamingos. Exploitation of forests for timber and fuel wood has been responsible for fall in density to forest cover. Grassland areas reduced to a greater extent, the fodder needs are partially met by the private landholdings.

3.2. Salt Affected Agro Ecological Sub-Regions

The eight agro climatic zones identified by the Gujarat Agricultural University have been further sub divided into Agro Ecological Sub Regions (Table 6). The coastal agro-climatic zones which are salt affected and their major characteristics are as below.

Table 6. Major characteristics of coastal salt affected agro ecological situations of different agro climatic zones (Source: NARP Status Report, GAU)

Agro climatic zone	Soil type	Soil Texture	Rain- fall	Principal agricultural Crops	Area ('000 ha)	Irrigation %
South Gujarat heavy rainfall	Salt affected	Clay to clay loam	1200-1500	Paddy, Sugarcane, Horticultural crops	21	52
South Gujarat	Black cotton, salt affected	Clay to clay loam	900-1000	Paddy, Cotton, Sorghum, Pulses	14	56
Middle Gujarat	Medium black, salt affected	Clay loam to silt loam	500-700	Paddy, Pearl millet, Cotton, Castor. Tobacco and banana	26	78

North Saurashtra	Saline Sodic	Clay	500-600	Groundnut, Sorghum, Pearlmillet, Wheat	187	22
	Coastal alluvial	Clay loam to clayey	300-400	Groundnut, Sorghum, Pearl millet	181	9
	Coastal alluvial	Silty clay	500-700	Groundnut, Sorghum, Pearlmillet, Chick pea	299	22
	shallow black/ Coastal alluvial	Sandy loam to clay loam	300-400	Groundnut, Sorghum, Pearlmillet, Sesamum	31	4
South Saurashtra	Low lying saline sodic with saline ground water	Clay	700-750	Cotton Sorghum	50	10
	Mixed red and black and salt affected	Sandy clay loam to clay loam	750-1000	Groundnut Sugarcane, banana, Coconut and other horti-cultural crops	96	15
	Coastal alluvial	Sandy loam to silty clay loam	750-1000	Groundnut, sesamum, Sorghum, Pearl millet, and horti-cultural crops	286	18
Kutch	Hydromorphic salt affected		400-500	Cotton, Pulses, Sorghum, Cluster bean, Fruit crops	49	8
	Highly salt affected	Clay loam to silt loam	350-400	Cotton castor		
Bhal	Sodic	Sandy loam to clay	550-650	Cotton Sorghum wheat cumin, dill seed	160	7
	Highly saline	Sandy loam to clay	600-700	Forestry	-	-

3.4. Water Quality-Related Problems in Irrigated Agriculture

3.4.1. Salinity

Gujarat state is characterized as arid and semi-arid region. Rain variation and successive droughts are common features. For irrigation, groundwater thus remains as the only way out. Overexploitation of groundwater is hence a consequent resultant. Overexploitation of groundwater depleted the water table at certain regions. The coastal association caused an increased salinity in groundwater. This leads to the use of saline groundwater (TDS > 2000 ppm) for irrigation in many areas. Huge quantities of groundwater in recent years is mined from the deep confined aquifers which are not replenished usually.

The depleting water table, increasing salinisation of groundwater and lack of alternative source for irrigation compelled the people to use the saline water for agriculture which resulted in development of salinity of the soils. Water from deep aquifers in North and Central Gujarat has a high TDS level. Water samples from places like Dholka, Kheda, Ahmedabad and the hard rock areas show an unfit attribute for permissiveness in irrigation purpose.

The increased frequency of water availability and acceleration of cultivation of water intensive crops raised the salinity problem to severity. The availability of irrigation facility in Hansot and Ankleshwar talukas of Bharuch district had accelerated the cultivation of water intensive *Rabi* crops like sugarcane, paddy, banana and wheat. This, coupled with the fact that coastal region has a high amount of saline groundwater due to poor surface and subsurface drainage, lead to a rapid increase in groundwater level. There is an alarming rise in groundwater table by 0.3 m every year. The rise of water table up to the root zone for a long period of time has resulted in water logging. Moreover, the soil being of black cotton nature that has least percolation, most of the surface water is lost by evaporation rather than drainage leaving behind a crust of salt on the topsoil. This resulted in decline in agricultural productivity and erosion of asset base of farmers.

The salinity/sodicity of the soil adversely affects the crop productivity. The reduction in the crop yield will be more if the crop/variety grown is not tolerant to salinity/sodicity. The salt affected soils in the state are more in the Saurashtra and Kutch areas. A perusal of the productivity of horticultural crops indicates clearly that the average productivities are lower in these zones as compared to the state average. Regarding the productivities of vegetable crops and spices and condiments, in 5 out of the 8 districts they are lower than the state average.

Salinity in the coastal areas has resulted in many a repercussion for the people inhabiting such areas *viz.,* deterioration of farms' natural features leading to property losses; decreased productivity due to reduced workable land rendering the farmers to have less returns, Deterioration of quality of farm water supplies resulting in lowered crop yields, Poor economic status resulting from loss of time and money in reclamation, Low level of prosperity of the community resulting in poverty, Population movement in search of food, drop in farm income resulting the drop in spending ability within the community, poor quality of water supplies resulting in health hazards and the change in physical environment such as changes in soil structure that affects all life processes.

The coastal areas of Gujarat especially the villages lying within 20-25 km from the seashore are suffering from the problem of Salinity Ingress. Most of the rivulets that drain this region are seasonal at best and their water does not last beyond monsoon. The other aquifers like ponds, which get water from these rivers, also dry up as early as October.

The problem of water shortage has worsened over the last few years because of the cultivation of water intensive crops like Sugarcane, Banana, Betel nut leaves, wheat, and coconut. It has resulted in lowering of the water table and increased ingress of saline water. This has had far reaching implications for both household and agricultural uses of water as the availability of fresh water has steadily declined, thus there is increased dependence on outside agencies like the state and other civil society organisations for basic needs like drinking water etc. Since 1980s conflicts have arisen over the access to limited fresh water resources available in this region.

3.4.2. Water Infiltration Rate

Infiltration problem related to water quality occurs when the normal infiltration rate for the applied water or rainfall is appreciably reduced and water remains on the soil surface too long period or infiltrates too slowly to supply the crop with sufficient water to maintain acceptable yields. Although the infiltration rate of water into soil varies widely and can be greatly influenced by the quality of the irrigation water, soil factors such as structure, degree of compaction, organic matter content and chemical make-up can also greatly influence the intake rate.

In Gujarat state, the coastal saline soils are either clay or silty clay in nature and infiltration rates by and large are low to medium, thus enabling the water stagnation and water logging situations during monsoon. In Bhal area, Bara tract and Ghed area and under irrigation commands, this situation prevails. The problem is more severe in South Gujarat which has high clay soils. The ground water is also saline and thus can not be used as such for irrigation and hence conjunctive use of saline water with stored surface water hold promise.

3.4.3. Ion Toxicity

Certain ions (sodium, chloride, or boron) from soil or water accumulate in a sensitive crop to concentrations high enough to cause crop damage and reduce yields. Toxicity problems occur if certain constituents (ions) in the soil or water are taken up by the plant and accumulate to concentrations high enough to cause crop damage or reduced yields. The degree of damage depends on the uptake and the crop sensitivity. The permanent, perennial-type crops (tree crops) are the more sensitive. Damage often occurs at relatively low ion concentrations for sensitive crops. It is usually first evidenced by marginal leaf burn and interveinal chlorosis. If the accumulation is great enough, reduced yields result. The more tolerant annual crops are not sensitive at low concentrations but almost all crops will be damaged or killed if concentrations are sufficiently high.

In coastal Gujarat, the ions of primary concern are chloride, sodium and boron. The coastal saline soils and the ground water are predominantly rich in sodium and chloride and the toxicity of these ions is seen in all the crops grown in these areas. Boron ion problems are noticed in ground waters of certain parts of Bara tract. Although toxicity problems may occur even when these ions are in low concentrations, toxicity often accompanies and complicates a salinity or water infiltration problem. The ions accumulate to a greatest extent in the areas where the water loss is greatest, usually the leaf tips and leaf edges.

3.4.4. Miscellaneous

Several other problems related to irrigation water quality occur with sufficient frequency for them to be specifically noted. These include high nitrogen concentrations in the water which supplies nitrogen to the crop and may cause excessive vegetative growth, lodging, and delayed crop maturity; unsightly deposits on fruit or leaves due to overhead sprinkler irrigation with high bicarbonate water, water containing gypsum, or water high in iron; and various abnormalities often associated with an unusual pH of the water.

4. Soil and Water Conservation Measures

Both agronomic (contour farming, mulching, tillage, strip cropping and mixed cropping) and engineering measures (contour bunding, graded bunding, bench terracing on sloping lands) are deployed, depending upon soil and agro climatic situations. The strategies employed are :

- Land leveling
- Contour bunding (continuous/intermittent)
- Field bunding
- Graded bunding
- Mulching
- Peripheral bunding
- Tillage

- Gully plugging
- Gully erosion
- Strip cropping
- Mixed cropping
- *In situ* mulching and green manuring
- Reclamation bund

4.1. Contour bunding

Contour bunding means construction of bunds passing through points of equal elevation/height/contours. Contour bunds intercept the overland flow going down to some other sources, beyond point of use. Contour bunding is adopted up to 600 mm annual rainfall and 6% slope on soils with high permeability. It reduces soil erosion in sloping land by impounding runoff water behind bund. It is extremely useful measure in arid and semi arid area. It also increases infiltration of rain/water in soil and thus increases crop production by providing moisture for longer duration. Contour bunds are recommended in dry farming area having low rainfall and light textured soils on slope up to 6%. These are designed to accommodate 24 hr duration runoff at 10 year frequency interval. Surplus arrangements are provided to dispose excess runoff.

4.2. Graded Bunding

Graded bunds are constructed in relatively high rainfall areas. The excess water has to be removed out of the field to avoid water stagnation, especially in deep black soils. These bunds are outlets for safe removal of water. The channels of graded bunds are wide and shallow.

4.3. Broad Bed Furrow System

This system BBF has been developed at ICRISAT, Hyderabad, which comprises of broad bed of 100 cm wide with sunken furrow of 50 cm along the slope in heavy black soils. Two, three or four rows of crop can be grown in broad bed. The system of mixed cropping and intercropping is followed. The furrow helps in safe disposal or surplus runoff without causing erosion of soil. This system provides better-drained and more easily cultivable soil beds.

4.4. Contour Furrow

Contour furrow is also called as strip farming. The cropping is usually intermittent on strips or in rows with catchments area left fallow. The principle is to collect runoff from catchment area to improve soil moisture on the cropped area.

4.5. Development of Catchment Area and Storing Runoff Water for Recycling

In semi-arid areas, rainfall is short in duration and comprises of limited rainy days. The intensity of rainfall is high which gives high runoff. This is because high intensity of rainfall has low infiltration rate and runoff rate is therefore, very high. Therefore, catchment area, which has low-lying region, is selected and bunded for collection of runoff water. Sometimes, bulldozers or road rollers are used to form a saucer around the proposed tank and runoff water is collected and recycled for crop-plant use.

4.6. Check Dams Construction on Nalas and Off-Stream

Nala bunding work consists of construction of bunds of suitable dimensions across nala or stream to hold maximum runoff water to create temporary flooding in the stream with arrangements to drain water at suitable intervals. Such bunds depend upon the slope of the nala or off-stream and the quantity of water expected to flow. The impounding of water facilitates percolation of water into deeper soil profile. The water released from bunds will be free from silts and will have very low velocity, which is unable to cause erosion. Thus, water shall be utilized for optimum period.

