Reclamation and Management of Salt Affected Soils for Increasing Farm Productivity and Farmers' Income

Anil R. Chinchmalatpure
ICAR-Central Soil Salinity Research Institute, Regional Research Station, Bharuch 392012 (Gujarat)

Introduction

Soil salinity is one of the main environmental problems affecting extensive areas of land in both developed and developing countries. Salinity is common in the region of arid and semi-arid regions where rainfall is too low to maintain a regular percolation of rainwater through the soil and irrigation is practiced without a natural or artificial drainage system. Such irrigation practices without drainage management trigger the accumulation of salts in the root zone, affecting several soil properties and crop productivity negatively. Globally, more than 900 million hectares (M ha) of land, accounting for nearly 6% of the world's total land area and approximately 20% of the total agricultural land is affected by salinity (Ghassemi *et al.*, 1995). Salinity is the product of complex interaction of many variables which lessen the current and/or potential capability of soil to produce goods and services. Presently, the total degraded land due to salinity and sodicity is estimated to be 6.74 M ha in India (Table 1) (NRSA and Associates, 1996) of which 2.22 M ha is present in Gujarat State (Table 2) and about 0.12 M ha area is affected by salinity in black soil region of Gujarat covering Bara tract area (Amod, Vagra and Jumbusar taluka of Bharuch district), Bhal area and part of Vadodara, Surat and Ahmedabad districts.

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 localized and more intensive in their impacts. 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 besides creating environmental pollution and affecting soil health and income of the farmers.

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, an excessive salt in soil accelerate land degradation processes resulting in increased impact on crop yields and agricultural production and ultimately leads to lower the farmers' income. 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.

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.

Table 1. Extent (ha) of salt affected soils in different states of India

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

Table 2. Extent (ha) of salt affected soils in different districts of Gujarat

District	Saline	Sodic	Total
Ahmadabad	161479	116428	277907
Amreli	42952	0	42952
Banaskantha	211722	83240	294962
Bharuch	62561	0	62561
Bhavnagar	78414	21249	99663
Jamnagar	82389	13389	95778
Junagadh	39800	69358	109158
Kheda	37852	0	37852
Kachchh	607336	13430	620766
Mehsana	117684	126077	243761
Rajkot	57634	0	57634
Surat	26287	0	26287
Surendranagar	135170	98259	233429
Vadodara	3863	0	3863
Valsad	15427	0	15427
Total	1680570	541430	2222000

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).

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.

Characteristics of salt affected soils

In general, saline and alkali (sodic) soils are the two major groups of salt affected soils 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 3. 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. 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 iso-electric 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 4. As there are large black soil (*Vertisol*) areas in the country, the limit of ESP for defining sodic soil can be appropriately lowered based on the study conducted. It is inferred from the study (Nayak *et al.*, 2004) 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 *i.e.*,> 6 dS m^{-1} even at fairly high ESP also, the soil saturated hydraulic conductivity (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* (Chinchmalatpure *et al.,* 2011).

Table 3. 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

Table 4. Indian system of classification

Soil Characteristics	Saline soils	Alkali soils
pH	< 8.2	> 8.2
ESP	< 15	> 15
ECe	> 4 dS/m	Variable, mostly < 4 dS/m
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 5. Grouping of sodic *Vertisols*

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

Saline soils

These soils have electrical conductivity (EC) of the saturation extract more than 4 dS m^{-1}, the exchangeable sodium percentage (ESP) 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 sometimes 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.

Saline-alkali soil

These soils will have EC of the saturation extract more than 4 dS m^{-1}, the ESP 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 non-saline alkali soils. On leaching of excess soluble salts, the soil may become strongly alkaline (pH > 8.5), the particles disperse and the soil becomes unfavourable for the movement of water and for tillage.

Non-saline alkali soil

Alkali soils which are known as Sodic or Solonetz have their ESP greater than 15, the ECe less than 4 dS m^{-1} and the pH ranges 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. Sometimes 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.

Salt affected agro ecological sub-regions

The eight agro-climatic zones identified by the Gujarat Agricultural University (NARP Status Report, GAU) 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 soils of different agro climatic zones

