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Current Status of Research, Technology Response and Policy Needs of Salt-affected Soils in India – A Review

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Salt-affected soils (SAS) in India pose serious threat to national economy. Over 6.74 million hectares of lands have been assessed to be salt affected, either saline or sodic in India, out of which 2.1 million hectares have been reclaimed. In the beginning, research on SAS by ICAR-CSSRI, Karnal, India focussed on basic research for understanding the problems of salt and water dynamics and balance, causes of salt accumulation and plants behaviour under such stresses. After decades of experiments, recommendation emerged as technologies for reclamation and management of SAS as, robust gypsum technology for reclamation of sodic soils, developing salt tolerant crop varieties, guidelines for use of poor quality waters, rehabilitation of salty lands using forestry species, etc. All these efforts contributed towards improving livelihoods conditions and gainful engagements of farming communities in salt-affected areas of the country. Despite having larger potential, often the success stories remained sporadic and limited. Technologies as recommended by researchers needs to be complemented by suitable policies to benefit larger communities. There is a lack of knowledge on what policy measures are needed to encourage farmers to adopt effective technologies for SAS. Key policy impediments needed to address for technology dissemination issue in order to reach targeted communities in salt-affected areas in India for turning research output to large scale practices and higher societal benefits. In this article the policy thrusts have been identified both for technology developers (scientists) such as need of generating real time database on SAS, testing of evolved technologies in larger areas as well as planners for promotion of technology to end-users (farmers) through incentives mechanisms and community engagements for out-scaling of proven technologies.

*(**Key words:** Salt-affected soils, Research strategy, Crop loss, Impact, Policy needs)*

The total area of salt-affected lands in the world is 932.2 million ha, of which 351.2 million ha are saline and 581 million ha are sodic (Sparks, 2003). For all important crops, average yields are only a fraction - somewhere between 20 to 50 percent of recorded yields; these losses are mostly due to drought and high soil salinity, environmental conditions (Shrivastava and Kumar, 2015). More recent estimation showed increasing trend in global saline area and about 1128 million ha area is affected by salinity and sodicity stresses. The regions with preponderance of salt affected soils were Middle East (189 m ha) followed by Australia (169 m ha) and North Africa (144 m ha). South Asia, including India, has about 52 m ha salt-affected area. Majority of global area (~85%) was only slightly to moderately affected by high salt concentrations while the remainder 15 per cent suffers from severe to extreme limitations for crop cultivation (Wicke *et al*., 2011). It is estimated that salinization of irrigated lands causes annual global income loss of about US$ 12 billion (Ghassemi *et al*., 1995), impacting aggregate national incomes in countries affected by degradation of salt-affected land and saline water resources. The extent of losses has further accentuated and the inflation-adjusted cost of salt-induced land degradation in 2013 was estimated at US $ 441 per hectare, with global economic losses pegged at US $ 27.3 billion per year (Qadir *et al*.,2014 Growing land degradation in the form of salt-affected soils in India is becoming a major constraint for food production and threatening economic growth and development of India. The environmental degradation, like desertification is reaching irreversible levels in some regions of India, especially in arid and semi-arid tracts. Often the replacement costs (in terms of enhanced input use, abatement and conservation costs), are mounting and would make a dent in the national income if these costs are taken into account (Reddy, 2003). Soil salinity is one of the most devastating among all kinds that

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causes land degradation. Salt-affected soils (SAS) are soils on which the growth of most crop plants is limited due to excess of soluble and insoluble salts. Unless preventive/ameliorative attempts are taken the areas under SAS are estimated to increase from 6.74 to 16.2 million ha by 2050 (CSSRI 2015) *i.e.*, an increase from 5 to 11 per cent of total net sown area of the country (141 million ha) and it may turn large areas of cultivable land to completely barren. The cost of inaction could be beyond repairable to the natural resources base in the country. Typical challenges of SAS management are that some soils (alkali or sodic soil) can be reclaimed by specific amendment and managed thereafter, but others (coastal salt affected soils, black soils) cannot be fully reclaimed, needs continuous soil & water management practices for its productive uses.

Cost-benefit analysis techniques have been developed for the valuation of changes in the supply of ecosystem services (Enters, 1998; Lutz *et al*., 1994). Often the impact, in terms of loss of production is not realised at the macro level, but serious concern at the regional level. Yield losses are particularly detrimental at a local scale because salt-affected soils are not uniformly distributed and threaten the continued existence of agriculture in some regions and countries (Eynard *et al*., 2005). At the micro level, the losses due to waterlogging are estimated at 40 per cent in the case of paddy and 80 per cent in the case of potato (Joshi, 1987). Joshi and Jha (1992) has detailed the problems of soil alkalinity and waterlogging in the major surface irrigation systems, Sharda Sahyak Irrigation Project, and measured the impact at farm level in terms of resource use, productivity and profitability of crops. They estimated that yields of paddy and wheat halved in about eight years of time due to increasing soil degradation and except barley, it was not viable to cultivate in salt-affected lands. It is estimated (based on 2012-14 moving average data) that due to salt-affected soils, India loses annually 16.84 million tonnes of farm production (cereals, oilseeds, pulses and cash crops) valued at ₹ 230.20 billion (Table 1). Among the various states, Uttar Pradesh accounted the highest production loss (7.69 million tonnes) followed by Gujarat (4.83 million tonnes). Whereas, in terms of monetary loss Gujarat is most affected (₹ 100.63 billion) followed by Uttar Pradesh (₹ 81.29 billion). Gujarat and Uttar Pradesh are the most affected states in terms of possessing salt-affected area (over 50 per cent) and sharing production (74 per cent) and monetary losses (79 per cent) in India (Sharma *et al*., 2015). Following these two states, Maharashtra, West Bengal, Rajasthan and Tamil Nadu states are accounting more than 5 per cent each, out of the total salt-affected areas in India (Table 1). All these states deserve policy attention for management of salt-affected areas to reduce the crop production and monetary loss.