4.7. Shallow dug wells

Shallow dug wells or *Virdas* are dug in low depressions in the land when the topography of the area is undulating and with depressions on the ground these structures harvest rainwater.

5. Rainwater Harvesting

The storage of rainwater on surface is a traditional technique and structures used were underground tanks, ponds, check dams, weirs etc. Water harvesting and artificial recharging to augment ground water resources has become a necessity and we should therefore develop and popularize some of the cost effective rainwater harvesting methods in urban and rural areas. The artificial recharge can be achieved by obstructing the flow of water, by storing the water, by spreading the water or by injection through wells and bore wells.

Water harvesting refers to collection and storage of rain water and also other activities aimed at harvesting surface and groundwater, prevention of losses through evaporation and seepage and all other hydrological studies and engineering interventions, aimed at conservation and efficient utilization of the limited water endowment of a physiographic unit such as watershed. Source of water, storage, duration and intended use of harvested water mostly decides the technique and design specifications of water harvesting structures. The main objectives of rainwater harvesting are:

- To conserve the surface run-off during monsoons
- To recharge the aquifers and increase availability of ground water
- To improve the quality of ground water where required
- To overcome the problem of flooding and stagnation of water during the monsoon season
- To arrest salt-water intrusion

There are two main techniques of rainwater harvestings.

- Storing the rainwater on the land surface for future use.
- Recharging the rain water to ground water.

The rainwater harvesting can be further elaborated as:

a. Surface water harvesting- over irrigation abstracted in pits, profiles, trenches, depressions, irrigation/percolation tanks/ponds, gravity wells, spreading channels, borrow pits, dual purpose channels, gully plugs, nala plugs, rock fill dams, anicuts, reservoirs, rivers, etc.
b. Sub surface water harvesting: sunken ponds, doruvu technology, horizontal and vertical drains and wells, recharging wells under gravity and inducement through laterals shafts as well
c. Deep sub surface water harvesting: mostly natural and induced recharge by injection and pumping of recharge shafts/wells in deeper layers

Surface water harvesting mostly needs one of the following tank (looking at the earth work and volume of water) to store the water for its subsequent usage in domestic and agriculture sectors. Surface water harvesting other than farm ponds, requires detailed investigations at the site and execution with enough care on stability of structure and overall system of use for drinking water/irrigation supply to rural sectors.

5.1. Farm Ponds

- Dugout farm ponds
- Embankment type farm pond
- Spring or creek fed ponds
- Off stream pond

5.2. Artificial Recharge of Ground Water

The process of artificially increasing the rate and amount of water entry in to the ground water reserves is known as artificial recharges. The artificial recharge is undertaken to conserve and dispose surface runoff and flow waters, augment the ground water availability and reduce or prevent salt water intrusion in coastal aquifers. Different surface methods used for artificial recharge include flooding method, basin method, ditch and furrow method, natural channel method, irrigation method, percolation tanks and channel bunding methods. The following are some methods used to recharge the ground water

5.2.1. Artificial Recharging Techniques

Artificial recharge to ground water is a process by which the ground water reservoir is augmented at a rate exceeding that obtaining under natural conditions or replenishment. Any man-made scheme or facility that adds water to an aquifer may be considered to be an artificial recharge system.

5.2.2. Pits

Recharge pits are constructed for recharging the shallow aquifer. These are constructed 1 to 2 m wide and to 3 m deep which are back filled with boulders, gravels, coarse sand.

5.2.3 Trenches

These are constructed when the permeable strata is available at shallow depth. Trench may be 0.5 to 1 m wide, 1 to 1.5 m deep and 10 to 20 m long depending on availability of water. These are back filled with filter materials.

5.24. Dug wells

Existing dug wells may be utilized as recharge structure and water should pass through filter media before putting into dug well.

5.2.5. Hand pumps

The existing hand pumps may be used for recharging the shallow/deep aquifers, if the availability of water is limited. Water should pass through filter media before diverting it into hand pumps.

5.2.6. Recharge wells

Recharge wells of 100 to 300 mm diameter are generally constructed for recharging the deeper aquifers and water is passed through filter media to avoid choking of recharge wells.

5.2.7. Recharge Shafts

For recharging the shallow aquifer which is located below clayey surface, recharge shafts of 0.5 to 3 m. diameter and 10 to 15 m deep are constructed and back filled with boulders, gravels & coarse sand.

5.2.8. Lateral shafts with bore wells

For recharging the upper as well as deeper aquifers lateral shafts of 1.5 to 2 m wide & 10 to 30 m long depending upon availability of water with one or two bore wells is constructed. The lateral shafts are back filled with boulders, gravels & coarse sand.

5.2.9. Spreading techniques

When permeable strata start from top then this technique is used. Spread the water in streams/ Nalas by making check dams, nala bunds, cement plugs, gabion structures or a percolation pond may be constructed.

5.3. Types of structures

5.3.1. Check dams

This may be a temporary structure constructed with locally available materials. The various types are: Brush wood dam, loose rock dam and woven wire dam. The main function of the check dam is to impede the soil and water removed from the watershed. This structure is cheap, but lasts about 5 years. A permanent check dam can be constructed using stones, bricks and cement. Small earth work is also needed on both sides. A little water is also stored above the dam. This water recharges the groundwater thereby the quantity of ground water is increased and quality improved.

5.3.2. Percolation Pond/Tank

The percolation pond is a multipurpose conservation structure depending on its location and size. It stores water for livestock and recharges the groundwater. It is constructed by excavating a depression, forming a small reservoir or by constructing an embankment in a natural ravine or gully to form an impounded type of reservoir. The capacity of these ponds or tanks varies from 0.3 to 0.5 mcft (10 000 - 15 000 m^3). Normally 2 or 3 fillings are expected in a year (season) and hence the amount of water available in one year in such a tank is about 1 mcft to 1.5 mcft (30 000 - 45 000 m^3). This quantity of water, if it is used for irrigation, is sufficient to irrigate 4-6 hectares of irrigated arable crops (maize, cotton, pulses etc.) and 2-3 hectares of paddy crop.

5.3.3. Irrigation Tank

The main function of this storage structure is irrigating crops. It is constructed below the above-mentioned structures in a watershed. Earthen bunds are reinforced with masonry to collect and store rainwater for irrigation. The cost of this tank (dam) depends upon the size, location and site condition. Water from the tanks is normally used to grow paddy and other comparatively more water consuming crops.

5.4. Benefits from Harvesting/Recharge

- The rising ground water will support irrigation and domestic requirement
- Mitigate ill effects of droughts, and contaminated water resources
- Reduces soil erosion and water from the productive fields
- Saving of energy for fetching water for domestic, agriculture purpose.
- Balance ecology of the catchment/command
- Overall increase in standards of farming communities.

6. Salinity Management

6.1. Agricultural scenario

Agriculture in Gujarat forms a vital sector of the state's economy (Fig. 9). It provides the required food grains for the state's population and raw materials for most of the agro-based industries. Unsuitable climatic conditions, land and water degradation, marine influence in saline area development in the coastal areas and secondary salinisation under irrigation command areas minimized the land suitable for arable farming. The difficulty of drainage in coastal areas and in the two Ranns has made a large part of the state agriculturally unproductive.

Fig.9 Cotton on coastal saline black soils of Bharuch district

The state's agricultural productivity because of the above features is low. The yields are poor that result from degraded soils, erratic rainfall, frequent droughts and floods, poor drainage and inadequate irrigation network. A characteristic feature of the state's agriculture is its cropping pattern un-proportionately dominated by cash crops. The high yield of cotton in fact the highest in the country, reflects the overall emphasis on cash crops, which have claimed the best agricultural land.

A higher percentage of the land is used for cultivation in central Gujarat. Kheda, Vadodara, Bharuch and Surat districts are the main contributors to the agricultural production of the state. Valsad has become India's first integrated horticulture district. The state produces a large variety of crops and its cropping pattern reflects the spatial

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variations in climate and topography. Groundnut (highest production in the country), cotton, Tobacco (second highest production in the country), isabgul, cumin, sugarcane, jowar, bajra, rice, wheat, pulses, pigeon pea and gram are the important crops of Gujarat. Another cash crop which has recently entered the field though in a few selected localities is banana. Plenty of mangoes for export as well as home consumption are part of cash crops.

6.2. Salinity Management

Reclaiming saline and sodic soils is a recurring and challenging problem. Reclaiming saline soils require sufficient leaching with good quality water to remove excess soluble salts from the root zone. The inhibiting factors generally include:

- Inadequate drainage because of high water table, low soil hydraulic conductivity and restrictive layers;
- An inadequate supply of good quality water for leaching; and
- The cost of irrigation to crops.

Factors inhibiting saline-sodic and sodic soils include the above plus the cost of availability of calcium sources used for exchanging the adsorbed sodium, and the difficulty of getting the calcium into the soil where reclamation can begin. Some of the technologies are briefly described below:

6.2.1. Reclamation of saline soils by leaching

Early reclamation practices involved leaching by water ponded on the soil surface. A general rule was to apply a given depth of water to remove 80% of the soluble salt from the same depth of soil. Removal of salts by ponding, though effective is time consuming and inefficient with respect to water use. Most arid soils contain large amounts of residual salts. As these soils are brought under irrigation, they are first tilled to a depth of few cm and then seeded. Irrigations if frequent enough, keep the salt moving downward in the profile. Salt damage does occur in areas encountered with poor infiltration and hydraulic properties.

6.2.3. Use of Mulches and other surface management to enhance leaching

Water and soluble salt movement through soil is a dynamic process. When sufficient water is applied for leaching, there is a net downward movement of water and salt. As the soil surface dries with the use of water by crops, the direction of movement may then reverse towards the water use. As the water is transpired or evaporated, most of the soluble salt is left in the soil where it accumulated until subsequently moved again by water. Thus, any practice that will reduce the upward movement of water and salt by reducing evaporation or by increasing infiltration will enable salt leaching and soil reclamation. Surface mulches reduce evaporation at the soil surface and enhance infiltration. Earlier studies indicated straw mulching effectively reduced evaporation from dry land cropped soils. Plastic mulches and even the soil mulching (scraping of top soil layer) could arrest the evaporation and thus the upward salt movement.

6.3. Reclamation and Management of Alkali soils

Pre-reclamation activities involve bunding, leveling and cultivation of the field before amendment application. Minimum land slope of 0.1 per cent to drain excess water has been recommended. Flushing of salts by applying heavy irrigation before amendment application was found helpful in decreasing the amendment dose.

6.3.1. Leaching

Leaching with water is the most effective procedure for removing salts from the root zone of soils. Leaching is most often accomplished by ponding fresh water on the soil surface and allowing it to infiltrate. Leaching is effective when the salty drainage water is discharged through subsurface drains that carry the leached salts out of the area under reclamation. Leaching may reduce salinity levels in the absence of artificial drains when there is sufficient natural drainage, i.e. the ponded water drains without raising the water table. Leaching should preferably be done when the soil moisture content is low and the groundwater table is deep. Leaching during the summer months is, as a rule, less effective because large quantities of water are lost by evaporation. The leached water should be carried through a drain which is lower than the root zone of the crop. It is important to have a reliable estimate of the quantity of water required to accomplish salt leaching. The initial salt content of the soil, desired level of soil salinity after leaching, depth to which reclamation is desired and soil characteristics are major factors that determine the amount of water needed for reclamation. A useful rule of thumb is that a unit depth of water will remove nearly 80 percent of salts from a unit soil depth. Thus 30 cm water passing through the soil will remove approximately 80 percent of the salts present in the upper 30 cm of soil. The quantity of water depends upon the amount of salt to be leached (Table 7).