Agro climatic zone	Soil type	Soil Texture	Rainfall	Principal agricultural Crops	Area (ha)	Irriga-tion %
South Gujarat heavy rainfall	Salt affected	Clay to clay loam	1200-1500	Paddy, Sugarcane, Horticultural crops	21000	52
South Gujarat	Black cotton, salt affected	Clay to clay loam	900-1000	Paddy, Cotton, Sorghum, Pulses	14000	56
Middle Gujarat	Medium black, salt affected	Clay loam to silt loam	500-700	Paddy, Pearl millet, Cotton, Castor. Tobacco and banana	26000	78
North Saurashtra	Saline Sodic	Clay	500-600	Groundnut, Sorghum, Pearlmillet, Wheat	187000	22
	Coastal alluvial	Clay loam to clayey	300-400	Groundnut, Sorghum, Pearl millet	181000	9
	Coastal alluvial	Silty clay	500-700	Groundnut, Sorghum, Pearlmillet, Chick pea	299000	22
South Saurashtra	Low lying saline sodic with saline ground water	Clay	700-750	Cotton Sorghum	50000	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	96000	15
	Coastal alluvial	Sandy loam to silty clay loam	750-1000	Groundnut, sesamum, Sorghum, Pearl millet, and horticultural crops	286000	18
Kutch	Hydromorphic salt affected	Clay loam to silt loam	400-500	Cotton, Pulses, Sorghum, Cluster bean, Fruit crops	49000	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	160000	7
	Highly saline	Sandy loam to clay	600-700	Forestry	-	-

Reclamation and management of salt affected soils

Technological knowledge generated till date has helped in taming the problem in large tracts of land in different countries to restore their full potential. However, new challenges are set to be faced either due to changing climate or land use anomalies, leading to exponential increase in the area under salinity. With new challenges cropping up, soil salinity related stresses can be more pronounced and more damaging to crop production in coming years. It is well established that plant growth can be restricted or entirely prevented by increased levels of salinity and alkalinity in the soil. The productivity of these soils can be restored by management and reclamation using different technologies available with the ICAR-Central Soil Salinity Research Institute. The processes of accumulation of salts and build-up of ESP have to be reversed. To achieve this, provision of adequate drainage, replacement of Na^+ ions from the exchange complexes and leaching out of soluble salts below root zone has to be ensured. For reclamation, different methods like physical, chemical, hydro-technical and biological are to be adopted so that yield level of the crops grown on these soils can be enhanced and in turn income of the farmers. Physical methods include deep ploughing, sub-soiling, sanding, profile inversion, scrapping etc. Hydro-technical methods include leaching of salts, provision of drainage, use of leaching curves *etc*. Under chemical methods, application of gypsum is the prominent one. Other chemical techniques include application of calcium chloride, calcite, phospho-gypsum and iron pyrites *etc*. Biological methods include green manuring, addition of FYM and other organic manures, incorporation of crop residues, press mud, municipal solid waste, microbial consortium, biosaline agriculture, use of salt tolerant varieties *etc.*

Strategies for enhancing farm productivity and farmers' income:

For increasing farmers' income, the rate of growth in farm income has to be sharply accelerated and therefore strong measures will be needed to harness all possible sources of growth in farmers' income and these sources are improvement in productivity, resource use efficiency, lowering of the cost of production, increase in cropping intensity, crop diversification with high value crops, use of salt tolerant varieties, use of proper technology, *etc*. ICAR-CSSRI has developed various technologies for reclamation and management of salt affected soils and with the use of these technologies for the purpose, the hitherto unproductive or low productive salt affected land can be put under optimum productivity which will lead to more production and income.

1. **Gypsum technology for reclamation of sodic soils**: Using this technology till date, about 1.94 Mha sodic land has been reclaimed and the reclaimed area contributes 14-15 million tonnes of food grains to the National pool. The cost of intervention and output per unit area is about Rs. 42500 per hectare. Farmers obtained 4 tonnes/hectare rice and 2 tonnes/hectare wheat yield from reclaimed alkali land right from the first year of the reclamation, which increased to 5 and 3 tonnes/hectare during 3rd year onwards, respectively with 135 man-days of employment generated per hectare per year. Its net present worth (NPW) estimated to be Rs. 52,000/ha. This technology improved soil health, increased resource use efficiency, raised farm income, reduced poverty, minimised inequity, reduce flood hazards and waterlogging and improve quality of overall environment.
2. **Sub-surface drainage technology:** Subsurface drainage is an effective technology for amelioration of waterlogged saline irrigated lands in India. The technology has been widely adopted and replicated in Haryana, Rajasthan, Gujarat, Punjab, Andhra Pradesh, Maharashtra and Karnataka and almost about 66084 ha waterlogged saline soils have been reclaimed. Due to notable increase in crop yields, the technology results in 3 fold increase in farmers' income. The technology also generates around 128 man-days additional employment per ha per annum and also enhanced the crop intensity by 40-50%, significant enhancement in crop yields (up to 45% in paddy, 111% in wheat, 215% in cotton and 138% in sugarcane in different parts of the country, and farm income by 200-300% leading to benefit cost ratio of 1.5. (Kamra and Sharma, 2015; Chinchmalatpure *et al.,* 2016 and Kaledhonkar *et al.,* 2009).
3. **Cultivation of *Salvadora persica* on highly saline land**: This species was found to grow well on saline black soils having salinity up to 55 dS m^{-1} and found to yield well. Based on the studies conducted, the National Bank for Agriculture and Rural Development (NABARD), Mumbai in association with the RRS, Bharuch has developed a bankable model scheme 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 and 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/- per hectare (Rao *et al.,* 2004)**.** Apart from this, the species provide a dwelling place for birds and enhances the environmental greening.