SAS in India are placed into two broad groups, sodic and saline soils.The major factors responsible for formation of sodic soils in the Indo-Gangetic region include: weathering of rocks and minerals containing high sodium minerals, irrigation with groundwater containing excessive quantities of carbonate and bicarbonate ions, rise in groundwater due to introduction of canal irrigation and salt laden run-off from the adjoining areas and un-drained basins. Inland saline lands are widespread in the canal irrigated, arid and semi-arid regions. High soil salinity is often accompanied by high water table. Since subsoil water is generally salty, its use for irrigation presents major constraints to crop production. Therefore, the formation of saline soils is generally associated with the rise in water table due to the introduction of irrigation and inadequate drainage (Singh, 2009). Case studies indicated that often irrigation development project has led to formation of salt-affected areas primarily due to inadequate attention to drainage problem. Thus, in many instances, after some years the negative externalities offset the positive impact. Sharda Sahayak Canal Command Area was initiated in 1978 to provide irrigation to 1.67 million ha area in 21 districts of Uttar Pradesh. After the introduction of the canal, agriculture productivity markedly increased in the command area. However, non-provision of drainage and continuous seepage from the canal resulted in a rise in water table and subsequent upward flux of salts to the surface. Although irrigation project was envisaged for positive benefits, but in a span of about three decades nearly 0.37 million ha area turned salt-affected (secondary salinization) and rendered barren (Singh, 2009). Similarly, the Indira Gandhi Nahar Priyojana (IGNP) earlier known as Rajasthan canal project was undertaken to provide irrigation facility to 1.79 million ha in Rajasthan. However, after few years, negative impacts emerged such as

Table 1. *State-wise share (%) of salt-affected soils vis-a-vis crop production loss in India*

State (1)	Saline soils (2)	Alkali soils (3)	Coastal saline soil (4)	Total (5)	No of salt affected districts (6)	Production loss (7)	Monetary loss (8)
Gujarat	71.2	14.3	37.1	32.9	15	28.69	43.72
Uttar Pradesh	1.3	35.6	-	20.3	40	45.69	35.31
Maharashtra	10.4	11.2	0.6	9.0	18	5.48	2.17
West Bengal	-	-	35.4	6.5	4	5.29	5.34
Rajasthan	11.4	4.7	-	5.6	29	1.13	1.75
Tamil Nadu	-	9.4	1.1	5.5	12	0.87	0.60
Andhra Pradesh	-	5.2	6.2	4.1	16	2.98	3.17
Haryana	2.9	4.8	-	3.4	17	4.27	3.38
Bihar	2.8	2.8	-	2.3	26	3.29	2.43
Punjab	-	4.0	-	2.2	16	0.85	0.42
Karnataka	0.1	3.9	-	2.2	9	0.09	0.13
Orissa	-	-	11.8	2.2	7	1.17	1.15
Madhya Pradesh	-	3.7	-	2.1	25	0.19	0.38
A & N islands	-	-	6.2	1.1	3	NA	NA
Kerala	-	-	1.6	0.3	6	0.02	0.03
J & K*	-	0.5	-	0.3	NA	NA	NA
Total	100 (1.71)	100 (3.79)	100 (1.25)	100 (6.74)	100 (243)	100 (16.84)	100 (230.20)

Note: Figures in parentheses in col. 2 to 5 indicates total area in million ha; Figure in parenthesis of col. 6 indicates total no of salt-affected districts; and Figures in parentheses of 7 & 8 indicates total production loss in million tonnes and total monetary loss in ₹ billion; NA indicates Not estimated. (Source: Compiled from Mandal *et al*., 2010 and Sharma *et al*., 2015).

