Salt Affected Soils and Their Management in India

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Soil salinization and alkalization are important desertification processes reducing drastically the land's capability to produce the optimum crop yields or even leading to complete failure of agricultural production in large arable areas in many countries of the world. In India alone, a vast area of about 7 million hectares is estimated to have the serious problem of soil salinity and alkalinity and has been lying barren for a very long period.

Secondary salinization

With the introduction of canal irrigation associated with improper use of water, more and more areas are being affected by the problems of water-logging and soil salinity, not only in India but also in several other countries. The problem is, however, more pronounced in the arid and semiarid regions. About 1/3rd of the cultivated land under irrigation in the world is considered to be already salt affected (FRAMJI [12]). Complaints about the development of soil salinity due to introduction of canal irrigation were made by some farmers in northern India in the middle of the 19th century. In the Deccan region of heavy black clay soil, the entire land was quite fertile in 1884, before opening of the canal, but in 1904 the land damaged due to faulty irrigation was reported to be 1680 ha.

Table 1

Water-logged area in different irrigation projects [21]

Project	Command area	Water-logged area	Water table in summer
	ha		m
Hirakud (Orissa)	106,280	60,000	2.7
Kosi (Bihar)	263,000	117,000	2.6
Nagarjunasagar (A. P.)	831,000	114,500	0.9—1.8
Chambal (M. P.)	700,000	32,725	0.5—1.5
Tungabhadra (Karnataka)	234,700	10,110	1.2—2.0

After the independence of the country, the cultivated area under irrigation has increased from about 22.6 million ha in 1950—51 to 49.5 million ha in 1979—80 through construction of several irrigation projects. It is further proposed to bring an additional area of 17 million hectares under irrigation during the Sixth Five-Year-Plan period (up to 1985). Some of the important irrigation

Table 2

Average annual rise of water table in different canal irrigated areas of Punjab and Haryana during 1941—1965 [18]

Name of the tract	Rise of water table, cm
Upper Bari Doab	11
Bist Doab	17
Ferozepur	12
Old Western Yamuna Canal	
A Zone	8
B Zone	30
Old Sirhind Canal	
A Zone	11
B Zone	36

projects, where serious water-logging and consequent soil salinity problems have arisen due to irrigation, are the Chambal Command Project in Madhya Pradesh and Rajasthan, the Gandak project in Bihar, the Tungabhadra project in Karnataka, and Purna-Jayakwadi in Maharashtra, the Nagarjunasagar in Andhra Pradesh and the Ukai-Kakrapar in Gujarat. The data in Table 1. regarding

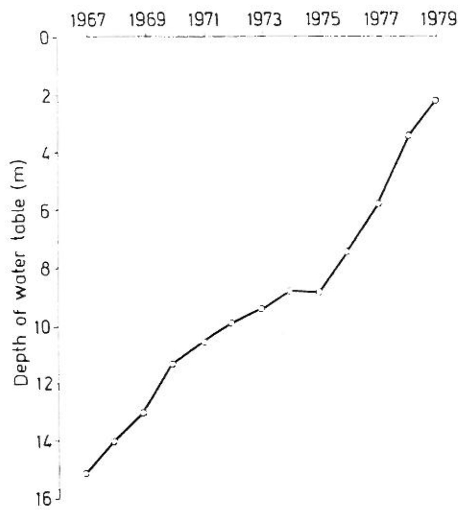

Fig. 1
Rise of water table at Hissar — June values

some irrigation projects in India show that several thousands of hectares of once fertile lands have been badly affected by water-logging within only a few years of the introduction of canal irrigation.

In some of the canal irrigated areas of Punjab and Haryana the data (Table 2.) collected on the extent of rise of the water table during the period of about 25 years from 1941 to 1965 reveal an average annual rise of 8–36 cm.

Table 3

Change in the spread of soil alkalinity due to canal irrigation in the western semiarid part of Uttar Pradesh, India

Village	Area of affected patch,[1] m^2		Per cent increase or decrease	Distance from canal, m
	1912	1952		
Bichpuri	70.8	93.6	+32	100
	64.0	197.2	+208	250
Unchagaon	364.8	370.0	+1	200
	107.2	240.4	+124	400
Punhera	191.2	193.2	+1	100
	30.0	25.2	−16	200
Gadesara	169.6	196.0	+16	150
	35.2	98.8	+181	

At the research farm of the Haryana Agricultural University, Hissar, under the Bhakra canal system, the water table was at about 16.7 m in 1967 but it has shown a steady and rapid rise and now rests at about 2 m below the surface (Fig. 1.), thereby resulting in serious problem of water-logging and soil salinity. A survey of the patches of the land affected by soil salinity in some irrigated areas of Etah district in the western semiarid tract of Uttar Pradesh, conducted initially in 1912 and subsequently after a lapse of 40 years in 1952, indicated an increase of about 1 to 208 per cent in the spread of soil alkalinity (Table 3.) except one patch wherein a reduction of 16 per cent was noticed (AGARWAL et al. [4]). This increase in the extent of affected patches was ascribed to the high water table and other related factors. Therefore, if proper soil and water management practices along with the introduction of irrigation are not adopted, the problem of soil salinity is likely to continue to increase at an alarming rate due to secondary salinization under irrigated conditions.

Regional differences in characteristics

The nature and characteristics of salt affected soils encountered in India vary considerably from one region to another, depending upon the climate, topography, geology, soil texture and drainability, hydrology, ground water quality and its fluctuations, management practices etc. Nevertheless, on the basis of the differences in the geographical location and other characteristics, the following four broad regions can be distinguished:

(i) Salt affected soils in the Indo-Gangetic plains, encompassing an area of about 2.5 million ha.