Table 7. Quantity of water needed for lowering the salt

Per cent salt reduction	Amount of water required (in inches)
50 %	6
80 %	12
90 %	24

***Example*: If electrical conductivity is 8 dS/m and to reduce it to 4 dS/m, 6” of water is required.**

After leaching, the following points should be kept in mind.

- The first crop after leaching should be preferably green manuring which should be followed by paddy wherever feasible.
- The crops should be fertilized with 25 per cent extra fertilizer/nutrients especially during the initial years of reclamation along with plentiful of FYM/ any other organic matter.
- Whenever a crop other than paddy is raised, it should be planted at the mid-point of the ridge where the salinity will be minimum.
- The land should be continuously under cropping to prevent resalinization.
- Crop selection has to be made according to the salinity status and crop tolerance.

6.3.2. Amendments

In case of sodic soils, improvement implies the reduction of the amount of sodium present in the soil. This is done in two stages. Firstly, chemical amendments, which are rich in calcium, are mixed with the soil; the calcium replaces the sodium. Then, the replaced sodium is leached from the rooting zone by irrigation water. Gypsum is the most common amendment for sodic soil reclamation, particularly when sodic water is used for irrigation. Calcium chloride is highly soluble and would be a satisfactory amendment especially when added to irrigation water. Lime is not an effective amendment for improving sodic conditions when used alone but when combined with a large amount of organic manure it has a beneficial effect. Sulphur too can be effective.

Of the different amendments such as gypsum, pyrites, sulphuric acid, nitric acid, press mud, aluminum sulphate and Farm Yard Manure, gypsum followed by pyrites were found as the most useful because of their easy availability and cost considerations. Gypsum ($CaSO_4 \cdot 2H_2O$) has been utilized for many years as Ca^{2+} source to replace Na^+ from the soil exchange complex to reclaim sodic soils. Surface applied gypsum generally increases infiltration rates and reclaims sodic soils, but the process sometime is rather slow because gypsum moves slowly in the soil. Mixing the gypsum with soil usually accelerates the reclamation process. Gypsum can also be added to the irrigation water to improve Ca^{2+}/Na^+ ratio of the water and subsequently to enhance the reclamation of sodic soils.

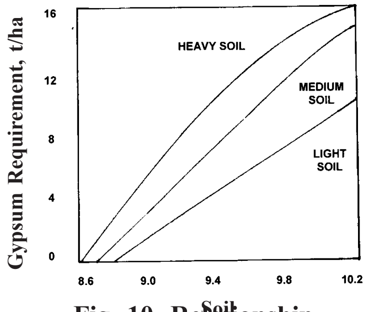

Fig. 10. Relationship between soil pH and gypsum requirement (Abrol et. al., 1981)

6.3.2.1. *Frequency*

Experiments on highly alkali soils proved that single application of gypsum at lower dose before the first crop of rice proved as effective as higher and repeated doses.

6.3.2.2. *Amendment Dose*

The dose of an amendment required for reclaim-ing an alkali soil is governed by initial ESP, texture and mineralogy of soil and crop salt tolerance. A good relationship was found between pH 1:2 soil-water suspension and the gypsum requirement of surface 15 cm soil (Fig. 10). Field experiments further showed that for cultivation of shallow rooted crops like rice, wheat, barley and berseem, application of 50 per cent gypsum requirement, which amounts to 10-15 t/ha in 0-15 cm soil is sufficient.

6.3.2.3.*Method of application*

The reclamation of sodic and saline soil requires application of amendments to remove the sodium from the exchange complex and proper drainage to remove the replaced sodium from the site. Though many amendments like gypsum, phosphogypsum, pyrites, Pressmud, Sulphuric acid, sulphur etc. are available, the most used and cheap amendment is gypsum. If mineral gypsum is not available, phosphogypsum which is an industrial by-product can be used as the amendment. The quantity of gypsum to be applied depends upon the quantity of sodium to be replaced. Hence the gypsum should be applied based only on the laboratory analysis report. Mixing gypsum in shallow depths was found more beneficial than mixing at deeper depths. Mixing limited quantities of gypsum in deeper depths results in dilution and lesser soil improvement.

- The calculated quantity of gypsum should be broadcast evenly on the soil surface during summer months, followed by application of FYM @10 -15 t/ha
- Mix the gypsum and FYM in the top 5-10 cm of soil by harrowing
- The field should be divided into smaller plots of about 1000 sq. meters with provision for surface drainage
- Pond the plots with water for 15-20 days. The ponding be done with irrigation water. If it is not available then ponding be done with rain water
- Drain the water after 15-20 days
- Start cropping with the *kharif* crop, preferably green manuring/paddy.

After applying gypsum and continuous cropping, the soil test for exchangeable sodium percentage (ESP) needs to be done every year. Even after 3-4 years, if the ESP does not go below 10 in light soils and 5 in heavy soils, then gypsum needs to be applied. It should be repeated based on the soil test report.

6.3.2.4. *Sulfuric acid for reclaiming sodic soils*

The reaction of applied acid with calcareous soils provides Ca^{2+} to exchange with Na^{+} from the exchange complex and initiate reclamation process. The ready availability of surplus sulfuric acid as an industrial by-product has made the use of this amendment a viable reclamation practice. Application of 5-15 Mt/ha proved superior to surface applied gypsum for calcareous sodic soils. Sulfuric acid requires specialized handling. But it is readily available in many areas. The soils should either contain a Ca^{2+} source or the needed Ca^{2+} should be added with the acid to effect reclamation.

6.3.3. Bio reclamation

As such it is rather difficult to reclaim these soils through adoption of proven chemical and physical technologies of reclamation on account of one or more of the following reasons.

- Inadequate infrastructure for removal of excess water carrying soluble salts.
- Ingress and inundation of sea water in the coastal belt.
- Shallow water table.
- Unavailability of good quality water for leaching.
- Small holding.
- No income during the process of reclamation.
- Chemical and physical reclamation is becoming costly affair.

Under the above circumstances, it is advisable to go for bio-reclamation technique. In this technique, certain plants are used as an ameliorant because of their inherent ability to thrive well under salt affected soil conditions. Broadly, such plants are grouped under two categories *i.e.* euhalophytes and pseudohalophytes and they are surviving under saline environment through different mechanisms. Once the plants are established under saline/alkali conditions, the process of reclamation start automatically. The mechanisms operating in this type of reclamation are (i) root passage act as channels for movement of water and (ii) decomposition of litter, dead roots, root exudates *etc*. releases organic acids which facilitate solubilization of calcium salts present in the soils. This Ca will ultimately replace the Na from exchange complex and improve the deteriorated physical conditions of the soils. In addition to this improvement in content of readily oxidizable C in the soil will beneficially affect the physical and biological properties of the salt affected soils. There are many grasses which due to its adaptability to adverse soil conditions and profuse rooting system can rejuvenate salt affected soils. The research work done in Gujarat has shown that in the coastal salt affected soils in South Gujarat and Bhal areas, Gatton Panic grass not only thrive well in the un-reclaimed soils even without irrigation, but also reclaims the soil in a couple of years.

6.4. Choice of crops

Crops differ widely in their tolerance to salinity and alkalinity. The relative crop tolerance to exchangeable sodium (%) is given in the table 8. The choice of tolerant varieties within a crop is essential for better production and economic returns for alkali soils.

Table8. Relative crop tolerance to exchangeable sodium (%) in the soil

Range of ESP*	Crops
10-15	Safflower, black gram, peas, lentil and pigeon pea
15-20	Bengal gram, soya bean and maize
20-25	Groundnut, cowpea, onion and pearl millet
25-30	Linseed, garlic, guar, sugarcane, cotton, lemongrass, palma rosa
30-50	Wheat, raya, sunflower, berseem, blue panic
50-60	Barley, sesbania, Matricaria, Para grass, Rhodes grass
69-70	Rice, Karnal grass

**Relative crop yields are only 50 per cent of the maximum in the alkalinity range indicated.*

6.5. Cropping patterns

As rice-based cropping systems are proved to be beneficial over sorghum-based cropping systems, the following crops have been recommended for cultivation during the post-reclamation phase (Table 9).

Table 9 . Cropping sequences recommended for alkali soils (post-reclamation phase)

Soil pH (0-15 cm layer)	Years after reclamation	Crops	
		Kharif	Rabi
9.2 to 9.3	3 to 4	Cotton, Sorghum, Pearl millet	Mustard, Rapeseed
8.9 to 9.0	5 to 8	Sugarcane, Arhar, Groundnut, Soybean	Berseem, Sunflower, gram, safflower, lentil, pea.
8.5 to 8.8	8 to 10	All crops including vegetables, flowers etc.	

6.6. Nutrient management

For efficient management of nutrients in alkali soils the practices followed are:

- Soil organic matter status can be improved by growing green manure crop at least once in two years;
- Nitrogen need be applied 20-25 per cent more than that required for normal soils. 150 kg N/ha through urea or ammonium sulphate need be applied in 3-4 split doses to compensate for higher volatilisation losses;
- Since alkali soils are generally rich in P and K they need not be applied in the initial three to four years.
- Zinc sulphate at the rate of 10-20 kg/ha may be applied in the initial two to three years.

6.7. Water management

Water management in saline soils involve irrigation methods, irrigation frequency, rainwater management and drainage. Prevention of water table rise through reduction in seepage from canals, distributaries and watercourses is crucial and thus requires cost-effective seepage control techniques. As conventional methods of irrigation result in low application efficiency, irrigation methods and procedures should be designed to increase the efficiency and uniformity of application.

6.7.1. Salt leaching and Drainage

Salinity in the soil root zone is a major concern for farmers of irrigated crops in arid regions. Typically, the irrigation water available in such regions contains measurable, sometimes substantial amounts of salts that must be leached from the soil after irrigation. The soil profile may also contain soluble minerals that contribute both to the salinity hazard to crops and to the salt load of agricultural drain water. Irrigation water salts are not always carried away in drain water, either; some of those salts may be deposited in the soil. Both root zone leaching and chemical precipitation are needed for maintaining favourable root zone salinity. Leaching involves applying enough excess water to translocate some of the salts out of the root zone. The amount of excess water required depends partly on the chemical composition of the water, in so far as that influences salt precipitation and the water's ability to carry salts.

The salinity of shallow groundwater directly affects the salt load removed by sub-surface drainage systems. Drain water salt loads in excess of those in the applied water do not necessarily represent additional leaching or mineral dissolution in the soil profile – they may just as easily represent saline shallow ground water resulting from prior salt leaching, from salts leached in other fields within a regional shallow water table or from evaporative concentration of salts.

6.8. Farm irrigation management

On farm management in saline soils comprise (a) scheduling of irrigation; (b) elimination of excessive salt build-up and (c) assurance in optimal crop production. Under saline conditions, irrigation should meet both the water requirements of crops and the leaching requirements to maintain a favourable salt balance in the root zone. More frequent irrigations need be applied on saline soils as the same would reduce the cumulative water deficits (both matric and osmotic) between the irrigation cycles.

6.8.1. Method of irrigation

Irrigation method can play an important role in controlling salts in the root zone. It has been discussed that frequent irrigations are helpful in saline soils in maintaining adequate availability of soil water. The most common methods of surface irrigation are i) flooding, ii) check basin, iii) basin, iv) border and v) furrow. The method of irrigation to be adopted depends upon the crop, available water quantity and quality of the irrigation water. It may be any of the surface/conventional irrigation methods or any of the pressurized irrigation methods like drip or sprinkler.