rise in the water table, water-logging, formation of marshy lands, increased soil salinity and decreased biodiversity and turned around 0.18 million ha of land affectedby salinity and sodicity (Singh, 2009). In coastal areas of Andhra Pradesh, many rice fields are being converted into brackish water fish farms due to high remuneration from aquaculture for more than a decade. Farmers draw brackish water from the sea through creeks and drains into the land and store millions of gallons of this salt laden seawater on the surface in big tanks for raising high value prawns. It is reported that an area of nearly 0.2 million ha is under saline aquaculture in the coastal districts of Andhra Pradesh. Unable to cope with the high instability of return and associated risk in prawn farming, many (over 50 per cent) of the small and marginal farmers have abandoned this activity (Singh, 2009). Building up of salinity in the adjoined agriculture field and fresh water reservoirs due to seepage of saline water from the brackish water aquaculture farm (Andhra Pradesh, West Bengal and Odisha) is a serious concern and needs special attention of the policy makers (Singh, 2009). For sustainable crop production in saline soils after providing the necessary drainage measures, adoption of specific system of management was essential based upon the soil, crop, and climatic factors at the site (Minhas, 1998). But crop production on saline-waterlogged soils is generally costlier and crop yields are usually low, therefore, fewer returns and also the risk of crop failures may still continue even after suitable drainage measures are provided (Minhas and Sharma, 2003). Use of land management practices to increase the uniformity of water distribution, infiltration, and salt leaching besides the optimal use of chemical amendments including time and mode of their application with judicious use of organic materials and chemical fertilizers (Minhas and Tyagi, 1998).

All these issues call for review of available strategies, their effectiveness towards sustainable agriculture and identification of specific policy needs for SAS development in the country. There is a lack of knowledge on what policy measures are needed to encourage farmers to adopt effective technologies for reclamation of salt-affected soils. Therefore, it is imperative to understand the key policy impediments needed to address technology dissemination issue in order to reach larger target communities in salt-affected areas in India for turning research output to large scale practices for higher societal benefits.

The paper is based on large number of literature survey, like Technical Bulletins, research papers and Annual Reports (1979 to 2017) published by ICAR-CSSRI to understand pathways and progress of salinity research in India. Besides, 66 numbers of scientists having research experiences varying from minimum of 4 years to 30 years have been consulted to draw their views on salinity research undertaken and prioritisation needs for Indian context. Feedback was obtained from the scientists asking specific questions like; what are the most important technologies that can be problem solving for salt affected areas? What are the most critical factors that inhibiting out-scaling of these technologies? What are the most critical factors for management of salt-affected soils in India? What would be the best strategies for turning science into policy and practices towards effective community engagement and higher social benefits? Views received from the scientists have been synthesised and used in this article for making policy recommendations.

TECHNOLOGY RESPONSE AND IMPACT

ICAR-CSSRI begun with basic research for understanding problems of salt and water dynamics & balance, causes of salt accumulation and plants' behaviour under stresses. After decades of experiments, recommendations emerged on technologies for reclamation and management solution for SAS, released salt tolerant crop varieties and effective ways to manage water logging and drainage conditions (Chinchmalatpure *et al*., 2015). Research efforts have also led to the identification of a number of field crops, forage grasses and shrubs, aromatic and medicinal species, bio-fuel crops, and fruit trees and agro-forestry systems, which are profitable and suits to variety of SAS (Qadir *et al*., 2008). The budget provision has increased by many folds, from ₹ 2.69 lakh (1971) to ₹ 359.97 lakh (1995) to ₹ 3730.59 lakh (2017) (Table 2) (Annual Report, 1971 to 2017). Probably, it is one of the largest group of scientists (currently 66 in position) in the world dedicated to solve the problems of salt affected soils in a country.

Gypsum technology for reclamation of sodic soils

So far about 2.07 million hectares of sodic land has been reclaimed with the application of gypsum (10-15 t ha^{-1}), which is contributing around 16.60 million tonnes of additional food-

Table 2. *Research investment on technology development for salt-affected soils in India through ICAR-CSSRI*

Year	Non-Plan budget	Plan budget	Total budget	Total Budget	No. of Scientists
	(Nominal Prices in ₹ Lakh)			(Real prices in ₹ Lakh)	
1971	-	2.69 (100)	2.69 (100)	84.99	43
1975	16.85 (28)	43.61 (72)	60.46 (100)	1241.36	59
1980	43.58 (62)	27.00 (38)	70.58 (100)	1087.83	62
1985	85.79 (57)	65.87 (43)	151.66 (100)	1507.36	63
1990	172.02 (84)	33.63 (16)	205.65 (100)	1358.42	68 (91)
1995	276.00 (77)	83.97 (23)	359.97 (100)	1478.08	67 (81)
2000	541.50 (55)	442.75 (45)	984.25 (100)	2821.39	66 (81)
2006	826.00 (61)	520.73 (39)	1346.73 (100)	2946.97	49 (81)
2010	1793.77 (74)	639.48 (26)	2433.25 (100)	3795.87	44 (81)
2015	2449.40 (78)	709.80 (22)	3159.20 (100)	3375.58	54 (81)
2017	2993.20 (80)	737.39 (20)	3730.59 (100)	3730.59	66 (81)

Note: (1). ICAR-CSSRI receive research grant from Govt. of India through Indian Council of Agricultural Research every year. Above budget has been indicated for every five years interval and of 2017. (2). Figures in parentheses indicate per cent share to total budget in respective years. Figures in parentheses under No. of Scientists column indicate no of sanctioned posts. Source: Annual Report (1971 to 2017), ICAR- Central Soil Salinity Research Institute, Karnal, Haryana, India. Source: http://krishikosh.egranth.ac.in. (3). Total budget in real prices has been computed by adjusting with respective Consumer Price Index (CPI) values based onhistoric inflation rate during 1971-2017 (2017 =100).