(ii) Salt affected soils in the arid regions of Rajasthan and Gujarat, covering an area of about 1.0 million ha.

(iii) Salt affected soils in the arid and semiarid regions of black cotton soil group, affecting an area of about 1.4 million ha.

(iv) Coastal saline soils, covering an area of about 2.1 million ha.

a) Saline soils of humid coastal area — 1.39 m.ha
b) Saline soils of arid coastal areas of Gujarat — 0.71 m.ha
c) Acid saline soils of Kerala — 0.01 m.ha

(i) *Salt affected soils in the Indo-Gangetic plains*

The salt affected soils of this region are found chiefly in the states of U.P., Haryana and Punjab and are generally sodic, excepting a few pockets which are only saline. The soluble salts comprise mainly of carbonates and bicarbonates of sodium, which are capable of alkaline hydrolysis. Owing to the almost flat topography of the area and impeded drainage, the problem has become more pronounced and about 40 per cent of the salt affected land in the

Table 4

Characteristics of a sodic soil, Karnal, Haryana [8]

Depth, cm	pH (1 : 2)	EC_e mmhos/cm	Composition of saturation extract, me/l					ESP
			Na^+	$Ca^{2+} + Mg^{2+}$	$CO_3^{2-} + HCO_3^-$	Cl^-	SO_4^{2-}	
0— 10	10.6	22.3	248	0.9	278	6.6	3.9	96
10— 48	10.2	6.3	82	1.2	77	2.8	1.7	91
48— 76	9.8	4.2	49	0.9	46	0.8	1.1	88
76—104	9.5	2.5	25	1.5	23	1.4	0.6	85

country are found in this region alone. Occurrence of a zone of calcium carbonate nodules at a depth of about 1 m is a common feature; at places it forms an indurated layer. Analysis of one representative soil profile from the research farm of the C.S.S.R.I., Karnal is given in Table 4.

(ii) *Salt affected soils in the arid regions of Rajasthan and Gujarat*

The chlorides and sulphates are the main soluble anions, though bicarbonates are also met with in some cases. Due to low rainfall and scarcity of irrigation water these soils present difficulties in reclamation. Besides, the poor quality of underground water imposes another constraint in this regard. The characteristics of a soil profile from Rajasthan (AGARWAL et al. [5]) are shown in Table 5.

(iii) *Salt affected soils in the arid and semiarid regions of black cotton soil group (Vertisol)*

These soils are mainly found in the States of M. P., Gujarat, Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu, and are characterized by black clays dominated by montmorillonite clay mineral with nodular lime in the sub-

Table 5

Characteristics of a soil profile from Pali, Rajasthan

Depth, cm	pH	EC_e mmhos/cm	Ca^{2+}	Mg^{2+}	Na^+	HCO_3^-	SO_4^{2-}	Cl^-	ESP
			me/l						
0—17	8.4	25.0	30	34	184	8	107	150	14
17—30	8.1	65.0	27	13	645	7	282	412	12
30—72	8.8	15.0	20	8	132	10	84	64	11

soil. They swell on wetting and crack on drying and show very poor infiltration rate when wetted, thereby rendering the leaching process rather difficult unless the physical condition of the soil is first improved through the addition of a suitable amendment. The quality of underground water in some cases is questionable and limits its use for irrigation and leaching. The analytical data of a soil profile from district Dhar, M. P. is given in Table 6.

Table 6

Characteristics of a soil profile from district Dhar, M. P.

Depth, cm	pH (1 : 2)	EC_e mmhos/cm	Composition of saturation extract, me/l						ESP	CEC me%	$CaCO_3$ %
			Ca^{2+}	Mg^{2+}	Na^+	HCO_3^-	Cl^-	SO_4^{2-}			
0— 15	8.4	17.4	27	26	150	6	171	Trace	33	51	12
15— 40	8.8	14.4	10	14	137	8	138	15	38	57	12
40— 70	9.0	6.8	5	6	63	8	58	8	48	50	15
70—100	9.4	3.9	5	3	36	10	29	6	52	58	18
100—150	9.8	1.8	3	2	20	12	7	5	50	59	23

(iv) *Coastal saline soils*

Extensive areas of salt affected soils occur in the river deltas, estuaries and creeks along the sea coast. The Sunderbans (West Bengal), delta areas of Krishna and Godavari rivers, Kari soils of Kerala and Khar lands of Maharash-

Table 7

Characteristics of a saline soil from the humid coastal area at Canning, West Bengal [6]

Depth, cm	pH	EC_e mmhos/cm	Composition of saturation extract, me/l					ESP	Clay %
			Na^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}		
0— 12	7.2	20.9	156	29	120	313	16	30	42
12— 28	7.5	6.5	37	11	16	57	8	14	43
28— 80	7.5	7.0	43	16	118	73	9	15	45
80—105	6.7	7.5	47	16	16	74	9	18	37

tra and Gujarat are, however, more important problematic areas. While chlorides and sulphates are the dominant anions, Na is the dominant cation though Mg is also present in appreciable amount in some cases. The rainfall is moderate

Table 8

Characteristics of a coastal saline soil from the arid area of Gujarat

Depth, cm	pH	EC mmhos/cm	Ca^{2+}	Mg^{2+}	Na^+	HCO_3^-	Cl^-	SO_4^{2-}	SAR
	(1 : 2.5)		me/l						
0—18	8.4	11.9	2	11	71	3	95	3	28
18—60	8.5	20.0	5	9	71	3	105	4	27
60—102	8.6	9.4	2	7	71	3	89	3	34
102—170	8.5	11.4	4	11	82	4	106	5	30

Source: Soil survey report of Govt. of Gujarat

to high in eastern and south-eastern areas and low in Gujarat, therefore the reclamation and managament of the two areas necessitate employment of different techniques. The characteristics of a coastal saline soil of West Bengal are shown in Table 7, while those of Gujarat are presented in Table 8.