A soil factor of considerable importance in relation to growth of plants is the location of salts in relation to root zone or seed placement. Irrigation practices can often be modified to obtain a more favourable salt distribution in relation to seed location or growing roots. It is well known that salts tend to accumulate in the ridges when using furrow type irrigation. With each irrigation salts leach out of the soil under the furrows and build up on the ridges. Where soil and farming practices permit, furrow planting may help in obtaining better stands and crop yields under saline conditions.

As the distribution of salts in soils vary with the method of irrigation, the irrigation methods need be aimed at low salinity build-up and maintain favourable water regimes in the root zone such that water is readily available for the plants without any adverse effects on yields. The surface irrigation methods including the border strips, check basin and furrows are the oldest and the most commonly used practices in India. However, even with the best designs, these methods result in excessive irrigation and non-uniformity in irrigation application resulting in low irrigation efficiency (60-70%). High energy pressurized irrigation methods such as sprinkler and drip are typically more efficient as the quantity of water to be applied can be adequately controlled. However, the initial investments and maintenance costs of such systems are very high.

6.8.2. Water table management

To minimise the salinity hazards under the high water table conditions, the salts are usually leached down and the water logging problems are alleviated by the installation of subsurface drainage system. Since the drainage water contains many toxic elements and salts in high quantities, their disposal become a problem. Since substantial contributions for the seasonal evapo-transpiration can come from shallow ground water tables for meeting a part of the crop-water use, maximising the use of shallow ground waters can reduce the volume of the drainage effluent.

6.9. Conjunctive use of Surface and Ground Water

In view of the limited available surface water through rain water harvesting (Fig. 11) and canal, we need to adopt conjunctive use of surface and ground water, in order to reduce crop failure by severity of droughts, stabilizing the income of the farmers through sustainable crop production and above all restoration of ecological balance.

Fig. 11. Rainwater harvesting in farm pond

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6.9.1. Multi-quality irrigation practices

Under saline conditions, canal water supplies are either unassured or in short supply, forcing the farmers to use saline ground water for irrigating the crops. Saline ground water and limited available fresh water can be applied either separately or mixed. It is suggested that the good quality water should be used for pre-sowing irrigation and early seedling growth and using poor quality water at later stages of growth when the plants/ crops grow. Rainwater needs to be conserved and collected in farm ponds (Fig. 11) can be used with saline ground water in conjunctive mode for cultivation of crops either in mixing mode or cyclic mode.

6.9.2. Possible Avenues for the use of Poor quality waters:

Saline Ground Water

↓

Conjunctive Use With Surface/Canal/Pond Water

↙ ↘

Mixing Mode — *Lowering the salinity level*

Cyclic Mode — *Irrigation as per crop growth stages*

Sea Water

↓

For Cultivation of Economic Halophytes – Saline Agriculture

6.9.2.1. *Mixing Mode of saline water*

If the ground water is too saline, the best way to use the same for agricultural crops is by reducing the salinity by mixing with freshwaters. This reduced saline water can be used for irrigating the crops (Tables 10, 11). Dill, *Anethum graveolens,* a non-conventional seed spice crop has been identified as potential crop for cultivation on saline black soils having salinity up to 6 dS m^{-1} in *rabi* season with the residual soil moisture. The crop gives fairly good yield on saline black soils in the coastal Gujarat having salinity of 4-6 dS m^{-1}. The crop responds well to saline water irrigation. Three critical stages for saline water irrigation have been noticed i.e. vegetative, flowering and seed formation stage. A substantial increase in yield can be obtained by using saline ground water in conjunction with best available surface water. Cost of cultivation and economics have been worked out for this species. The cost of cultivation comes to Rs. 6000/- ha^{-1} and the crop would yield net returns of Rs. 16500/- ha^{-1}. The benefit: cost ratio works out to be 2.75 (Table 12). This crop thus would help farmers of the region to go for the second crop in the *rabi* season on lands, which hitherto remain fallow due to water and salinity constraints (Gururaja Rao et al., 2000).

Table 10. Seed yield of dill (q/ha) as influenced by different salinity levels under different farm sites

Salinity, dS m^{-1}	Khanpur	Warsada	Bamangam
2-4	3.74	4.09	3.16
4-6	3.03	2.25	2.37
6-8	2.34	1.76	1.64
8-10	1.95	1.36	1.56
CD (0.05)			
Farm	NS		
Salinity	0.13		
Farm x Salinity	NS		

Table 11. Effect of quality and number of irrigation waters on yield of dill (t ha^{-1}) on saline black soils

Salinity, dS $^{-1}$	One Irrigation		Two Irrigations		Three Irrigation	
	Seed	Stover	Seed	Stover	Seed	Stover
BAW	0.784	2.352	0.834	2.500	0.914	2.651
4	0.650	1.958	0.815	2.526	0.906	2.808
8	0.354	1.200	0.417	1.334	0.567	1.814
12	0.209	0.689	0.292	0.992	0.367	1.212
CD (0.05)						
No. of irrigations (I) 0.030						
Quality of Water (Q) 0.033						
I x Q 0.081						

Table 12. Cost of cultivation of Dill and economic returns

Items of Expenditure	Cost, Rs.
Field preparation	1200=00
Seed material	150=00
Seed treatment and sowing	300=00
Fertilizers	800=00
Application of fertilizer	200=00
Interculture and weeding	350=00
Irrigation*	1500=00
Harvesting and threshing	1000=00
Miscellaneous	500=00
Total	6000=00
Returns	
Yield of Dill, 0.75 t ha^{-1}	
Gross returns @ Rs. 30000 t^{-1}	22500=00
Net returns	16500=00
B/C Ratio	2.75

6.9.2.2. *Use of saline water in cylic mode – Field Crops*

This strategy involves substitution of non-saline water (canal/surface) for saline water during most critical stages and saline water at other stages with a view to minimize the soil salinity. This method provides a scope to obtain yields comparable to those obtained with fresh waters.As the real potential of land and water resources are not assessed, the proper utilization of the land and groundwater resources have not been done to its fullest extent for the agricultural production. The non-use of saline groundwater is not only making the crop production stagnant but also contributing to the increase in the ground water table and salinity. The salinity of groundwater is too high in the saline tracks in Gujarat that cannot be used for irrigation purposes as such and thus it needs to be mixed with limited surface water available. In the absence of inadequate irrigation water supplies in the region, technologies evolved for conjunctive use of saline groundwater in mixing and cyclic modes for growing *rabi* season crops like dill, mustard, safflower and wheat proved to be remunerative (Gururaja Rao et al., 2001a) due to its long-term potential impacts on the economic development, employment generation and environmental improvement (Table 13).

Table 13. Effect of conjunctive use saline water and surface water in cyclic mode on the yield (q/ha) of arable crops on saline black soils.

Treatment	Dill	Safflower	Mustard	Wheat
T1 - All BAW	8.32	8.25	7.35	29.1
T2 - SW at Branching stage/ crown root initiation stage in wheat + rest BAW	7.93	7.45	6.65	27.2
T3 - SW at Flowering stage/maximum tillering stage in wheat + rest BAW	7.84	7.65	6.29	28.1
T4 - SW at Seed formation stage/ Flower initiation stage in wheat + rest BAW	7.68	7.75	6.45	27.4
T5 (SW – Branching/ tillering & Flowering) rest BAW	7.52	6.35	5.59	22.2
T6 (SW – Branching/ tillering & Seed) + rest BAW	7.44	6.85	5.19	23.0
T7 (SW – Flowering & Seed) + rest BAW	7.36	6.88	5.35	22.3
T8 (All saline)	6.82	4.99	3.26	16.8
$CD_{0.05}$	0.06	0.21	0.75	0.50

BAW: Best available water, SW- Saline Water

Dill (Fig. 12), a potential seed spice crop can be grown during *rabi* season on saline black soils having salinity up to 4-6 dS m^{-1} with average seed yield of 3 t ha^{-1} without any irrigation, which otherwise remained fallow during the *rabi* season. However, the conjunctive use of saline groundwater with surface water can improve the productivity manifold. In dill, if surface water is available for one irrigation, it should be applied at the seed formation stage and saline water at the vegetative flowering stages. If surface water is available for two irrigations, it should be applied at the time of flowering and seed formation stage and saline water at the vegetative stage. In areas with high groundwater table and lack of sufficient surface water, surface water up to 66 per cent can be saved by application of saline groundwater (4 dS m^{-1}) at branching and flowering stage and surface water at seed formation stage without further increase in soil salinity. This method can increase seed yield by 150 per cent over the yield obtained under unirrigated condition.

Fig. 12. Dill under saline water irrigation

In safflower (Fig. 13), branching and flowering stages were found to be sensitive stages for saline water irrigation. If surface water is available for one irrigation, it should be applied at branching stage and saline water at vegetation and flowering stages. If surface water is available for two irrigations it should be applied at branching and flowering stages and saline water at vegetative stage. In safflower by applying saline groundwater (4 dS m^{-1}) at flowering and grain filling stages and surface water at branching stage, 86 per cent increase in yields over the yield obtained under unirrigated conditions (3.7 q ha^{-1}) can be obtained .

Fig.13 Safflower under saline water irrigation

In wheat (Fig. 14), good quality water, if available, should be applied at crown initiation stage and saline water at maximum tillering and flower initiation stages. If best available water (BAW) for two irrigations is available, it should be applied at crown root initiation and flower initiation stages. Under high saline water table prevailing in saline black soils, in wheat, when saline water is applied, flowering and maximum tillering stages are equally sensitive as that of crown root initiation stage for salinity because of their exposure to increase in groundwater salinity (Gururaja Rao et al., 2001a). Application of saline water (4 dS m-1) at these stages and good quality water at crown root initiation stage resulted in an increase of 180 per cent seed yield when compared to the yield obtained under unirrigated condition.

Fig.14 Wheat under saline water irrigation

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In the absence of sufficient good quality of water, Indian mustard can be grown on saline black soils with saline ground water having EC of 4 dS m^{-1} in conjunction with the limited surface water. Flowering and pod formation stages are relatively more sensitive to saline water irrigation. In mustard, application of two saline water irrigations (4 dS m^{-1}) at branching and pod formation stages and surface water flowering stage resulted in yield of 5.59 q ha^{-1}. Flowering and pod formation stages are relatively sensitive to saline water irrigations. This method while saving 66 per cent surface irrigation water increased the yield by 123 per cent over the yield obtained under unirrigated conditions (2.2 q ha^{-1}).

6.9.2.3. *Physical and economic Impacts*

In areas where the salinity of ground water is too high and cannot be used for irrigation purposes as such, the same needs to be mixed with limited surface water available for which the following technologies are ideal. The strategies developed for conjunctive use of saline water and ground water for four important crops of the saline areas would improve the dill yield by 4.46 q/ha, mustard by 2.37 q/ha, safflower by 5.18 q/ha and wheat by 12 q/ha over the yield under unirrigated condition. The surface water saved per hectare would create 2 acre additional command under irrigation. This technology as well can be extrapolated to other canal command areas and coastal areas of the state where the salinity problems are prevailing.

Surface water up to 66% can be saved by application of saline ground water (4 dS m^{-1}) at branching & flowering stage and surface water at seed formation stage with-out further increase in soil salinity in dill. In Safflower, irrigating with saline ground water (4 dS m^{-1}) at flowering and grain filling stages and surface water at branching stage, 86 per cent increase in yields over the yield obtained under un-irrigated conditions.