grains to the national food basket annually. Farmers can harvest 4 t ha^{-1} of rice and 2 t ha^{-1} of wheat (5 t ha^{-1} and 3 t ha^{-1} during subsequent years, respectively for rice and wheat) with an incremental cost of ₹ 76500 ha^{-1}. Financial viability for investment on gypsum technology has been found positive with favourable Net Present Value/NPV (₹ 2,80,000 ha^{-1}), Benefit Cost Ratio/BCR (2.47), Internal Rate of Return/IRR (67 per cent) and payback period of 3 years (Tripathi *et al*., 2011). The agricultural income generated from the reclaimed sodic area is ₹ 25320 crores (Chinchmalatpure *et al*., 2015). This also provides an employment opportunity to about 2.8 million man days annually.

Sub-surface drainage (SSD) technology for reclamation of waterlogged saline soils

Developed in 1980, the SSD technology has been successfully implemented over 70,000 ha in Haryana, Rajasthan, Gujarat, Punjab, Andhra Pradesh, Maharashtra and Karnataka. The per hectare cost of adoption was estimated to ₹ 74000 for medium to light textured soils with 67 m spacing and ₹ 1,15,000 for heavy textured black soils with 30 m spacing. The SSD resulted in 3 folds increase in farmers' income after installation. The financial feasibility analysis showed that the minimum payback period of 2 years with an NPV (₹ 113000 ha^{-1}), BCR (2.71) and IRR (40 per cent) (Raju *et al*., 2016). This reclaimed area contributing about 0.56 million tonnes of foodgrain production and an income generation of ₹ 8.60 million annually (Raju *et al*., 2016; Raju *et al*., 2017).

Land shaping technologies

Most suitable ways of crop-fish integration system and financially viable land shaping technologies have been tested in coastal salt-affected areas are farm pond, paddy-cum-fish and deep-furrow & high ridge types. Initial investment was estimated as ₹ 1.45 lakh, ₹ 1.36 lakh and ₹ 0.88 lakh (primarily on land excavation) on farm pond, paddy-cum-fish and deep furrow and high ridge, respectively. All financial feasibility criteria on these forms of land shaping technologies favoured the investment propositions as profitable with IRR (46, 42 and 36 per cent); NPV (₹ 2.85, ₹ 2.32 and ₹ 0.97 lakh); BCR (1.58, 1.55 and 1.20) and payback period (1.41, 1.78 and 2.13 years) (Mandal *et al*., 2013; Mandal *et al*., 2015). Cropping system in the coastal region of West Bengal is dominated by mono-cropping of *kharif* rice. Baseline survey report covering 990 farm households from 6 blocks (5 blocks from South 24 Parganas and 1 block from North 24 Parganas) across 17 villages of Sundarbans estimated that the cropping intensities were quite low (varying from 114 to 127 per cent) in the region and more than 80 per cent of the farm land remained fallow during rabi season (Mandal *et al*., 2011; Mandal *et al*., 2017). Implementation of land-shaping models (modification of land suitable for on-farm water harvesting) like farm pond, paddy-cum-fish and deep-furrow-and-high-ridge system along with scientific management of soil, water and nutrient management were capable to increase the cropping intensities significantly (from 114 to 186 percent). Increased cropping intensities have resulted into higher cropping system intensification and finally helped enhancing farmers' income significantly, from net return of ₹ 5,644 ha^{-1} (wet rice) to ₹ 1,43,982 ha^{-1} (wet rice-fish-vegetables) (Mandal *et al*., 2017). Similarly, land modification technology (pond based and raised & sunken bed) under sodic soil in Uttar Pradesh also generated favourable return (Verma *et al*., 2012).

Salt tolerant crop varieties

To enhance productivity in salt-affected soils ICAR-CSSRI has developed 18 number of salt tolerant crop varieties including rice (8), wheat (5), mustard (4) and chickpea (1) which are widely used by the farmers under salt-affected areas. Some important and popular rice varieties are CSR 10 (3.0 t ha^{-1}), CSR 13 (3.5 t ha^{-1}), CSR 23 (4.0 t ha^{-1}), CSR 27 (4.0 t ha^{-1}), CSR 30 (Basmati, 2.0 t ha^{-1}), CSR 36 (4.0 t ha^{-1}), CSR 43 (3.5 t ha^{-1}) and CSR 46 (3.55 t ha^{-1}), whereas wheat varieties includes KRL 1-4 (3.0 t ha^{-1}), KRL 19 (3.0 t ha^{-1}), KRL 210 (3.4 t ha^{-1}), KRL 213 (3.3 t ha^{-1}) and KRL 283 (3.5-4.1 t ha^{-1}) and the mustard verities are CS 52 (1.5-1.6 t ha^{-1}), CS 54 (1.6-1.9 t ha^{-1}), CS 56 (1.6-1.9 t ha^{-1}) and CS 58 (2.0-2.2 t ha^{-1}) (Sharma *et al*., 2016).The additional income from CSSRI salt tolerant varieties of rice, wheat and mustard estimated ₹ 25663 million during the decade from 2000-01 to 2010-11, which was valued at ₹ 2566 million contributing every year at the national level. (Tripathi *et al*., 2012). For coastal salt-affected areas, rice varieties Amal-Mana (3.85 t ha^{-1}), Sumati (3.5 t ha^{-1}), Bhutnath (3.4 t ha^{-1}) and Utpala (3.22 t ha^{-1})