Kari soils in Kerala, which are heavy clay in texture, black in colour and highly acidic in reaction, contain a high amount of organic matter, nitrogen and soluble salts of chlorides and sulphates. There is no horizon differentiation in the profile. The soils are extremely plastic and sticky and present difficulties for the cultivation of many crops except paddy. The physico-chemical characteristics of a coastal saline soil from Kerala (BHARGAVA et al. [7]) are given in Table 9.

Table 9

Characteristics of a coastal saline soil from Calicut district, Kerala

Depth, cm	pH	EC_e mmhos/cm	Composition of saturation extract, me/l					ESP	Clay	Organic matter
			$Ca^{2+} + Mg^{2+}$	Na^+	HCO_3^-	Cl^-	SO_4^{2-}		%	
0— 9	4.4	43.6	123	322	2	354	120	6	48	4.8
9—20	4.8	12.6	38	100	1	106	36	6	39	3.6
20—36	4.8	11.7	41	82	2	86	53	7	46	2.4
36—70	4.5	8.4	25	76	2	57	65	11	63	2.6
70+	3.4	38.6	112	285	2	337	75	20	50	40.5

Management practices

Considering the seriousness and importance of the problem of soil salinity and alkalinity and the likely danger of its further extension in the other fertile areas coming under irrigation on the one hand and their immense potentiality for agricultural production on the other, research work on the characterization and management of these problem soils has been intensified greatly in India with the establishment of the Central Soil Salinity Research Institute (CSSRI) at Karnal in 1969. As indicated above, wide variations occur in the characteristics of the salt affected soils of the different regions, therefore ameliorative measures to be adopted should be location-specific. Generalization of any technique is not desirable under such conditions. From the point of view of management, however, salt affected soils can be broadly divided into two distinct categories: 1. alkali (sodic) soils; 2. saline soils.

1. Alkali (sodic) soils

The alkali soils are predominantly found in the States of Punjab, Haryana and U.P. of the Indo-Gangetic plains, though they also occur in some other parts of the country. The important characteristics of these soils which are responsible for the very low yields or even for the complete failure of crops are as follows:

- Excessive amount of exchangeable and soluble sodium;
- High soil pH often exceeding 10;
- Deficiency of available calcium;
- Extremely low water intake rate and hydraulic conductivity, leading to poor moisture transmission characteristics;
- Presence of calcium carbonate nodules called Kankar, often occurring to a depth of about 1 m;
- Imbalance of plant nutrients;
- Poor physical condition leading to hinderance in root penetration.

Reclamation. — During the last few years, a series of experiments on the various aspects of the alkali soils, including the methods of reclamation, kind, dose and method of application of amendment, crops and varieties, fertilizer requirement, agronomic and cultural practices, water management etc. have been carried out and a package of technology has been developed at CSSRI, Karnal. Some of the essential components of this package are:

- Proper bunding and land levelling;
- Application of suitable amendment in right quantity and right manner;
- Choice of suitable crops, varieties and cropping sequence;
- Adequate fertilizer application including zinc;
- Use of appropriate cultural and agronomic practices;
- Proper water management including requisite drainage.

a) Amendment. — For the reclamation of alkali soils many inorganic and organic amendments are used. In most cases the reclamation of alkali soils involves replacement of sodium on the exchange complex with calcium and improvement of their physical condition. Gypsum is by far the most popular and is frequently used on a large scale in many countries. The dose of gypsum application depends upon the nature and degree of deterioration of the soil, soil texture, the depth to which the soil is to be reclaimed, the extent of improvement desired and the kind of crops to be grown, etc. The approach adopted at the CSSRI has been to reclaim initially only the upper (0—15 cm) soil layer, so that the relatively shallow rooted and tolerant crops like rice and wheat could be grown and this has ultimately helped in reducing the dose of amendment application to a considerable extent, and thereby the cost of reclamation. Application of gypsum only once in the beginning is adequate to achieve the desired results provided all other necessary management practices are followed properly and the land is not kept fallow for a long time.

MEHTA and YADAV [16] found the by-product phospho-gypsum as promising amendment. It is, however, necessary to work out in detail the adverse

Table 10

Chemical soil properties as influenced by the growth of rice plants

Treatments	pH		ESP		Exchangeable Na+ (me %)		Exchangeable $Ca^{2+} + Mg^{2+}$ (me %)	
	A	*B*	*A*	*B*	*A*	*B*	*A*	*B*
Original soil	10.3	9.5	93.3	26.0	7.9	3.9	0.1	4.2
Without rice plants	9.6	8.9	68.6	26.3	5.9	2.0	2.1	5.0
With rice plants	8.9	8.3	28.6	1.2	2.4	1.0	5.7	7.0

A and B indicate two different levels, artificially created in the soil.

effect, if any, of the fluorine contained in phospho-gypsum on the soil properties and crop growth. Furthermore, Khosla and Yadav [14] observed that addition of 20 to 30 t/ha of rice husk to the 10—12 cm thick upper layer of a sodic soil resulted in a significant improvement in the infiltration rate and in increased paddy yields.