In mustard, conjunctive use of saline water while saving 66 per cent surface irrigation water increased the yield by 123 per cent over the yield obtained under unirrigated conditions. In wheat, application of saline water (4 dS m^{-1}) at vegetative and tillering stages and good quality water at crown root initiation stage resulted in an increase of 180 per cent seed yield over the yields under unirrigated conditions.

6.10. Irrigation methods

6.10.1. Drip Irrigation

Drip irrigation is defined as the precise, slow and frequent application of water through point or line source emitters on or below the soil surface at a small operating pressure (20-200 kPa) and at a low discharge rate (0.6 to 20 LPH), resulting in partial wetting of the soil surface. It is also known as Trickle irrigation. The method is suitable for perennial or seasonal row crops; it has been found particularly useful when irrigating with water of high salinity. The method has the advantage that it keeps the soil moisture continuously high in the root zone, therefore maintaining a low salt level. The roots of the growing plants tend to cluster in the high soil moisture zone near the tricklers and therefore avoid the salts that accumulate at the wetting front.

6.10.2. Sprinkler Irrigation

Sprinkler irrigation is an ideal method for irrigating frequently and with small quantities of water at a time. Sprinkler irrigation tends to simulate the rainfall and it is operated in such a way to minimize run off and deep percolation losses. However, care should be taken to have the uniformity of application remain as close as to that of the rainfall. When choosing a sprinkler, several factors should be considered. The size and shape of the area to be watered, the soil type, and the rate of water flow are all important.

Soils containing a large amount of clay should be watered more slowly and less often than sandy soils. Though the infiltration rates are slow in clay soils, their water holding capacity is high. Sandy soils are just the opposite of clay soils. They absorb water very quickly, but it drains out of them almost as fast. Loamy soils fall somewhere in between.

Leaching of soluble salts is also accomplished more efficiently when the water application rates are lower than the infiltration capacity of the soil and such a condition cannot be achieved by flood irrigation methods. Sprinkler irrigation also has the advantage that small local differences in the level of the field will not cause non-uniform water application and salt leaching.

6.10.3. Drum kit

Drum kit (Fig. 15) has been designed for a small commercial vegetable garden. This is being extremely popular with marginal farmers in villages who have little access to water. It is similar to bucket kit in principle and is 5 times bigger. It has 5 lateral lines of 10 m each and fitted with a total of 200 micro tubes. It covers a total area of 150 m^2. Depending on the crop it is suitable for irrigating 200-800 vegetables plants. This kit has been designed to be fitted to a drum of water placed at 1m height. However, this can also be fitted to running water from a tap or stream. Depending on the season the drum needs to be filled once or twice a day. The total investment on this kit is about Rs 1500/= which can cover 150 m^2 of area. However, these systems need to be fed with water routinely which is cumbersome and farmers do not find them convenient whenever the water source is far off from their small fields. The labour involved in filling the tank or bucket will be highly difficult if the water source happens to be far off from the field. Also, due to lack of proper filtration systems, lack of chemical treatments to avoid clogging, very low useful life of the components, etc result in their disuse.

Fig. 15. Irrigation by drum kit method

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7. Crop Management

Crops differ in their ability to tolerate to salinity/alkalinity. The high-water requiring crops like sugarcane and rice should be avoided with brackish water, as these aggravate the salinity problems. Proper time of sowing also plays an important role in salt tolerance of the crop. For example, late sown crops like wheat can tolerate only lower levels of salinity than timely sown crop. Crop tolerance is also increased when crops are grown in cooler climate due to low ET demand prevailing in such conditions. In coarse textured soils, comparatively highly saline water can be used when compared to clay soils, due to lower salinity build up in root zone.

7.1. Crop Growth Stages

Crop tolerance to salinity varies with crop growth stages. In most crops, germination and early seedling establishment are the most critical stages. Some relative sensitivity of the crops and their growth stages are given below (Table 14)

Table 14. Growth stage sensitivity of different crops to salinity.

Crop	Relative sensitivity
Wheat	Presowing > Crown Root initiation > Milking > Flowering > Jointing
Maize	Silking > Tasseling > Presowing > Knee Height
Pigeon pea	Presowing > Flowering to pod development
Dill	Vegetative > Flowering > Seed formation
Mustard	Branching > Flower initiation > Pod formation
Safflower	Grain filling > Flower initiation > Branching

7.1.1. Agronomic management for crop production

- Crop production on salt affected soils demands agronomic skills that are as per the requirements of the physical and chemical characteristics of the soils. The following features are suggested.
- As the mortality of the seedlings and decrease in growth of the young plants are common feature in saline conditions, higher seed rate/closer plant spacing is needed to increase plant population to counter the adverse effects of salts. A seed rate of 25% more has been recommended for salty lands than normal soils.
- Shallow and frequent irrigations have been proved beneficial under saline conditions. Irrigation practices under saline conditions should be aimed at minimising the osmotic stress created by salts present in the soil profile. If available, good quality water be used for pre-sowing irrigation. Heavy post-sowing irrigation with fresh/saline water will facilitate further establishment of the crops.

7.2 Technological interventions for saline soils

Salt affected soils coming under panchayat lands, community lands and government owned lands reserved for specific purposes can be profitably used for the cultivation of salt tolerant woody biomass species which would yield value-added materials like timber, fodder, food, pharmaceuticals which in turn add to the national economy. Reclamation of such lands for crop production is posing problems owing to common property rights. For afforestation of alkali lands plants like *Prosopis juliflora, Acacia nilotica, Eucalyptus tereticornis* and *Tamarix articulata* which would yield appreciable amounts of biomass are ideal (Table 15).

Table 15. Biomass production of woody species on alkali soils in 10 years

Tree species	Biomass production, kg tree^{-1}		
	Bole Weight	Branches + leaves	Total
Prosopis juliflora	113	43	156
Acacia nilotica	85	44	129
Casuarina equisetifolia	84	28	112
Eucalyptus tereticornis	66	24	90

Source: *Singh* et al., 1994.

In addition to biomass production, these tree species would help in ameliorating soils by improving soil physical, chemical and biological properties of the soil. Leguminous tree species like *Prosopis juliflora* and *Acacia nilotica* ameliorate alkali soils at a much faster rate than non-leguminous trees.

7.2.1 Cultivation of Halophyte, *Salvadora persica* on highly saline soils (ECe > 55 dS m^{-1})

Salt affected soils, which pose serious threat to the economy of the state. While soils with low and moderate salinity have been put under cultivation, highly saline black soils *by and large* remain either barren or possess some native hardy species. Thus, for the management of moderate to highly saline black soils, agro-technology for the cultivation of economically important and salt tolerant halophyte has been evolved.

Salvadora persica L. (Meswak), a facultative halophyte which is a potential source for seed oil has been identified as a predominant species in highly saline habitats of coastal and inland black soils. This species is a medicinal plant of great value and its bark contains resins and an alkaloid called Salvadoricine. The seeds are good source of non-edible oil rich in C-$_{12}$ and C-$_{14}$ fatty acids having immense applications in soap and detergent industry (Fig. 16 & 17).

Fig. 16. *Salvadora persica* on highly saline soil

Through different field experiments under-taken, the Regional Research Station of CSSRI at Bharuch has evolved agro-technology for raising of saplings using saline water; field planting and crop harvest and also worked out cost of cultivation. The studies indicated that the saplings could be raised using

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saline water of 15 dS m^{-1}, which is an advantageous feature under limited fresh water available situations. Cost of cultivation indicated that total cost for raising 500 saplings works out to be Rs. 455/=. The cost of cultivation under field conditions including raising of nursery comes to Rs. 2760/- per hectare in the first year (Table 16).. In subsequent years recurring costs would be mainly the labour for fertilizer application and harvesting. By fifth year, the plants would yield about 1800 kg ha^{-1}, thus giving net returns to a tune of Rs. 8400/= per hectare (Table 17). Thus, this species, while giving economic returns for the highly saline black soils with salinity values up to 50 dS m^{-1}, also provides eco-restoration through environmental greening and thus forms a niche for highly saline black soils (Gururaja Rao et al., 2003, 2004).

Fig. 17. Luxurious growth of *Salvadora* on highly saline soil

Table 16. Cost of cultivation of *Salvadora persica* on highly saline black soil

Field operations (Input costs)	Cost (Rs.)
Field preparation (by tractor)	500=00
Pitting (625 pits of 1' x 1' x 1')	625=00
Cost of Saplings @ Rs. 0.90 per plant	565=00
Planting (3 labourers)	50=00
Irrigation during first year (saline water)	150=00
Digging of pit of 2.5 x 2.0 x 1m (for saline water)	300=00
Fertilizer (@ 50 g DAP/plant) & FYM	300=00
Plant basin making @ Rs. 0.35/plant	220=00
Miscellaneous (gap filling at 5%)	50=00
Total	**2760=00**

Table 17. Seed production and economic returns of *Salvadora* plantation on highly saline black soils (ECe > 55 dS m^{-1})

(Cost taken per hectare of plantation, after Gururaja Rao et al., (2004)

Year	Seed Yield, Mg ha^{-1}	Cost of planting, Rs/ha	Cost of harvesting and irrigation	Returns, Rs ha^{-1} Gross	Net	Cost/ Benefit Ratio
I Year	Nil	2760=00	--	Nil	Nil	Nil
II Year	0.725	2760=00*	500=00	3625=00	365=00	8.93
III Year	0.978	--	550=00	4890=00	4340=00	0.13
IV Year	1.580	--	650=00	7900=00	7250=00	0.09
V Year	1.838	--	750=00	9190=00	8440=00	0.09

* Though there was no seed yield in the first year the cost of planting, irrigation and harvesting costs were taken in the second year i.e. 2760 + 500 = 3260/= as the cost

** During second, third and fourth years, expenditure was incurred only on harvesting i.e., 550=00, 650=00 and 750=00 respectively and thus this only was taken as cost for working out C/B ratio. Third year onward no irrigation was given and hence no cost component.

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7.2.1.1 *Impacts*

This species was found to grow well on saline black soils having salinity up to 65 dS m^{-1} and found to yield well. A spacing of 4 m x 4 m has been found ideal for planting on saline black soils (Gururaja Rao et al., 2004). Based on the studies conducted, the National bank for Agriculture and Rural Development (NABARD), Mumbai in association with the Station has developed a bankable model scheme (Fig. 18) for cultivation of *Salvadora persica* on salt affected black soils through the project sponsored by NABARD. Regreening of highly saline black soils that cannot be put under arable farming; reduction in salinity by 4th year onwards that enable to take up intercropping with less tolerant crops/forages. Planting of *Salvadora persica* would fetch about Rs. 7000=00 per hectare. Apart from this, the species provide a dwelling place for birds and enhances the environmental greening. The technology has been widely adopted in Bhal area (Dholera, Wattaman, Ishanpur) and Bara tract (Thakor Talavdi, Jambusar, Amod). The Research Station had imparted training to the farmers on nursery raising, field planting and harvesting.

Fig. 18. Bankable Model scheme for cultivation of Salvadaora developed by NABARD based on the studies conducted by CSSRI, RRS, Bharuch.


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Biopesticide Unit Biofertilizers

Reclamation of Saline

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TECHNICAL ASPECTS AND AGRONOMIC PRACTICES OF *SALVADORA*

With R&D grant assistance from NABARD Central Soil Salinity Research Institute, Regional Research Station, Anand (now in Baruch) have conducted a field experiments and standardized package of practices for growing Salvadora. Based on a detailed study conducted by NABARD in Gujarat and also discussions had with Scientists of CSSRI, Regional Research Station, Bharuch, the techno economic aspects of *Salvadora* has been finalized.