have been developed. Contribution in terms of area coverage and economic gain due to adoption of major salt tolerant rice varieties as produced by CSSRI and purchased by farmers indicated that salt tolerant rice varieties have good potential to contribute to national exchequer and there is a growing demand for such varieties among farmers.

Besides ICAR-CSSRI, other ICAR research organisations like ICAR-NRRI, Cuttack, State Agricultural Universities (SAUs) or IRRI, Philippines are also contributing to research and technology development for salt-affected soils in India. Khan *et al*., (2014) reported that an average yield advantage of 20-30 per cent over the existing rice yield of 2.9-3.3 t ha^{-1} can be obtained by using biocompost 2 to 6 t ha^{-1} and would be a helpful contribution to food security and improve the livelihood of rice growers under sodic soils of Uttar Pradesh. The National Institute of Oceanography (NIO), State Agricultural Universities located at states having coastal areas and ICAR-Central Island Agricultural Research Institute (CIARI) have carried out research work in the field of marine biology for development of numerical taxonomic coding system, database on marine biology and biotechnology, marine prawns and crabs, exploration of sea weeds for industrial purposes and mangroves (Chavan *et al*., 1998; Dagar *et al*., 2005; Tyagi, 2018). Seaweeds comprising numerous algal groups, have been used initially for domestic purposes as food and feed, and later in industrial uses (gels, fertilizers) (Delaney *et al*., 2016). But over the years the industrial use of seaweed biomass has shifted as fertilizers and a source of potash, via iodine production, to hydrocolloid extraction (Synytsya *et al*., 2015). Technologies like cultivation of *Salvadora* (tolerates salinity up to 50 dS m^{-1}) for the restoration of highly saline (>40 dS m^{-1}) soils and Dill (tolerates salinity of 4-6 dS m^{-1}) have been adopted by the farmers, NGOs and Govt. Institutions like Gujarat State Land Development Corporation (GSLDC) are growing these crops on a large scale in Gujarat (Sharma and Chaudhuri, 2012). An innovative '*Dorovu*' technology has gained popularity in coastal regions of the country. Shallow depth fresh water are collected in dug out conical pit is locally know as '*Doruvus*'. Further this skimming well technology has been refined by the All India Coordinated Research Project on Management of Salt affected Soils and Use of Saline Water in Agriculture, Bapatla Centre of Acharya N. G. Ranga Agricultural University, popularly known as 'Improved Doruvu Technology' (Babu *et al*., 2009).

POLICY IMPEDIMENTS FOR TECHNOLOGY DISSEMINATION

The adverse effect of irrigated agriculture due to water-logging, soil salinity and alkalinity can be reversed sustainably by introducing a combination of surface and subsurface drainage (Datta *et al*., 2000). Such interventions can lead to cropping pattern change in favour of more remunerative crops with increased yields, income and also the investment was financially viable (Datta, 2002; Datta and Jong, 1991; Joshi *et al*., 1987; Joshi *et al*., 1996; Tyagi and Joshi, 2017). Datta and Dayal (2000) highlighted that the promotion of soil and water conservation measures like watershed development, sprinkler or drip irrigation systems are needed for management of poor quality irrigation water for gainful purposes. Despite all these good efforts and available technologies for management of SAS, the adoption of such technologies has been sporadic.There is a lack of knowledge about the effectiveness and efficiency of soil conservation policies in agriculture and there is a little understanding of how policy measures should be designed to encourage farmers to adopt soil conservation practices (Prager *et al*., 2011). Consequently, adoption of these farming systems is slow as subsistence farmers in saline environment are uncertain to choose crops due to uncertain market responses, need policy attention (Qadir *et al*., 2008). Some of the policy thrusts are identified both for technology end-users (farmers) as well as technology developers (scientists) and described in the following sections:

Out-scaling constraints of salt-affected soils management technologies

The evolved options out of research experiments are technologically sound and profitable in terms of output-input ratios, but often the success stories are sporadic and limited to the areas where research institutes are functioning. Socio-economic factors like input prices, market environment, fragmented and small/marginal land holdings, availability of own or hired human labour, labour wage rates, financial and credit needs, availability and capacity to absorption of credit, risk preferences etc., all these factors affect the adoption behaviour towards new technologies.

Gypsum technology for sodic soil reclamation

The ICAR-CSSRI has perfected the gypsum technology through continuous research and subsequent refinement over the years. Adoption of gypsum technologies are constrained with various technological, economic, social, administrative and environmental issues.