b) Agronomic and cultural practices. — Due to the problematic nature of salt affected soils, the agronomic practices have to differ from those recommended for normal soils. For sodic soils, rice-wheat-dhaincha rotation has been generally adopted on a field scale. Inclusion of rice crop in the rotation has been found to be very helpful in reclamation because of its relatively greater adaptability to alkali conditions and its remarkable effectiveness in bringing about appreciable reduction in pH and ESP values of the soil (Chhabra and Abrol [9]). The data showing the reclaiming effect of rice crop are given in Table 10. The practice of puddling, which is normally used in growing rice on good soils has been found to be harmful in sodic soils in the initial stage of reclamation. In case of wheat crop, light and frequent irrigations result in better growth, though the total quantity of water used remains the same. If sufficient irrigation water is available during the summer months, growing of dhaincha *(Sesbania aculeata)* as a green manure crop after wheat has proved very beneficial in reclamation and contributes to a saving in nitrogen equal to 60—80 kg/ha to the subsequent rice crop (Table 11.). Further, the experiments show that an extended period of decomposition is not required for the effective use of dhaincha as green manure (Venkata Krishna et al. [22]). Paddy crop can, therefore, be transplanted within a few days after burying dhaincha.

The use of manures and fertilizers in alkali soils is important as these soils are generally deficient in available plant nutrients like nitrogen, calcium and zinc, and are often poor in organic matter. The work done at the CSSRI has shown that an increase in the dose of N by about 20 to 25 % as compared to the amount used on normal soils benefits the crops. Amongst nitrogenous fertilizers ammonium sulphate has given better results than either urea or calcium ammonium nitrate. Deficiency of available zinc is a common feature in alkali soils and therefore application of zinc sulphate has been found to be beneficial. It has been observed that by missing application of both P and K, there was no reduction in the yields of rice and wheat crops when compared to nitrogen application alone in the initial few years of reclamation of the sodic soils (Dargan and Chhillar [10]).

Table 11

Nitrogen requirement of rice after fallow and after dhaincha green manuring (Yield, t/ha)

Treatments	N_0		N_{40}		N_{80}		N_{120}	
	1974	1975	1974	1975	1974	1975	1974	1975
Fallow	2.64	3.41	3.86	4.27	5.56	5.87	6.01	6.35
Green manure	5.64	5.35	6.31	6.25	7.39	6.95	7.71	7.53

C. D. at 5%:
for fallow v/s G. M. 1974: 0.39; 1975: 0.23
for nitrogen 1974: 0.55; 1975: 0.32

c) Biological methods. — The reclamation process of salt affected soils is enhanced and continued further if suitable biological methods which include green manuring, growth of crops, addition of organic materials etc. are also followed simultaneously (YADAV [23]).

d) Hydrotechnical methods. — In the areas which have serious problem of soil alkali, leaching in combination with gypsum application has been found more efficient. The drainage requirements of salt affected soils are location specific and vary according to local conditions like the extent and nature of deterioration, soil texture, hydraulic conductivity, depth of water table and quality of ground water etc. The subsurface drainage in the sodic soils of the Indo-Gangetic plains having poor water transmission characteristics as observed at the CSSRI research farm is not effective and therefore, proper manipulation of the excess rain water alone, by storing maximum permissible water in the rice fields, conserving most of the remaining water in the dug-out pond in the low-lying area and finally allowing only the excess water to go to the nearby drain, could give good results.

The studies (DHRUVANARAYANA et al. [11]) carried out to examine the progressive changes resulting from reclamation of sodic soils indicate that reclamation reduces the runoff and flood hazard significantly, enhances the ground water recharge substantially and minimizes the drainage needs of the area appreciably (Table 12.). It will be seen that the unreclaimed area produced 46 cm runoff during the monsoon period of 1976 as against the corresponding value of only 8 cm in the reclaimed area. Thus, by reclaiming alkali soils not only the agricultural production can be enhanced but also favourable water balance situation can be created to meet the water needs for reclamation.

e) Selection of crops and varieties. — Crop production on salt affected soils can be made an economic proposition by either suitably modifying the soil conditions in the root zone to suit the plant type or by genetically manipulating the plants to suit the existing (or partially improved) soil conditions. However, judicious combination of both the approaches is more advantageous. AGARWAL and YADAV [3] proposed a salinity-cum-alkali scale to evaluate the saline alkali soils of the Indo-Gangetic plains for crop responses.

After critical evaluation of various parameters, it has been found that the slope of the regression line can be considered as a criterion for judging the tolerance of a particular crop. Comparative studies (JOSHI et al. [13]) on mineral analyses of wheat plants growing in normal and sodic soils revealed that the Na/K status at the tillering phase of the plants growing in alkali soils gives a negative correlation with sodicity tolerance (Fig. 2.). Thus, the Na/K index of plants at early growth stage can be used to predict sodicity tolerance without causing much damage to the growing plants. MURTHY et al. [17] also observed a positive relationship between the K/Na ratio and the tolerance of wheat for

Table 12

Comparative runoff and ground water recharge in unreclaimed and reclaimed alkali area

Characteristics	Un-reclaimed	Reclaimed
Infiltration rate, cm/day	0.5	5
Depth of water retained in crop land, cm	—	5
Runoff (cm) from a storm of 25 cm	23	4
Average monsoon rainfall, cm	57	57
Runoff produced during monsoon season, cm	46	8
Water available for recharge to ground water, cm	—	13

saline water irrigation in vertisol soil. Based on the results of the investigations carried out at CSSRI, tolerance of some important crops for varying exchangeable sodium percentage (ESP) has been determined (Fig. 3.). The list of crops (ABROL and FIREMAN [1] according to their tolerances is given in Table 13.