4. **Cultivation of dill (*Anethum graveolens*):** Non-conventional crop like dill can be grown using residual moisture resulting in 2.6 q/ha seed yield with net returns of Rs. 8000/-. This crop forms an ideal option for the state in general and the region in particular, which *by and large* faces water scarcity problems (Rao *et al*., 2000). Under saline water irrigation, crop would yield net returns of Rs. 16500/- ha^{-1} with Rs. 6000/- per hectare as cost of cultivation. 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. 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.
5. **Farmers based ground water recharge:** The ICAR-Central Soil Salinity Research Institute, Karnal along with its Regional Research Station at Bharuch, Gujarat has designed artificial groundwater recharge structures for better harnessing rainwater in Bharuch and Narmada districts mainly for cultivation purposes. The CSSRI, RRS, Bharuch has installed 15 artificial rainwater recharge wells at farmers' fields in Bharuch and Narmada districts of Gujarat through the financial assistance from the Ministry of Water Resources, Government of India. The Prolonged availability and improvement in groundwater quality in recharge well of Gujarat increased farmer's income by Rs. 30000 to 75000 per ha in banana and papaya crops (Success Story-ICAR website, 2013).
6. **Integrated farming system model for salt affected black soils:** The farming system model comprised of a rain water harvesting structure, fruit species like papaya and vegetables on dykes, other fruit crops like banana, jamun, aonla, seed spices, woody biomass species like *Eucalyptus* and *Pongamia* and a compost pit has been developed with a aim to get farmers a staggered income throughout the year. Water productivity of banana, papaya, dill, coriander, brinjal, bottle gourd and tomato has been worked out along with benefit: cost ratios. Papaya followed by banana amongst different fruit species; dill followed by ajwain and coriander amongst spices and bottle gourd followed by tomato and brinjal amongst vegetables showed higher B:C ratios. The B/C ratios of vegetables and spices were more than that of the fruit species. The productive components like fruits, vegetables and spices could provide a net income of about Rs. 52258/- ha^{-1}. In view of low water requirement, spices, vegetables and papaya are better suited for water scarce regions like Bara tract of Gujarat with saline black soils (Rao *et al.*, 2009).
7. **Cotton-pulse intercropping proved to be beneficial on moderately saline black soils:** Farmers who take cotton as rainfed mono crop in the Bara tract in Amod, Vagra and Jambusar talukas of Bharuch district of Gujarat and other parts 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 farmer in the event of failure of cotton crop. The farmers of the region have been adopting the cotton intercropped with pulse technology for maximising the production and income also.
8. **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}. For maximizing forage production on saline black soils, *Dichanthium* on ridges and *Leptochloa* in furrows form ideal proposition. 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 (Rao *et al.,* 2011).

9. **Cultivation of *desi* cotton on saline *Vertisols*:** *Desi* cottons are known for their short staple characteristics, deep root system, resistance to diseases and pests and drought. The ICAR-CSSRI, RRS, Bharuch has been working on improvement in salt tolerance of herbaceum and arboreum cotton and has screened and identified salt tolerant germplasm of cotton. Studies conducted by the station has revealed that *desi* cotton line (G Cot 23) as salt tolerant and high yielding even at 11.2 dS m^{-1} salinity and identified as salt tolerant *desi* cotton variety. On-farm Trials were undertaken on farmers' fields in Bhal area (Rajpara village, Dholera taluka, Ahmedabad district) and Bara tract (Bojadra and Kalak villages of Jambusar taluka, Bharuch district), where G Cot 23 recorded yield of 1.8 to 1.9 t ha^{-1}. Field trials were also taken up on farmers' fields with G. Cot 23 on saline *Vertisols* in four villages namely Rajpur, Mingalpur, Shela and Kamatalav in Dhandhuka taluka of Ahmedabad district indicated seed cotton yields in the range of 1.7-1.8 t/ha and the salinity ranged from 9.4 to 10.2 dS m^{-1} (Success Story-ICAR website, 2015).
10. **Salt tolerant cultivars in field crops**: Salt tolerant cultivars (STCs) capable of growing in un-reclaimed or partially reclaimed soils represent a sustainable approach to obtain high productivity in saline soils and increase in income of farmers. This strategy assumes several greater importances in sodic areas still uncovered by the gypsum-based package and other technologies. Again, they are an attractive option for the poor farmers lacking material resources to use the costly chemicals. STCs developed in different crops (Table 7) have been adopted in many parts of Punjab, Haryana, Uttar Pradesh and other states (ICAR-CSSRI, 2015). Many promising lines such as CSR 46 in rice, KRL 283. KRL 345, KRL 347 and KRL 351 in wheat have been identified and are being evaluated for release. Several potential genetic stocks have also been developed for the use as parents in future selection and hybridization programs.