Technological issues

As far as scaling of gypsum doses are concerned, so far, it has been recommended for reclamation of upper 15 cm of soil to cover the root zone of cereal crops. However, reclamation of deeper layer of soil up to 30 cm will double the cost of gypsum application. In order to address this issue, use of cheaper alternative (like sulphur, phospho-gypsum, marine gypsum, etc.) has to be explored and standardised for which a national research and development program will be required.

Economic issues

The economic issues concerned with the use of gypsum technology include high cost of gypsum in which the resource poor farmers could ill afford. It has been estimated that around ₹ 76500 investment is required for reclamation of one ha area of sodic land. There is a need for government support in the form of subsidy by bringing the gypsum under the category of fertilizer so that farmer can avail the benefits like other fertilisers. Having looked into the local situation carefully, it is evident that there is a need for location specific micro-management for agricultural risk mitigation. In many cases land degradation is observed in terms of declining land use intensity, high input use and declining profits (Joshi,1987).

Social issue

It is a well known fact that the community land in almost every panchayat of the country has been by and large neglected over the long run and consequently, becomes degraded and unproductive for agriculture. Majority of the degraded land are also sodic or saline to a great extent. In view of shrinking arable land on account of urbanisation and industrialisation, sooner or later these community lands will have to be brought under cultivation to sustain our food production. Government schemes like community pond, community watershed program, etc. a national program for reclamation of community land coming under sodic or saline soils needs to be initiated. Institutionalized arrangement for implementation of reclamation programme is a significant departure from the past and helped in adoption of land reclamation technologies by the farmers with demonstrations on farmers' fields and their success catalysed by the state governments (Tyagi and Joshi, 2017).

Environmental issue

The impact of climate change on sodic and saline soils assumes significance in light of the fact that the movement of salt in the soil biosphere is closely governed by temperature and rainfall pattern in a particular season (Chaudhuri *et al*., 2013). So far, research on climate change on the dynamics of soil sodicity and salinity has been lacking and a national research program on these lines is the need of the hour. More often it is weather aberrations not climate change needs to be addressed for which State Govt. can be made more empowered financially for better decision making and mitigation.

Administrative issue

Purity of gypsum supplied by various agencies is an important concern to be looked into. Often the purity of gypsum falls below the recommended standard which distorts the actual rate of application in the field, thereby increasing the expenditure of the farmers. Purity of gypsum to meet the recommended standard as supplied by the developmental agencies has to be monitored by some authority at state or national level. The gap between demand and supply of gypsum has also to be bridged on priority in order to make the material available to the farmers as well.

Subsurface drainage (SSD) technology for saline soil reclamation

In India, there are 2.95 million ha of area under saline soils having abundance of chlorides of sodium, potassium and magnesium (CSSRI, 2015). These are soluble salts which could be removed from the soil by draining out with the help of SSD technology already developed, standardised and recommended by ICAR-CSSRI. The technology of SSD involves laying of underground pipes at a particular depth and at particular spacing. The depth and spacing are often manipulated by the farmers or even by the private implementing agencies. Regulatory mechanism needs to be devised under which licensing for SSD installation may be given only to those who conform to the designs and guidelines recommended by the ICAR-CSSRI. Another issue of SSD technology is the reclamation measure, which has to be implemented on community basis since it involves the land of several farmers to reap the benefits of the technology. Farmers having land at the tail end of SSD installation often do not cooperate on account of natural topographical advantage. So, the installation does not operate efficiently and even fail in due course of time. In most cases there is a lack of cooperative feelings to run the system effectively. Often the government agencies take up the responsibility of installation of SSD system and leave the operation part to the beneficiary farmers. However, due to lack of coordination among the farmers, many installations fail. Around 95 per cent of the SSD technology cost is spent on installation and only 5 per cent is required for its operation and maintenance for initial 2 to 3 years. Policy shift is required wherein the implementing government agencies should take the responsibility of installation and running of the SSD system for initial 3 years, enabling beneficiary farmers to realise the tangible benefits and get motivated to own the system for further operation.

Salt tolerant crop varieties for salt affected soils

ICAR-CSSRI has developed 18 crop varieties suitable for growing in salt-affected areas, which helps in reducing the cost of reclamation apart from giving economic yield under stressful situation. It has been estimated that growing of salt tolerant varieties of rice, wheat and mustard in sodic soils reduces 25 per cent of the dose (10-15 t ha^{-1}) of gypsum required for reclamation of such soils for productive agriculture (Chinchmalatpure *et al.*, 2015). The institute regularly produces breeder seeds of rice, wheat, mustard and chickpea crop varieties developed for salt-affected areas and supplies those seeds to the department of agriculture and cooperation (DAC) for further distribution. However, there is no established mechanism in the country where by the demand of breeder seed of salt tolerant varieties are put up by the salt affected states and accordingly the breeder seed produced by ICAR-CSSRI is allocated to meet those demand in order to ensure further multiplication of the breeder seed at state farms for onward distribution to the farmers. A comprehensive initiative at national level is needed to increase the awareness about salt tolerant varieties and subsequent indenting of the breeder seed of these varieties by the affected states. Farmers have different preference criteria for rice varieties for the wet and dry seasons. Farmers' assessment was multivariate and involves multiple traits, including agronomic characteristics, tolerance of prevailing abiotic stresses, and socio-economic conditions (Burman *et al.*, 2018). Besides, the cost-effective nursery management approaches have great potential for enhancing yield in stress-prone rainfed coastal areas and will help sustain rice yield while ensuring sustainability of the cropping system (Sarangi *et al.*, 2015).