References:
1. Technical Bulletin No.1/2003 "Salvadora persica: A life support species for salt affected black soils" by G Gururaja Rao, A K Nayak and Anil Chinchmalatpure, published by Central Soil Salinity Research Institute (ICAR), Regional Research Station, Bharuch, Gujarat
2. R&D Project Report "Management of salt affected black soils using Salvadora – forage grass based land use system" submitted to NABARD by CSSRI, Regional Research Station, Bharuch in 2002.

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7.2.1.2. *Physical Impact - Targeted areas*

Saline black soil region in Bhal area and Bara tract regions in Gujarat (Parts of Ahmedabad and Anand districts) and Amod, Vagra and Jambusar talukas in Bharuch district covering about 500ha and coastal areas of Kutch.

Output capacity: Seed yield: 1846 kg/ha (by fifth year)

Unit cost: Rs. 2760/= per ha in the first year

Total realization: Rs. 9230/-= per ha (net income)

User Agencies: Gujarat State Land Development Corporation, State Agricultural Development, NGOs like Coastal Salinity Prevention ell, Ahmedabad, Saline Area Vitalisation Enterprise, and farmers of coastal areas.

7.2.2. Cultivation of dill (*Anethum graveolens*)

Dill, *Anethum graveolens* (Fig. 19), a non-conventional seed spice crop has been identified as potential crop for cultivation on saline black soils having salinity up to 6 dS m^{-1} in *rabi* season with the residual soil moisture. It has multiple uses viz., pot herb, leafy vegetable, seeds used as condiments and seed oil for aromatic and medicinal purposes. The herb contains Vitamin-C as high as 121.4 mg/100g. The oil of dill seeds and its emulsion in water (Dill water) are considered to be aromatic, carminative and effective in colic pains and possesses anti-pyretic and anti-helmenthic properties. The crop gives fairly good yield on saline black soils having salinity of 4-6 dS m^{-1}. The crop responds well to saline water irrigation. Three critical stages for saline water irrigation have been noticed i.e. vegetative, flowering and seed formation stage. A substantial increase in yield can be obtained by using saline ground water in conjunction with best available surface water. Cost of cultivation and economics have been worked for this species. The cost of cultivation comes to Rs. 6000/- ha^{-1} and the crop would yield net returns of Rs. 16500/- ha^{-1}. The benefit: cost ratio works out to be 2.75. This crop thus would help farmers of the region to go for the second crop in the *rabi* season on lands, which hitherto remain fallow due to water and salinity constraints (Gururaja Rao et al*.,* 2000).

Fig. 19. Dill (Suwa) irrigated with saline water

7.2.2.1 *Impact*

Non-conventional crop like dill can be grown using residual moisture resulting in 2.6q/ha seed yield with net returns of Rs. 8000=00/ha. This crop forms an **ideal option**

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for the state in general and the region in particular, which *by and large* faces water scarcity problems (Gururaja Rao *et al*. 2000). Under saline water irrigation, crop would yield net returns of Rs. 16500/- ha^{-1} with Rs. 6000/- ha as cost of cultivation. The benefit: cost ratio worked out to be 2.75. This crop thus would help farmers of the region to go for the second crop in the *rabi* season on lands, which hitherto remain fallow due to water and salinity constraints. Thus dill crop can be taken up using residual moisture and/or with saline ground water. The green can be used as leafy vegetable, an additional source of income.

Physical Impact

The technology evolved in cultivation of this species on saline soils in *rabi* season (after paddy) with residual moisture has been widely adopted by farmers of Bhal region covering villages Khanpur, Indranaj, Ishanpur, Warsada, Golana, Pipaliya, Dholka (Ahmedabad district) etc., covering an area of about 1200 ha. Apart from this, through the network of Gujarat State Land Development Corporation, Gandhinagar, the technology has been widely adapted by the farmers in other parts of the Bhal region in Dhandhuka taluka of Ahmedabad district covering about 300 ha. The seed materials have also been provided to Coastal Salinity Prevention Cell, Ahmedabad for its cultivation in Coastal Saurashtra.

Economic Impact

Output capacity: Seed yield: 750 kg/ha

Unit cost: Rs. 6000/= per ha in the first year

Total realization: Rs. 16500/-= per ha (net income)

7.2.3. Cultivation of forage grasses on saline black soils

Gujarat state has one of the largest dairy industries in the country. As the fodder produced on arable lands and grasslands is not sufficient to meet the demands of the cattle population, cultivation of forage grasses, *Dichanthium annulatum* and *Leptochloa fusca* in a ridge-furrow planting system with 50 cm high ridge and 1 m between midpoints of two successive ridges was found ideal in saline black soils having salinity up to 8-10 dS m^{-1} (Table 18). For maximizing forage production on saline black soils, *Dichanthium* on ridges and *Leptochloa* in furrows form ideal proposition. Nitrogen given at the rate of 45 kg ha^{-1} (in the form of urea) at the time of rooted slip planting, boosted forage production and improved forage quality traits (Table 19). *Leptochloa fusca* also gave maximum forage yield. Furrow method of planting is suitable for cultivation of this grass. Application of nitrogen as urea increased the forage yield by about 70 per cent in *Dichanthium annulatum* (Gururaja Rao *et al.* 2001b). The cattle and camel populace form the important livestock of the region. Cultivation of salt tolerant grasses like *Dichanthium annulatum* and *Leptochloa fusca* on moderate saline soils result in 1.9 t/ha and 3.2 t/ha, respectively. *Dichanthium annulatum,* has been found most suitable for saline black soils, as it possessed well-defined salt compartmentation, wherein the roots act as potential sinks for toxic ions like sodium and chloride, making the shoot portions relatively salt free (Gururaja Rao et al., 2001b).

Table 18. Growth and yield of forage grasses under ridge and furrow planting system

Grass species	Height, m		Tillers plant^{-1}		Green forage yield, t ha^{-1}	
	Ridge	Furrow	Ridge	Furrow	Ridge	Furrow
Leptochloa fusca	1.18	1.02	10.62	9351	3.17	3.73
Dichanthium annulatum	0.91	0.74	6.41	5.32	1.85	1.76
CD $_{0.05}$		Height		Tillers		Yield
Planting method		0.12		0.91		NS
Grass species		0.16		1.53		0.82
Planting method x Grass species		NS		2.24		NS

Soil salinity of the saturation extract (0-30 cm) : 15.4 dS m^{-1}

Table 19 . Effect of nitrogen on growth and forage yield of forage grosses

Grass species	Height, m		Tillers plant^{-1}		Green forage yield, t ha^{-1}	
	+ N	- N	+ N	- N	+ N	- N
Leptochloa fusca	1.39	0.99	12.54	4.46	3.21	2.13
Dichanthium annulatum	1.01	0.87	10.24	7.38	2.24	1.32
CD $_{0.05}$		Height		Tillers		Yield
Planting method		0.13		3.11		0.88
Grass species		0.22		2.32		0.55
Planting method x Grass species		NS		NS		NS

7.2.3.1. *Impacts*

***Physical Impact*:** The technology has been widely adapted in the Bhal areas covering Tarapur, Dholka, Dhandhuka talukas and also through the NGOs in Coastal saline villages in Cambay talukas. The planting of grasses was also taken up by the National Tree Growers Federation , Anand in Cambay taluka. These grasses being perennial in nature, while providing fodder also brings up the environmental stability in the area which is extremely fragile in nature.

Unit cost: Rs. 3000/= per ha in the first year for planting, fertilizers and labour input. The grasses used to give 3-4 cuts and together gave economic returns of about 10000=00 per hectare.

Some of the prominent grasses identified for alkali soils are Kallar grass (*Leptochloa fusca),* Rhodes grass (*Chloris gayana),* paragrass (*Brachiaria mutica)* and Bermuda grass *(Cynodon dactylon)*. Other promising grasses for saline soils rehabilitation are *Aeluropus lagorpoides, Chloris barbata, Echinocloa colonum, Dchanthium annulatum, Sporobolus halvolus, Phragmites and Sida spp. Dichanthium annulatum* owing to its typical salt exclusion mechanism forms a good forage species for cattle, as the salt transported to the shoot is significantly negligible. A silvi-pastoral model comprising Kallar grass and *Prosopis juliflora* has been identified as an ideal system for alkali soil. For salt affected black soils *Salvadora-Dichanthium* system was found ideal one.

7.2.4. Cotton-pulse intercropping on moderately saline black soils

Farmers who take cotton as rainfed mono-crop, do face crop losses due to salinity development at later stages of crop growth. Under such situations, intercropping with pulses provides some remuneration to the farmer in the event of failure of cotton crop. On-farm trials have indicated cotton - cluster bean proved to be beneficial on moderately saline black soils having salinity of 4-6 dS m^{-1}. Cotton intercropped with cluster bean (Fig. 20) produced cotton seed yield at par with that of sole cotton. Increase in nitrogen up to 80 kg N ha^{-1} significantly increased the seed cotton yield under saline conditions. Cluster bean while improving the fertility of the soil provides an insurance against the failure of cotton crop (Table 20).

Fig. 20. Cotton intercropped with Cluster bean

Table 20. Performance of cotton intercropped with pulses under different levels of fertilizers on moderately saline Vertisols of Bara tract

Main-plot Treatments	**Seed cotton Yield, Kg/ha**	**Treatments** Sub-plot Treatments	**Seed cotton Yield, kg/ha**
Inter crops (pulses)		Fertilizer levels (kg/ha) 80 kg N + 40 kg P_2O_5/ha	
Sole cotton	572.0	Control	355.1
Cotton + Black gram	532.7	20	440.3
Cotton + Cluster bean	559.3	40	537.6
Cotton + Soybean	556.9	60	626.1
S Em (±)	9.3	80	676.3
CD (5%)	22.7	100	685.8
		SEM (±)	15.2
		CD (5%)	30.7
Coefficient of variation		6.7 %	

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7.2.4.1. *Impact*

Farmers who take cotton as rainfed mono crop in inland and coastal areas of the state do face crop losses due to salinity and due to other climatic vagaries. Under such situations, intercropping with pulses provides some remuneration to the father in the event of failure of cotton crop. The system would fetch about Rs. 16000/= per hectare from cotton and further the pulses due to their nitrogen fixing ability enrich the soils with nitrogen. Cotton as well as pulses can be taken as rainfed crops, providing saline water irrigation, if available further boosts the crop yields. Use of saline water in cotton has been proved beneficial on saline black soils (Gururaja Rao et al. 2013).

Targeted Areas: **Coastal saline Vertisols**

7.2.5. Biosaline Agriculture

Highly salt affected soils with plenty of saline ground water are available in many parts of our country. These soils, by and large remain barren, as arable farming is not feasible. Such soils can be profitably used for production of economically important products such as timber, fodder, fuel, pharmaceuticals using salt tolerant plants and economic halophytes and saline water. Some important species which can be used in Biosaline agriculture programmes are *Salvadora persica, Salicornia brachiata, Cressa cretica, Aeluropus lagopoides, Sprorobolus airoides, Eragrostis* species. These species not only thrive well and can use both saline soils and saline water for economic production and environmental regreening.

8. Salt tolerant crops

Most crops do not grow well on soils that contain salts. The salt accumulation may limit plant growth to salt tolerant plants (halophytes) only. High salt concentrations are toxic or limit plant growth because nutrients are proportionally less available or create physiological drought as a consequence of the high osmotic pressure of the soil solution. This means that salt reduced the rate and amount of water that the plant roots can take up from the soil. Therefore saline soils are often left in their natural state and used for extensive grazing. Arable use is only possible under careful irrigation management or in the more humid regions, where salt tolerant crops such as rice, millet or palms can be grown as well as salt tolerant forage species and biomass species (Tables 21-22). The highly tolerant crops can withstand a salt concentration of the saturation extract up to 8 dS/m. The moderately tolerant crops can withstand salt concentration up to 4 dS/m. The limit of the sensitive group is about 3 dS/m.