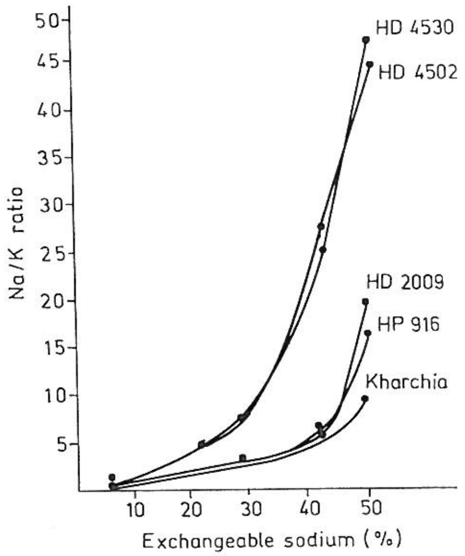

Fig. 2
Na/K ratio in leaves of five wheat varieties grown at four levels of ESP

Prospects of growing fodder crops and trees in alkali soils. — A significant advancement has been made at the CSSRI to explore the possibility of utilizing alkali soils without amendments or with the addition of a very small quantity for growing certain tree species and forage grasses. In this context the

Table 13

List of crops according to their tolerance for exchangeable sodium percentage

Tolerant	Semi-tolerant	Sensitive
Bermuda grass	Wheat	Cowpeas
Para grass	Barley	Gram
Rice	Oats	Groundnut
	Raya	Lentil
	Senji	Mash
	Berseen	Mung
	Sugarcane	Peas
	Millets	Maize
	Cotton	Cotton (at germination)

Yields are seriously affected if ESP is more than about 55, 35 and 10 in respect of tolerant, emi-tolerant and sensitive crops, respectively.

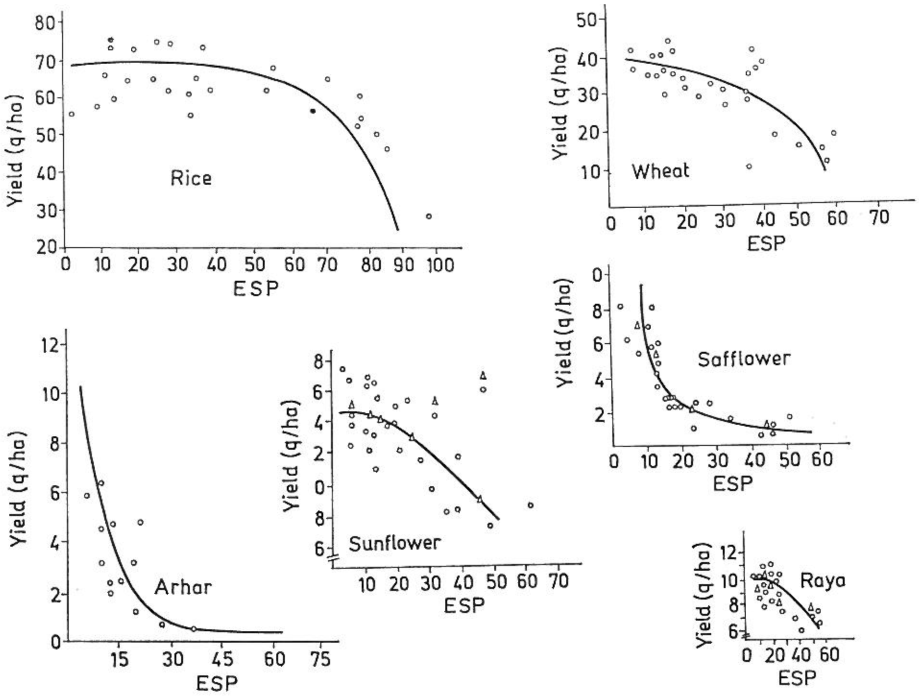

Fig. 3
Effect of varying ESP levels on yield of different crops

performance of *Brachiaria mutica*, *Panicum antidotale*, *Diplachne fusca*, *Chloris gayana* and *Cynodon dactylon* among the grasses, and *Prosopis juliflora*, *Eucalyptus hybrid* and *Acacia nilotica* among the trees, has been found to be promising. A comparative study of rice, para grass *(Brachiaria mutica)* and Karnal grass *(Diplachne fusca)* on a sodic soil (pH ranging from 10.6 to 10.2 with depth upto 120 cm) revealed that *Diplachne fusca* could produce 19.9 t/ha of green forage without gypsum application (Table 14.).

Table 14

Average rice grain yield and forage yield of para grass and Karnal grass [15]

Treatments	Yield, t/ha
Rice with gypsum, 50% G. R.	3.7
Rice without gypsum	0.0
Para grass without gypsum	4.8
Karnal grass without gypsum	19.9

In a field experiment on a calcareous sodic soil with pH above 10.0 and EC ranging from 0.45 to 1.75 mmhos/cm, YADAV et al. [24] found that the growth of *Eucalyptus* hybrid was almost as good after treating the soil with gypsum + FYM in the planting pit as when the original soil was replaced with good soil. Most of the control seedlings died out. The height growth of the plants increased further with fertilizer application. Deeper mixing of gypsum in the planting pit (Fig. 4.) resulted in greater height increment of *Eucalyptus* hybrid (SHARMA and YADAV [20]). In a recent trial, planting of *Eucalyptus* seedlings in auger holes has also shown promising results (ABROL and SANDHU [2]). The planting of suitable trees in the common village alkali lands has considerable potentialities to meet the local demands of fuel, timber and fodder.

Transfer of reclamation technology to farmers' fields. — The Central Soil Salinity Research Institute, Karnal through its Operational Research Project on the reclamation of alkali soils initiated in 1975 and 1976 in 2 clusters, one of 4 villages and another of 3 villages around Karnal, has amply demonstrated on more than 300 farmers' fields that the use of reclamation technology evolved by the Institute leads not only to a good harvest already in the first year of reclamation but also to progressive soil improvement and increase in crop yields during the subsequent years. In the very first year on the average 4 t/ha of rice and 1.5—1.8 t/ha of wheat were obtained on the demonstration plots, where nothing could be grown earlier for decades. Nearly 1200 ha of alkali land have already been brought under reclamation under the project.