Applications of salt-affected soils database in decision making

Assessment of accurate salt-affected areas is one of the major impediments for effective planning and implementation of any policy. Although land degradation is recognised as a serious problem but information available on the severity as also the area affected (real time) by various forms of degradation is limited, highly variable and sketchy. Although district wise information on extent of SAS is available but the fact is planning for intervention on SAS is difficult to make due to the high variation (sketchy) of salt-affected areas even within the districts. For effective decision making, there is a need for block level intervention planning. Almost every state is having detailed database on land use statistics developed by National Remote Sensing Centre (NRSC), ICAR-National Bureau of Soil Survey & Land Use Planning (NBSS&LUP) or ICAR-CSSRI; however, its application in planning has been limited so far. Although we have district wise statistics of the salt affected saline as well as sodic soils as a whole but actual spot/location in the districts to be traced out is difficult by the stakeholder. The available information on the extent of SAS has to be simplified and made user friendly so that one can locate the actual salt affected area. Besides, there is a need for developing socio-economic database for salt-affected farmers and collating this information with the existing land use data for identifying particular needs of the farmers and possible implications on technology dissemination at macro level.

Management of water in salt-affected areas

Most of the salt affected areas are also having poor quality underground water which often drawn by the farmers for irrigation purpose, although these waters are unfit for irrigation. The areas having sodic soils are many times accompanied by high residual sodium carbonate in underground water. Use of such water for irrigation further increases the problem of sodicity, thereby rendering the crop cultivation almost difficult.Similarly, areas affected by saline soils are mostly having saline underground water. ICAR-CSSRI has developed technologies for use of such poor quality water for irrigation purposes by mixing with good quality water in a cyclic mode. However, the availability of good quality water in such areas is a major concern for which intensive program for rainwater harvesting has to be initiated. Alternatively, provision have to be made in the ongoing schemes like Pradhan Mantri Krishi Sinchayee Yojna, National Mission for Sustainable Agriculture, etc. for provision of subsidy support to the farmers for creation of water harvesting tank/pond in the command areas of salt affected soils. Use of drip and sprinkler irrigation system in the salt affected soils has also been found to be highly effective in improving the crop productivity (Horneck *et al*., 2007). These micro-irrigation systems could be integrated with the rainwater harvesting structure for supply of freshwater to the crops in more efficient and effective manner.

Effective community engagement for private *vis-à-vis* social benefits

Agriculture is a state subject and interventions on land management activities are always complex and sensitive. Understanding local community, private bodies and common property resources needs particular focus. Technologies for salt-affected land management have been demonstrated in farmers field in various parts of the country and benefits accrued mainly to the individual farmers. These technologies have been highly successful for increasing the private benefits and needs to be made socially inclusive for equitable distribution of benefits (CSSRI-NAIP, 2014; Mandal *et al*., 2005). Adoption of technologies for management of salt-affected lands requires sizeable investment on land reclamation or modification. Incentives for such investment on land, particularly for the tenant farmers are not very attractive proposition and thus impeding its large scale adoption. Effective engagement through collaboration with non-governmental organisations (NGOs) and focussing on higher community engagement would be leading to higher social benefits and larger adoption. Besides developing technologies effective for private lands, there is a need for community level land management technologies effective for community at large.

Building incentives and mandatory measures for adoption of management options

Experience with technology adoption during implementation of livelihoods projects in the past had shown that capital intensive natural resources management technologies do not go very far without supportive policy environment (Prager *et al*., 2011). The expectations of return from farming in salt-affected areas are normally much lower as compared to other good land due to substantial production loss. The extent of losses a farmer can afford and still be in the farming depends on the farmers' own available alternative options and his motives of farming (Mandal *et al*., 2005). Since the poor depend heavily on a limited natural resource base, they have greater motivation to conserve it (Jodha, 2000). However, very often it is seen that farmers are de-motivated and leave farming abandoning the cultivable lands subject to further degradation. Under these circumstances the Govt. tries to bring the farmers back into his farming business through an incentive mechanism (subsidy for amendment, cost sharing) or enforce rules and regulation (limiting groundwater extraction, crop choice) to arrest further degradation of soils. Policy interventions for effective management of salt-affected soils need to be a blend of providing incentives and regulating mandatory measures. Incentive measures to be included consists of providing subsidies for buying amendments, initial investment for land shaping/ modifications, based on actual costs and need of the farmers and thus main streaming them in developmental programmes of State/Central Governments.