Table 21. Relative tolerance of crops to salinity and sodicity (Gujarat).

Salinity			Sodicity		
Tolerant	**Modera-tely tolerant**	**Sensitive**	**Tolerant**	**Moderately tolerant**	**Sensitive**
Barley	Wheat	Cowpea	Barmuda grass	Wheat	Cowpea
Sugar beet	Oats	Gram	Para grass	Barley	Gram
Spinach	Rice	Peas	Rice	Oats	Groundnut
Cotton	Maize	Guar	Sugar beet	Berseem	Moong
Safflower	Sunflower	Moong		Sugarcane	Peas
	Potato			Millet / Sorghum	Maize
	Cotton,			Cotton	

Table 22. Tolerance of fruit trees to sodicity

Tolerance to sodicity	ESP	Fruit crop
High	40 – 50	Ber, Tamarind, Sapota Wood Apple, Date palm
Medium	30 – 40	Aonla, Karodna, Phalsa, Fig, Pomegranate
Low	20 – 30	Guava, Bel, Lemon, Grape
Sensitive fruit	20	Mango, Jack fruit, Banana

9. Recommended Package of Practices of Crops Grown in Coastal Area

Some important agronomic practices for field and vegetable crops ideal for coastal region are given below (Table 23).

Table 23. Package of practices of different crops means for coastal areas

Field Crops

Parameter	Bajra	Wheat (Irrigated)	Wheat (Un Irrigated)	Sorghum(Grain)
Varieties	GHB15, GHB235 MH179, MH169 GHB183, GHB229 GHB316, GHB526 GHB528	GW496, KRL 210, KRL 19, KRL 238, LOK 1	Arnej206, GW1 GW2	GJ35, GJ37 CSH5. CSH6 CSH8, GSH1, GSH4, GJ39, GJ40, GJ41
Sowing time	*Kharif*: June-July Summer: Feb.-March	15-25 November	October	June-July
Seed rate (kg/ha)	3.75	100-125	50-60	10-12

Row Spacing (Cm)	45/60 cm	22.5	30	45
Plant Spacing (Cm)	10/15	-	-	15
FYM(t/ha)	10-12	8-10		8-10
N:P:K	80:40:0	120:60:0	20:0:0	80:40:0
Inter cultivation)	1-2	2-3	2-3	
Irrigation		7-9	-	
Maturity (Days)	70-80	95-110	100-120	100-115
Productivity (kg/ha)	2000-2500	4000-5000	1400-1800	Hybrids: 3000-4000 Improved Varieties 1500-2000

Parameter	Groundnut (*Kharif*)	Groundnut (summer)	Castor (rainfed)	Castor (Irrigated)
Varieties	Spreading: GHUG10, GG11, GG12, GG13Semi Spreading: GG20 Bunchy: GHUG1, T G.26, GG2, GG4, GG6, GG7, GL24		GAUCH1, GCH2, GCH4, GCH5, GC2, GCH6	
Sowing time	Premonsoon: June Normal: Onset of monsoon	Middle of January	June July	June-July
Seed rate(kg/ha)	80-100	120	8-10	5-7
Row Spacing (Cm)	Bunch:45 Spreading:60	22.5-30	90	90
Plant Spacing (Cm)			20	60
FYM(t/ha)	8-10	8-10	8-10	8-10
N:P:K	12.5:25:0	25:50:0	40:40:0	75:50:0
Inter cultivation)	3-4	3-4	2-3	2-3
Irrigation	As per monsoon	7-9		As per monsoon
Maturity (Days)	90-120	90-1`20	160-210	160-210
Productivity (kg/ha)	1000-1500	2000-3000	1500-2000	2000-4000

Parameter	Sesamum (*kharif*)	Sesamum (Semi *Rabi*)	Rai	Mustard
Varieties	Gujarat1,Gujarat2 Gujarat10	Purva1	Varuna, Gujarath Rai1 Gujarath Rai 2	Patan66, G.sarsaon1
Sowing time	June –July	August-September	First week of October	First week of October

Seed rate (kg/ha)	2.5-3	2.5-3	3-3.5	3-3.5
Row Spacing (Cm)	45	60	45	45
Plant Spacing (Cm)	15	15	15	15
FYM (t/ha)	6-8	6-8	8-10	8-10
N:P:K	25:25	12.5:12.5	50:50	50:50
Inter cultivation)	2-3	2-3	2-3	2-3
Irrigation	As per monsoon	3-4	3-5	3-5
Maturity (Days)	85-90	15-120	105-120	105-120
Productivity(kg/ha)	700-800	800-1000	2000-2500	2000-2500
Parameter	Cotton (Hybrids)	Cotton (Improved Varieties)	Onion	Garlic
Varieties	Sankar4, G.Cot.6 G.Cot.8, G.Cot10 G.Cot DesiHybrid 7 G.Cot.Desi Hybrid 9	American Deviraj, G.Cot10 G.Cot12, G.Cot14,G.Cot16, G.Cot18 Desi Cotton, Digvijay, G.Cot11, G.Cot13, G.Cot17, G.Cot21, G.Cot23	Talaja local, Junagadh local, Agrifound light red, Pusa white flat-131, G.Safed *Kharif*: Dungri-1, Agrifound dark red, N53	G.Lasson-1,2,3 and10
Sowing time	June-July	June-July	June-July October-November	October -November
Seed rate (kg/ha)	2.5-4	10-15	8-10	600-800
Row Spacing (Cm)	120/90	60x30 to 90x30	15,10	15,10
Plant Spacing (Cm)	90x30		10	10
FYM(t/ha)	15-20	8-10		
N:P:K	160:0:0	80:0:0	75 : 37.5 : 50	40 : 25 : 25
Inter cultivation	3-4	2-3		
Irrigation	3-6	2-5	As and when required for *kharif* and 8-10 days interval for *rabi*	7-8
Maturity (Days)	170-200	210-220	135-145	125-130
Productivity (kg/ha)	2500-4000	1000-1500	40000-50000	5000-7000

B. Vegetables

Parameter	Brinjal	Tomato	Chilli	Bhindi	Cluster bean
Seed rate Kg/ha	0.35 to 0.40	0.25 to 0.30		8-10	8-10
Crop geometry (cm)	90x60 75x60 40x40	90x60 75x60 40x40	75x60 60x60 60x45	60x30 30x15	60x20 45x20
FYM (t/ha)	12	20	20	10-12	10-12
Nitrogen (kh/ha)	100	75	100	100	25
Phosphorus (kg/ha)	37.5	37.5	50	50	37.5
Potash (kg/ha)	37.5	37.5	50	50	37.5
Normal yield (t/ha)	35-40	25-30	8-10	15-16	12-15
Recommended variety	Gujarat long- 1, Gujarat hybrid Brinjal - 1 & 2PLR-1,JBGR-1	Pusa ruby, Avinash-2,Gujarat tomato 1 and Gujarat tomato 2	S 49, Gujarat Chili 101, 111, 121Dholera	Gujarat Okra 2, Parbhani Kranthi,, Gujarat hybrid Okra 1	Pusa Navbahar, Pusa Sadabahar, Gowri

10. Agroforestry in salt affected soils

The adoption of reclamation measures, *inter alia,* removal of soluble salts through leaching and drainage, reduction of exchangeable sodium through application of amendments in large quantity, addition of manure and fertilizers, irrigation over the entire area, are costly operations. Due to high cost, greater attention is focused on growing tolerant trees using suitable planting techniques. Salt tolerant trees (like *Prosopis, Acacia, Eucalyptus, Parkinsonia etc.*) may be grown directly on such soils by spot treatment i.e. by making pits or auger holes. Some of the fruit trees like Aonla, Karonda, ber, Jamun, Phalsa, Guava, Bael, Wood apple can also be grown.

In between rows of salt-tolerant trees, tolerant grasses may also be grown, e.g. *Vetiver, Cenchrus, Cymbopogon, Aristida, Bothriochloa, Chloris, Chrysopogon, Dichanthium, Digitaria, Eragrostis, Heteropogon, Iseislema, Saccharum, Aeluropus lagopoides, Eragrostis, Schima,* in silvipastoral system of agro forestry.

Ameliorative effect of trees: Tree growth is reported to exert ameliorative effect by improving physical, chemical and biological properties of soil.

Planting methods of trees: For successful tree plantation on salt-affected soils, selection of proper method of soil working is of utmost importance. Due to the inhospitable conditions for plant growth, all the species do not grow equally well under all situations.

Based on the considerable volume of research work done, certain crops, fruit trees and forest tree species have been identified for their tolerance limits to salinity /sodicity by different workers. After selection of the plant species, appropriate planting technique should be adopted. Number of techniques is available for this purpose and some of them are described here (Table 24).

Table 24. Planting methods ideal for saline soils

1	Pit method/Auger hole method	A pit of 45 x 45 x 45 cm size is excavated and mixture of soil, sand, FYM and gypsum (if soil is alkali) is filled. Under normal soil conditions, gypsum addition is not required.
2	Sub surface planting	This method is useful when only surface soil is saline. An auger hole of 15 cm diameter is made up to 45 cm depth and planting is done at 15 cm depth so as to avoid adverse effect of surface salinity.
3.	Ridge and trench	A ridge of 40 cm height is prepared and planting is done at the top of ridge. This method is useful where assured irrigation supply is available. Under saline soil conditions, ridges are unsuitable.
4.	Furrow planting	A 20 cm deep and 60 cm wide furrows are prepared and planting is done in furrow which enable to give irrigation more effectively.

10.1. Selection of the trees

The crop tree/grass to be grown for reclamation purpose on salt affected soil should posses some of the following characteristics

- Capacity to grow on adverse soil site,
- High biomass production,
- Dense network of fine roots coupled with some deep roots,
- High and balanced nutrient content in the foliage,
- Appreciable nutrient content in the roots,
- Moderate rate of decay of foliage and
- Absence of toxic elements / substances in foliage and root exudates

For successful establishment and growth of species, the following factors need to be given more and due attention:

- Selection of the tree species matching the site
- Site preparation
- Nursery and planting techniques: pit, saucer pit, trench, ridge ditch, mound auger hole

- Time of, and spacing in, plantations
- Improvement of soil fertility through manures& fertilizer
- Irrigation
- Cultural practices

10.2. Tolerant Tree Species

The list of tree species tolerant to soil sodicity and salinity. The level of tolerance decreases as we move down the table 25.