The successful application of alkali soil reclamation technology at the farmers' fields has prompted the affected states of Punjab, Haryana and Uttar Pradesh to launch ambitious programmes of reclamation through the Land Reclamation Corporations by providing the necessary inputs to the needy farmers, creating infrastructural facilities and providing credit etc. on easy terms. It is estimated that more than 100,000 ha of alkali land have already been brought under reclamation through these efforts.

2. Saline soils

Saline soils contain mostly neutral salts of chlorides and sulphates of sodium in excessive quantities which interfere with crop growth. Because of the high content of these salts the saline soils are often flocculated and exhibit satisfactory physical condition. In some cases the proportion of Mg is higher than that of Ca, which may exert unfavourable effect on the soil properties. Some of the characteristics which adversely affect plant growth in the saline soils are as follows:

- Excessive concentration of neutral salts, resulting in high osmotic pressure;
- Imbalance of plant nutrients, leading to toxicity or deficiency;
- Toxic effects of specific ions;
- High water table, causing water-logging in many cases;
- Poor quality of ground water in most cases;
- Impeded drainage.

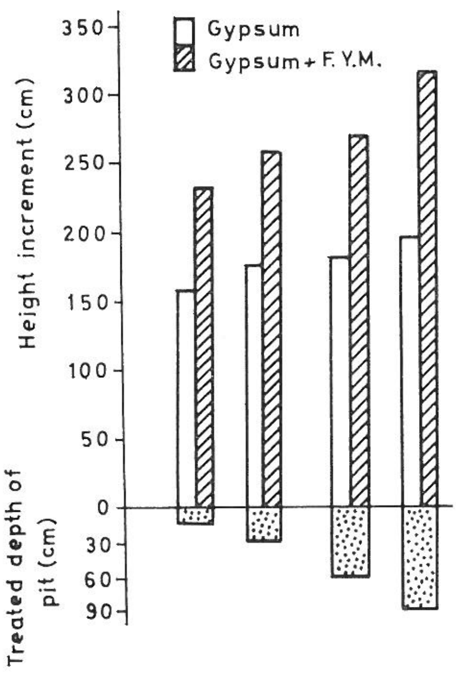

Fig. 4
Increment in height of *Eucalyptus* hybrid two years after planting

Saline soils occur both inland and along the sea coast. The analytical data of inland saline soils are shown in Tables 5. and 6., while those of the coastal saline soils are given in Tables 7., 8. and 9. Coastal saline soils vary widely in different areas. The relevant data (YADAV et al. [25]) on the range of pH and salinity level encountered in the coastal soils of India are assembled in Table 15.

Table 15

Range of soil pH and salinity in different coastal areas

State	pH	EC mmhos/cm	State	pH	EC mmhos/cm
West Bengal	5.5—7.0	4—35	Kerala	3.5—5.5	1—20
Orissa	5.0—7.5	2—50	Karnataka	5.0—7.5	3—10
Andhra Pradesh	6.0—8.8	0.5—17	Maharashtra	7.0—8.5	4—14
Pondicherry	6.5—8.5	1—50	Goa	5.0—6.0	4—15
Tamil Nadu	6.0—8.2	2—10	Gujarat	7.5—8.5	9—20

Amelioration. — Relatively much less attention has been paid to studying the characteristics of these soils and also to developing suitable techniques for their amelioration and utilization for crop production.

(i) *Leaching and drainage.* — Saline soils can be reclaimed through the process of leaching with good quality water if the water table is also lowered simultaneously. The experiments carried out under the Coordinated Project for Research on Water Management and Soil Salinity revealed that in a saline area of sandy loam soil with high water table at IARI, New Delhi, the digging of 1 m deep open ditches 32 m apart significantly lowered the water table and soil salinity, and resulted in high grain yields of crops like sorghum, maize and wheat as against complete crop failure or very poor yield in the undrained area. Placement of tiles (10 cm in diam.) 1.2 m deep at 12—18 m spacing proved effective in lowering the water table and leaching the salts from the saline black soil in Karnataka.

Recently some experiments have been undertaken in Sonepat and Rohtak districts of Haryana to determine the leaching requirement, drainage needs, suitability of crops etc. for the local saline soils. During the monsoon season of 1979 a salt removal of 3201 kg/m^2 was recorded from the drained plot as against only 0.16 kg/m^2 from the undrained plot from 105 cm depth near Kailana Khas village in Sonepat (Singh, 1980, unpublished). Very encouraging results in reduction in water table and soil salinity as well as in increased crop yields as a result of provision of drainage have been noticed in Gujarat State.

Some of the coastal saline areas receive high rainfall in the monsoon season but get very little rain in the winter and summer months, whereas certain parts of Gujarat receive very little rainfall in the whole year and have arid climate. The figures on water balance of the coastal areas (Yadav et al. [25]) are given in Table 16. It is seen that an appreciable portion of the rainfall remains in excess in the monsoon season in many coastal areas, which can be stored in the dug-out farm ponds and be used for irrigation during the dry period.

In the coastal saline areas of Sunderbans in West Bengal, provision of suitable drain to remove excessive rain water and to store the later part of the rainfall for use as an irrigation source has been found to be beneficial. In a field experiment conducted recently at Canning (West Bengal) on the subsurface open drains (1.75 m deep and 35 m long) spaced at 15, 30 and 45 m distance, the greatest reduction in soil salinity has been recorded in the plots having drains at 15 m spacing. In order to protect the land against the ingress of sea water high embankments are provided with one way sluice gates, which at the same time operate to allow the excess rain water to drain into the creeks or sea.