Prioritisation of research and scientist's dilemma

Historical review of research on problems of salt-affected soils in India indicated distinct phases like understanding basic cause-effect relationship of salt and plants productivity, crop variety development with salt tolerance, finding solution and optimisation of amendment applications, transferring technologies to problem areas and analysing impacts. Besides, amendment options, development of crop varieties and agronomic management for higher returns have been given top priorities. As productive agricultural lands and freshwater are diminishing with time, considerable attention has been paid to bring the marginal soils under agricultural production. Conventional salinity-management practices have paid positive dividends; however, the emerging constraints calls for a paradigm shift from the business-as-usual approach to ensure consistent gains from the soil reclamation interventions for their profitable use (Sharma *et al*., 2016). Emerged research output needs to be translated into higher social benefits. Constraints of farmers needs to be understood why they often failed to own the successful technology and mis-match between priorities of problems as assigned by researchers and those faced by the farmers needs to be aligned. Research prioritisation needs clear distinction as well as blending of basic, applied and action research. Due importance needs to be assigned for contribution of researchers on each categories of research by analysing clear understanding on basic research for whom, action research for whom and applied research for whom.Research priorities needs to be based on target areas (how much area affected?), target population base (how many households?) and with due consideration of farmers' socio-economic conditions (which categories of farmers?).

CONCLUSIONS AND POLICY RECOMMENDATIONS

Extent of SAS in Indian states poses serious threat to national economy. Technological options are available for its management and productive use. By adopting these management options SAS can be managed sustainably. Policy support is needed for wider application of these technologies. Some specific policy recommendations are:

Launching of salt-affected area programme

Management of SAS needs location specific solution at micro-management. Initially programme may include selected blocks of salt affected areas in the states of Gujarat (possessed 33 per cent of country's salt affected soils), Uttar Pradesh (20 per cent), Maharashtra (9 per cent), West Bengal (6.5 per cent), Rajasthan (5.6 per cent) and Tamil Nadu (5.5 per cent).

Outreach research activities in salt affected states

Currently technologies are disseminated in the areas where most of the research institute (or regional research station) are located. Financial provision is needed specifically to out-scale the technologies to other regions/zones. Outreaching research output can be connecting farmers through national level programme

Promotion of cropping system intensification

Introducing schemes for public investment on creation of rainwater harvesting & utilisation, wherever possible for sustainable cropping system intensification. Promote high value horticultural crops wherever possible.

Incentives and mandatory measures for management of salt-affected soils

Incentives are needed for reducing cost of amendments and mandatory measures to check excessive groundwater exploitation.

Effective community engagement

Technology benefits of salt-affected soils are focussed on private than social benefits. High degradation leads to marginalisation of community and they are forced to leave cultivable lands. Technology development needs to be focussed on minimising cost of adoption and instability of crop output. Building incentive mechanism (cost sharing) for motivation (remunerative price) and engagement.

Prioritisation of research on salt-affected soils

Research priorities needs to be based on target areas (how much area affected), target population base (how many households) and with due consideration of farmers' socio-economic conditions (which categories farmers) for translating science to higher social benefits.

Converging of existing schemes

Need to converge ongoing schemes (e.g., Mahatma Gandhi National Rural Employment Guarantee Act;

Bringing Green Revolution in Eastern India, Rashtriya Krishi Vikash Yojana, etc.) to mobilise financial resources towards large scale implementation of these technologies to farmers' field for socially inclusive agricultural growth in the marginal areas.

International collaboration platforms

Development of salt-affected soils are dynamic and challenging, needs mutual sharing of knowledge and expertise for technology development at faster pace.

Applications of salt-affected database in actual decision making

Collaborations among scientists of other national research institutes and state planners are required for decision making effecting grassroots level.

Collaborative research for upcoming challenges and future harvest

ICAR-CSSRI is endowed with dedicated group of scientists engaged in research on solving problems of salt-affected areas.There are many other national (CRIDA, Hyderabad; CAZRI, Jodhpur; NIASM, Pune; IIT, Kharagpur; CSIR-NIO, Goa; etc.) and international research institutes (IRRI, Phillippines; CSIRO, Australia; IWMI, Colombo; ICRISAT, Hyderabad; ICARDA, Beirut; ICRAF, Nairobi; JIRCAS, Japan; ICBA, Dubai; etc.) also conducting research focussing on similar challenges including salinity stresses. Successful collaboration with IRRI facilitated identification of several salt tolerant rice varieties in India (Burman *et al*., 2018; Krishnamurthy *et al*., 2017; Sarangi *et al*., 2015). Mutual sharing of knowledge and responsibilities through increasing level of joint efforts will facilitate new research product development (e.g., amendment options, drainage design, crop varieties, utilisation of microbial resources, utilisation of ocean resources, etc.) at a faster pace. Creation of international platform and increasing autonomy to the research institute will foster the mutually benefiting collaboration.

Creation of socio-economic database and impact assessment

Understanding the agricultural pathways and fitting the research output into the development process. Regular monitoring of soil degradation (including sodicity and salinity) as well as impact assessment is important for preparing long-term strategic plans to take timely action for rehabilitating degraded lands and for creation of socio-economic database.

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