Table 7. Salt tolerant cultivars developed and released

Crop	Cultivars
Rice	CSR 10, CSR 13, CSR 23, CSR 27, CSR 30 (Basmati), CSR 36 and CSR 43
Wheat	KRL 1-4, KRL 19, KRL 210 and KRL 213
Chickpea	Karnal Chana- 1
Indian Mustard	CS 52, CS 54, CS 56 and CS 58
Dhaincha	CSD-123 and CSD 137

Conclusion:

Salt affected soils either due to excess soluble salts or due to high exchangeable sodium content have become non-productive, so to restore its productivity, it is highly essential to reclaim and manage these soils using different specific technologies. To achieve this restoration, there would be a need for the involvement of relevant stakeholders such as farmers, public institutions (research and extension institutions, other line department of government, KVK, NGO) for expansion, adoption and awareness about available technologies which not only help in restoring the productivity but also enhancing the productivity and directly or indirectly increase farmers' income.

References

Abrol, I.P., Chhabra, R. and Gupta, R.K. (1980). A fresh look at the diagnostic criteria for sodic soils. *In*: International Symposium on Salt Affected Soils. Central Soil Salinity Research Institute, Karnal. February 18-21, pp. 142-147.

Abrol, I.P., Yadav J.S.P. and Massoud, F.I. (1988). Salt-affected soils and their management. FAO Soils Bulletin No. 39, Food and Agriculture Organization of the United Nations, Rome.

Chinchmalatpure, Anil R., Kad, Sanjay Vasant and Kamra, S.K. (2016). Evaluation Report of subsurface darainage project at Mulad, taluka Olpad, district Surat (Gujarat). ICAR-Central Soil Salinity Research Institute, Karnal 132001 (Haryana), 20 pp.

Chinchmalatpure, Anil R., Nayak, A. K. and Rao, G. Gururaja (2011). Saline *Vertisols*-characteristics, distribution and management. *In*: *Salt affected soils of India*, Bulletin No **28** (Eds. Rattan, R. K. and Singh, A. K.) Indian Society of Soil Science, New Delhi. pp117.

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

Ghassemi, F., Jakeman, A.J., and Nix, N.A. (1995). *Salinisation of land and water resources. Human causes, extent and management and case studies.* CABI Publishing, Wallingford.

Kaledhonkar, M.J., Gupta, S.K. and Singh, G. (2009). An overview of research, development, opportunities and challenges for subsurface drainage in India. *In*: 60th International Executive Council Meeting & 5th Asian Regional Conference, New Delhi, India, pp. 1–12.

Kamra, S.K. and Sharma, D.K. (2015). Critical evaluation of performance and organizational framework of subsurface drainage projects in Haryana and Maharashtra. *Water and Energy International*, **72**(4): 64-72.

Nayak, A.K., Chinchmalatpure, Anil R., Rao, G. Gururaja and Tyagi, N.K. (2004). Effect of electrolyte concentration, ESP and soil texture on the flocculation, hydraulic conductivity and bulk density of *Vertisols*. *Extended Summaries*, International conference on Sustainable management of Sodic lands, Lucknow, India. Pp 203-205.

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

Rao, G. Gururaja, 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.

Rao, G. Gururaja, Nayak, A.K., Chinchmalatpure**,** Anil R., Abhaynathand Babu,V. Ravindra (2004). Growth and yield of *Salvadora persica*, a facultative halophyte grown on saline black soil (Vertic Haplustept). *Arid Land Research and Management,* **18:** 51-61.

Rao, Gururaja G., Chinchmalatpure, Anil R., Khandelwal, M. K. and Singh, Gurbachan (2009). Studies on enhancing water productivity of farming system components on Saline *Vertisols* of Bara Tract of Gujarat State, India. *4th World Congress on Conservation Agriculture*, New Delhi, February 4-7, 2009.

Rao, Gururaja G., Chinchmalatpure, Anil R., Meena, R.L. and Khandelwal, M.K. (2011). Saline agriculture in saline *Vertisols* with halophytic forage grasses. *J. Soil Salinity and Water Quality*, **3**, 41-48.

Szabolcs, I. (1974). Salt affected soils in Europe. Martinus Nijhoff, The Hague. 63 p.

Szabolcs, I. (1979). Review of research on salt affected soils. Natural Resources Research XV, UNESCO, Paris, France.