Table 16

Water balance in coastal areas of India

State	June to September			October to December		
	Rainfall	PET	Water surplus or deficit	Rainfall	PET	Water surplus or deficit
	mm					
West Bengal	1325	519	+806	177	310	−133
Orissa	1140	477	+663	180	280	−100
Andhra Pradesh	570	590	−20	330	337	−7
Tamil Nadu	340	640	−300	480	357	+123
Karnataka	2850	375	+2475	250	345	−95
Kerala	2010	395	+1615	550	335	+215
Maharashtra	2700	475	+2225	130	344	−214
Gujarat	930	556	+374	30	357	−327
Saurashtra	450	714	−264	20	413	−393

PET = Potential evapotranspiration.

(ii) *Mulching.* — In order to minimize salt accumulation in the post rainy season, use of mulch has been found to be of advantage. The studies conducted at Canning (Sen and Bandyopadhya [19]) show that the mixing of rice husk (10 t/ha) into the surface soil by ploughing during the fallow winter period after the harvest of *Kharif* rice, brought about appreciable reduction in soil salinity (Fig. 5.) and resulted in increased yield of subsequent rice crop in the following monsoon season.

(iii) *Selection of suitable crops and varieties.* — Many coastal areas which receive rainfall only in the monsoon season are mono-croped with rice during the

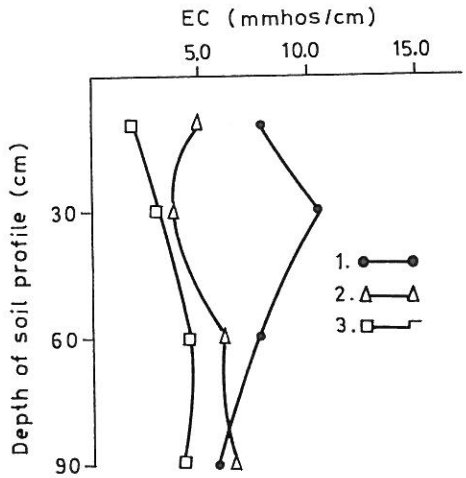

Fig. 5

Salt distribution in the soil profile with and without addition of rice husk. 1. Before first monsoon rain, without rice husk; 2. After first monsoon rain, without rice husk; 3. After first monsoon rain, with rice husk

kharif season. It is, therefore, necessary to develop suitable rice varieties which can give higher yields under these conditions. A large number of rice germ plasm collected from different saline areas of India and abroad have been screened at Canning and some genotypes have been identified which are tolerant to these adverse conditions and are being used in recombination breeding programme. A new mutant strain of rice named CSR-4 has been evolved by subjecting the seeds of variety IR-8 to X-irradiation. Attempts are also being made to find suitable crops which can be grown in the winter season. Crops like barley, chillies, watermelon and linseed have shown promising performance.

(iv) *Fertilizer use.* — Like on alkali soils, the application of nitrogenous fertilizers is essential for optimum crop production in the coastal saline soils. Highest rice yield was obtained with N application at the rate of 100 kg/ha. Urea was found to be a better source of nitrogen, and its efficiency was increased further when applied in the form of sulphur-coated urea in the monsoon season. Application of 75 per cent and 25 per cent of total nitrogen at tillering and flowering stages, respectively, or 1/3rd of the total nitrogen, each at transplanting (basal), tillering and flowering stages, produced the maximum yield of rice (variety Jaya) as shown in Table 17.

Table 17

Grain yield of rice as influenced by split application of N

Percentage N application			Grain yield, t/ha	
Basal	Tillering	Flowering	Kharif 1973	Rabi 1972 – 73
0	0	0	2.1	2.3
75	25	0	4.3	3.1
0	25	75	4.6	3.8
0	100	0	4.0	3.9
50	50	0	3.9	2.8
0	50	50	5.0	4.2
25	75	0	4.0	3.8
0	75	25	5.0	5.1
33	34	33	5.0	5.0
C. D. at 0.1 %			0.5	0.5

Finally, it should be mentioned that the salt affected soils in India vary considerably from one region to another, therefore their management practices have to be location specific. The technology developed at the CSSRI for the reclamation of alkali soils has proved effective and has been adopted on a large scale on the farmers' fields, in the Indo-Gangetic plains. Substantial additional quantities of rice and wheat grains are being produced on the alkali lands which had been lying barren for many years and where nothing was grown before. The work has also been undertaken to develop the alternative uses of these problematic lands with minimum use of inputs. Some of the common village alkali lands can be put under tree plantations to meet the local demand of fuel, timber and fodder. Relatively much less work has been done to develop suitable techniques for the amelioration of saline soils. The lack of availability of good quality water for irrigation and leaching on the one hand, and socio-economic as well administrative difficulties encountered in involving a group of farmers for providing effective drainage on the other hand pose serious problems for the utilization of saline soils for efficient crop production.

Summary

In India about 7 million ha of land are estimated to be affected by soil salinity/alkalinity mainly in the Indo-Gangetic plains, arid areas of Rajasthan and Gujarat, black cotton soil region and coastal tracts. Secondary salinization is also afflicting more and more areas due to the introduction of canal irrigation coupled with improper use of water. The properties of the representative soil profiles show wide variation from one region to another and suggest adoption of different techniques of management in different areas. The salt affected soils are divided broadly into 1. alkali soils and 2. saline soils. The various characteristics which render these soils unfavourable for crop growth have been explained. The research findings obtained on different aspects of these problem soils and the details of the package of technology for the reclamation of the alkali soils for crop production at the Central Soil Salinity Research Institute, Karnal, have been elaborated.