Table 25. Tree species suitable for sodic and saline conditions

Soil sodicity	Soil salinity
Prosopis juliflora (Ganda babul)	*Avicennia martina* (Twar)
Acacia nilotica (Desi babul)	*Prosopis juliflora* (Ganda babul)
Eucalyptus tereticorniis (Nilgiri)	*Rhizophora species* (Karod)
Zizyphus species (Ber)	*Casuarina equisetifolia* (Sharu)
Capparis decidua	*Salvadora persica* (Pilu)
Capparis decidua (Kerdo)	*Tamarix articulata* (Farash, Lai)
Pongamia pinnata (Karanj)	
Butea monosperma (Keshuda)	*Atriplex nummularia* (Atriplex)
Casuarina equisetifolia (Sharu)	*Acacia nilotica* (Desi babul)
Acasia auriculiformis(Aust. Babul)	*Pongamia pinnata* (Karanj)
Emblica officinalis(Aonla)	*Prosopis cineraria* (Khejri)
Terminalia arjuna (Arjun sadad)	*Eucalyptus camaldulensis* (Nilgiri)
Azadirachta indica (Neem)	*Parkinsoia aculeata* (Ram baval)
Dalbergia sissoo(Sissoo)	*Acacia tortilis* (Israeli babul)
Tamarindus indica (Tamarind,Amli)	*Azadirachta indica* (Neem)
Albizia procera (Kilai)	*Acacia auriculiformis*(Aust. Babul)
Albizia lebbeck(Siras)	*Eucalyptus tereticornis* (Nilgiri)
Syzygium cummini (Jamun)	*Dalbergia sissoo*(Sissoo)
Leucaena leucocephala (Subabul)	*Albizia lebbeck*(Siras)
Populus deltoids (Poplar)	*Leucaena leucocephala* (Subabul)
Ailanthus excelsa (Arduso)	*Cassia siamea* (Kashid)

11. Recommended/improved technologies for coastal tracts of Gujarat for improving the crop productivity

South Gujarat Coast

- Apply gypsum @ 75% of gypsum requirement of the soils in the partially reclaimed saline sodic soils of South Gujarat
- Dandi, SLR24 and Jaya are suitable for cultivation in the partially reclaimed saline sodic soils of South Gujarat

- Instead of growing only paddy, under conditions of low water availability farmers of coastal salt affected soils of South Gujarat, should follw paddy- wheat or paddy- oat sequence
- For sustained crop production in the partially reclaimed saline sodic soils of South Gujarat farmers should apply zinc sulphate to their paddy crop @25 kg/ha once in three years.
- Green manuring with Sesbania (Dhiancha) or use of Azolla as bio-fertilizer or application of urea coated neem cake can reduce the nitrogen requirement of paddy by about 25- 40 per cent in the partially reclaimed saline sodic soils of south Gujarat.
- In the coastal tail end portion of canal command areas where the water availability is erratic and undependable, for growing wheat successfully, the canal water should be stored in a farm pond and used for irrigating *rabi* crops.
- In unreclaimed saline sodic soils of South Gujarat Gatton Panic can be grown as fodder crop even without irrigation. This crop also acts as a bio-reclaiming agent for amending the saline sodic conditions. The broad bed furrow method of land configuration for Gatton panic (*Panicum maximum* Jacq) is markedly more productive, remunerative and sustainable system as compared to traditional method of flat planting under coastal salt affected soils.
- Brinjal crop can be profitably and sustainably without deteriorating soil health in saline sodic soil with saline water of 8 dS/m provided it is irrigated through drip and followed by paddy during *Kharif* season.
- Under paddy-wheat sequence, in the coastal salt affected soils of South Gujarat 60 kg of nitrogen to paddy crop can be saved if the wheat straw is incorporated in the soil 15-20 days before transplanting @5 tonnes per hectare.
- In the unreclaimed coastal salt affected soil, *Prosopis juliflora* is found to be the best forestry species which can slowly reclaim the soil. The other most promising species is the Australian basbul. Among the shrubs, *Atriplex* is the best one. Ber and Gunda thrive very well in these conditions.

Bhal Region

- In the Bhal region, Safflower, Dill seed and cumin are identified as suitable crops for diversification.
- Raised bed shallow bed system has been standardized for Bhal area. Paddy should be grown in the shallow bed the less water demanding and crops susceptible for water logging like cotton etc should be grown in the raised bed
- Giving one irrigation at tillering stage of wheat from farm pond with the harvested water results in considerable increase in the productivity

- The gram and mustard crops crop with one irrigation to each from the farm pond, responded up to 40 kg N and 60 Kg N+20 Kg phosphorus respectively
- Gatton panic grass, Para grass and *Dichanthium annulatum* thrived well in Bhal conditions and with stood the irrigation water salinity level of 8dS/m

Saurashtra Region

- In North Saurashtra conditions groundnut + castor inter cropping in 3:1 ratio is very profitable
- In North Saurashtra conditions growing of *Dichanthium annulatum* especially in sloppy fields conserves soil and moisture.
- Deep ploughing in creases moisture storage in the soil profile and increases the yield of *kharif* groundnut
- Instead of growing sorghum alone, inter cropping it with pigeon pea on alternate rows is more economical in the North Saurashtra conditions
- Growing three rows of sesamum after 6 rows of groundnut gives more insurance and economical in North Saurashtra
- In between perennial pigeon pea or subabul, grown at 8.1 meter distance growing of either groundnut or sorghum (16 rows) is found to be economically viable alley farming in North Saurashtra
- Farmers of South Saurashtra should apply "tanch" @50t/ha for more returns from *Kharif* groundnut They are also advised to apply gypsum @ 500kg/ha for their groundnut crop
- The farmers of Kutch are advised to adopt mixed cropping of bajra, moong and castor with 50, 60 and 20 per cent of the recommended seed rate respectively
- In South Saurashtra inter cropping of groundnut or green gram or black gram in sugarcane field is more economical
- In South Saurashtra, castor should be preceded by sun hemp green manuring to save 60 % of nitrogen
- In ground nut –wheat cropping sequence, in South Saurashtra, the groundnut crop should be given FYM @10 t/ha and the wheat should be fertilized with 120 kg N and 60 kg phosphorus
- In South Saurashtra, when a saline water is to be used for irrigating, farmers should apply FYM gypsum @ 75% of Gypsum requirement of the soil
- In alluvial saline sodic soil, when bajra-wheat sequence is followed and irrigated with poor quality well water, gypsum should be applied @100 per cent of the gypsum requirement on alternate years or 50 % every year.

12. General Recommendations for Agriculture in Coastal Areas

As far as possible saline/sodicity resistant crops/varieties should be selected. For long duration crops, farmers should give minimum of 1 irrigation after the cessation of rainfall in the coastal areas

Where no other crop performs satisfactorily, in the saline tracts, date palm plantation cultivation will improve the economic condition of the farmers.

The seed rate should be 15 to 20 per cent more in the saline soil conditions.

At least 30-50 per cent more nitrogen need be applied in saline agriculture.

Under conditions of scarce sweet water availability, cyclic use of good and poor quality water should be made.

The impact of saline water on soil health will be less in light textured soil than heavy textured ones. Hence higher salinity water can be used in light soils and not in heavy textured soils.

The poor quality water is best used through micro irrigation especially drip method.

When moderately poor irrigation water is applied through sprinkler, care must be taken that it is not used for summer crop and also very high saline water should be used through sprinkler as it may form a salty layer on the leaves and there by the transpiration and ultimately the yield.

Application of FYM/compost/cakes or green manuring can reduce the impact of the salinity. Whenever sodic water is to be used for irrigations, sufficient quantity of gypsum should be added based on the Residual Sodium Content of the water. If the soil is also sodic additional gypsum as per the laboratory analysis should be added to the soil. Mulching the soil will go a long way in reducing the impact of soil and water salinity. Hence, it is always better to mulch the soil especially when saline water is used fertigation. Those who can afford plastic mulch should go for it as it is the best one for overcoming the salinity impacts in along run though the initial investment may be high.

13. References

Abrol, I.P., Chhabra, R and Gupta, R.K. 1980. A fresh look at the diagnostic criteria for sodic soil . Proc. Int. Symp. On Salt Affected Soils, Karnal , India, 142-147 pp.

Agassi, M., Shainberg, I and Morin, J. 1981. Effect of electrolyte concentration and soil sodi ity on infiltration rate and crust formation. Soil Sci. Soc. Am. J. **48**: 848-851.

FAO, 1988. World Agriculture toward 2000. An FAO Study. N. Alexandratos (Ed). Bellhaven Press, Londond, 338 pp.

Gururaja Rao, G., Ravender Singh and Bhargava, G.P. 1997. *Vegetation types in Mahi Right Bank Canal Command area Ukai Kakrapar command area and parts of*

Bhal Region in Gujarat state. Technical Bulletin 20, Central Soil Salinity Research Institute, Regional Research Station, Anand. p. 52.

Gururaja Rao, G, Nayak, A.K. and Chinchmalatpure, Anil R. 2000. Dill (*Anethum graveolens* L.) – A potential crop for salt affected black soil. Technical Monograph No. 1 Central Soil Salinity Research Institute, Regional research Station, Anand (Gujarat). p. 10.

Gururaja Rao, G., Nayak A.K. and Chinchmalatpure, Anil R. 2003. *Salvadora persica:* A Life Support Species for Salt Affected Black soils. *Technical Bulletin*: CSSRI/Karnal/2003/1. Central Soil Salinity Research Institute, Regional Research Station, Anand (Gujarat). p. 44.

Gururaja Rao, G., Nayak A.K., Chinchmalatpure, Anil R. and Babu, V.R. 2001b. Growth and yield of some forage grasses grown on salt affected black Soils. *Journal of Maharashtra Agricultural Universities* **26**: 195-197.

Gururaja Rao, G., Nayak A.K, Chinchmalatpure, Anil R. and Babu, V.R. 2004. Growth and yield of *Salvadora persica* : a facultative halophyte grown o highly saline black soil. *Arid Land Research & Management,* **18**: 51-61.

Gururaja Rao, G., Nayak A.K., Chinchmalatpure Anil R, Singh, Ravender and N.K. Tyagi, 2001a. *Resource characterization and management options for salt affected black soils of Agro-Ecological Region V of Gujarat State*. Technical Bulletin, CSSRI/Karnal/2001/1. Central Soil Salinity Research Institute, Regional Research Station, Anand (Gujarat).p. 83.

Gururaja Ra, G., Sanjay Arora, Chinchmalatpure Anil R. Kumar, V and Sharma, D.K. 2103. Salt tolerant cotton accessions suitable for Saline Vertisols. Paper presented at National Convention, India Cotton: Gearing up for Global Leadership. 6-7 January, 2013, Navsari Agricultural University, Main Cotton Research Station, Surat, Gujarat.

Levy, G.J., Levin, J. and Shinberg, I. 1994. Seal formation and interril soil erosion. Soil Sci. Soc. Am. J. **58**(1):203-209.

Morin, J. and Van Wimkel, J. 1996. The effect of rain drop impact and sheet erosion and infiltration ate and crust formation. Soil Sci. Soc. Am. J**. 60**:1223-1227.

NRSA and Associates, 1996. Mapping of salt affected soils of India, 1:250000 map sheets, Legend, NRSA Hyderabad.

Rengasamy, P. 2002. Transient salinity and subsoil constraints to dryland farming in Australian sodic soils: An Overview. Aust. J. Exp. Agric. **47**(3): 351-361.

Richards, L.A. 1954.. *Diagnosis and Improvement of Saline and Alkali Soils*. USDA Agricultural Handbook, U.S. Department of Agriculture. 60,pp.160.

Russel, J.c., Kadry, L. and Hanna, A.B. 1965. Sodic soils of Iraq. Agronomica ES Talajtan Tam. **14** (Suppl.) : 91-97.

Shainberg , I., Levy, G.J., Rengasamy, P and Frankel, H. 1992. Aggregate stability and seal formation as affected by drop impact energy and soil amendments. Scol Sci., **154**:113-119.

Singh, G., Singh, N.T. and Abrol, I.P. 1994. Agroforestry techniques for the rehabilitation of degraded salt affected lands in IndIA. Land. Degr. Rehabilit. **5**: 223-242.

Szabolcs, I. 1979. Review of Research on Salt Affected Soils. UNESCO, Paris, France.