The methods of reclamation of alkali soils embrace the work on land preparations, kind, dose, method and time of application of amendment, selection of suitable crops, varieties and cropping sequence, fertilizer requirement, agronomic and cultural practices, water management, drainage etc. The results of the field experiments carried out to utilize the common alkali lands in the villages for growing forest trees and forage grasses with or without addition of gypsum have been highlighted. The technology of the Institute has been adopted on a large scale on the farmers' fields in the States of Haryana, Punjab and U. P. Already over 100,000 ha of alkali land have been reclaimed and good crops of rice and wheat are being obtained where nothing could be grown earlier for decades. An account has been given of the research work done on drainage, crops, agronomic practices including mulching, water management etc. in the inland and coastal saline soils.

References

[1] ABROL, I. P. & FIREMAN, M.: Alkali and saline soils — identification and improvement for crop production. CSSRI. Karnal. Bull. No. 4. 32. 1977.
[2] ABROL, I. P. & SANDHU, S. S.: A new technique to make alkali soils green. Intensive Agric. **18.** (1—2) 5. 1980.
[3] AGARWAL, R. R. & YADAV, J. S. P.: Salinity and alkali scale to evaluate saline alkali soils for crop responses. J. Indian Soc. Soil Sci. **4.** (3) 141—145. 1956.
[4] AGARWAL, R. R., MEHROTRA, C. L. & GUPTA, C. P.: Spread and intensity of soil alkalinity with canal irrigation in Gangetic alluvium of Uttar Pradesh. Indian J. Agric. Sci. **27.** 363—373. 1957.
[5] AGARWAL, R. R., YADAV, J. S. P. & GUPTA, R. N.: Saline and alkali soils of India. Book ICAR. New Delhi. 1979.
[6] BHARGAVA, G. P. & SINGHLA, S. K.: Annual Report. CSSRI. Karnal. 1972.
[7] BHARGAVA, G. P., SHARMA, R. C. & SHARMA, S. K.: Mapping and classification of salt-affected soils. Annual Report. CSSRI. Karnal. 11. 1976.
[8] BHUMBLA, D. R. et al.: Soil of experimental farm. CSSRI. Bull. No. 1. 43. 1973.
[9] CHHABRA, R. & ABROL, I. P.: Reclaiming effect of rice on sodic soils. Annual Report. CSSRI. Karnal. 47. 1975.
[10] DARGAN, K. S. & CHHILLAR, R. K.: Effect of missing application of P or both P and K in rice or wheat. Annual Report. CSSRI. Karnal. 56. 1975.
[11] DHRUVANARAYANA, V. V., KALRA, V. D. & TIWARI, A. K.: Studies on hydrologic balance and trends in groundwater exploitation. Annual Report. CSSRI. Karnal. 75. 1976.
[12] Irrigation and salinity: A world wide survey. (Ed.: FRAMJI, K. K.) Int. Commission on Irrigation and Drainage. New Delhi. 1976.
[13] JOSHI, Y. C., QADAR, ALI & RANA, R. S.: Mineral analysis and growth characteristics. Annual Report. CSSRI. Karnal. 56. 1976.

[14] KHOSLA, B. K. & YADAV, J. S. P.: Rice husk improves physical condition and crop growth in sodic soils. Indian Farm. **25.** (10) 9—11. 1976.
[15] KUMAR ASHOK, DARGAN, K. S. & ABROL, I. P.: Studies on reclaiming effect of grasses in sodic soil. Annual Report. CSSRI. Karnal. 56—60. 1979.
[16] MEHTA, K. K. & YADAV, J. S. P.: Phospho-gypsum for reclamation of alkali soils. Indian Farm. **27.** (7) 6—7. 1977.
[17] MURTHY, A. S. P., VENKATARAMU, M. N. & YADAV, J. S. P.: Effect of -aline water irrigation on sodium and potassium uptake in UP 301 wheat (*Triticum aestivum*). Ann. Arid Zone. **18.** 62—67. 1979.
[18] SEHGAL, S. R. & GULATI, A. D.: Increase in ground water potential due to rise of water table in canal irrigated tracts of Punjab and Haryana. Proc. 37th Session. Bhubneswar. Pubh. 88. Vol. 1. 1968.
[19] SEN, H. S. & BANDYOPADHYA, A. K.: Note on displacement of salts in soil under water-logged conditions, with special reference to mulching. Indian J. Agric. Sci. **44.** 772—773. 1974.
[20] SHARMA, B. M. & YADAV, J. S. P.: Effect of method of gypsum application in planting pit on properties of sodic soil and growth of Eucalyptus hybrid. Annual Report. CSSRI. Karnal. 123—124. 1979.
[21] Symposium on "Water-logging, causes and measures for its prevention". C. B. I. P. Publ. 118. Vol. I and II. New Delhi. 1972.
[22] VENKATA KRISHNA, S., BATRA, L. & DARGAN, K. S.: Studies on values of dhaincha as a green manure crop. Annual Report. CSSRI. Karnal. 43. 1978.
[23] YADAV, J. S. P.: Improvement of saline alkali soils through biological methods. Indian Forester. **101.** 385—395. 1975.
[24] YADAV, J. S. P., BHUMBLA, D. R. & SHARMA, O. P.: Performance of certain forest species on a saline sodic soil. Internat. Symp. on New Developments in the Field of Salt Affected Soils. Cairo. 1972. 683—690. 1975.
[25] YADAV ,J. S. P. et al.: Coastal saline soils of India. CSSRI. Karnal. Bull. No. 5. 1979.