Agronomic research in salt affected soils of India: An overview

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Agronomic research in salt affected soils of India: An overview

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ABSTRACT

The salt-affected soils always existed on the globe, only its presence was felt with increasing pressure on cultivated lands. Present paper describes an overview of ouotstanding agronomic/agricultural research carried out on salt affected soils throughout the country. Understanding of salt impacts on agricultural lands existed in pre- and post-Vedic era. Agronomic research, though sporadic in nature, was initiated during the Aryan civilization. During the pre-independence period, problems of salt affected soils were first recognized in the United Province (presently Uttar Pradesh), Sind Province and undivided Punjab Province. Constitution of *Reh* Committee was the first systematic step leading to preliminary research on salt affected soils. But salinity research got a boost only in post-independence period after establishment of Central Soil Salinity Research Institute at Karnal. Basic research on salt affected soils and their properties were extensively carried out and agronomic research on crop response to salinity was followed. Agronomic research advanced in reclamation and management of salt affected soils, and devising standard agro-practices for salt affected soils. Alternate land-use systems were developed for moderately and severely degraded salt affected lands. Research on salinity excelled in the country through AICRP on Soil Salinity and Use of Poor Quality Waters, and also through Indo-Dutch Network Project. Further Agronomic Research has been extended to salt affected Vertisols, coastal saline soils and sodic soils of IGP. Paper also describes the Impact of salinity research on Indian agriculture. Future issues in agronomic research on salt affected soils of India are also elaborated in the present paper.

***Key words* :** Alkali soils, Drainage, Land reclamation, Saline soils, , Sodic soils, Waterlogging

Agricultural scenario in India is rapidly changing in response to various stresses experienced by cultivated lands. Agriculture sector cannot wait and must respond to manage the change and to meet the growing and diversified needs in the production to consumption chain. Nearly 7.0 million ha of agricultural land is affected by varying degrees of salt problems in the country. The affected area is likely to increase in the near future due to secondary salinization in irrigation commands and lift irrigated schemes, increase in dependence of agriculture on poor quality waters in semi-arid and arid regions, sea water intrusion and brackish water aquaculture in coastal regions. By 2025 area projected under salt affected soils in India is about 13 million ha. Agronomists have been playing and will have to play a crucial role in managing such lands and enhance productivity through agronomic research, develop comprehensive understanding and better contingency plans based on resource efficient, socio-economically viable and environmentally safe technologies to deal with salt affected soils in changing climatic scenario. In the recent past, a detailed historic perspective of salt affected soils was published by Singh (1998). Present paper is an effort to bring forward an account of the agronomic research made during the Vedic, pre- and post-independence era; and to present a clear picture of outstanding efforts made by the researchers on salt affected soils with its impact on society and environment.

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Salt affected soils in pre- and post-Vedic era

All the landforms and landscapes are developed over weatherable rocks and minerals. Thus, salts are the part of every landscape. From the day one, these have existed as part of it, either in soluble forms or as a part of weatherable rocks and minerals constituting the soil fabric. It is only their accumulation beyond a certain proportion that creates a saline land. The earliest recognition of saline lands dates back to 2400 BC from the Tigris-Euphrates alluvial plains in Iraq (Russel *et al.,* 1965). Saline lands were first located and correlated with irrigation in North-Eastern Sumer in the vicinity of modern Telloh. Their increasing prevalence was mentioned for the next 700 years till the Sumer civilization disappeared. There are evidences of civilizations, which knew the importance of irrigated agriculture and secondary salinization in irrigated areas. Parallel with the Sumerian civilization of Mesopotamia flourished the Indus valley civilization on river banks of North-Western India. These people of pre-*Harappan* and *Harappan* ages were agriculturists. *Harappans* dug wells, constructed tanks and different kinds of engineering structures, laid drainage system and cultivated mainly the winter season *(rabi)* crops. *Harappans* lived on recent flood plains, where salinity had little chance to appear owing to annual flooding of the land by swollen rivers in the monsoon season. The Vedic era started with the arrival of Aryans in the Indus Valley around 1500 BC. It is during Vedic and later periods that lands were distinguished on the basis of their productivity. The infertile lands were further distinguished for the cause of their infertility. Thus salt affected lands were called *Usar.* Medieval religious and other scripts have used *Usar* as also *Kallar* and other terms for salt-affected lands. By the middle of second millennium AD, the pressure on lands had increased, forcing the people to consider saline lands for crop husbandry in place of their use as pasture lands.

Pre-independence evidences of salt affected soils in undivided India

Evidences of existence of salt affected soils in the then United Provinces of Agra and Oudh are quoted by Moreland (1901). He also gave an account of the indigenous methods of reclamation by the cultivators. This shows that reclamation of salt affected soils using different methods was practiced in the United Provinces much before any scientific research had been conducted on the subject. As regards the extent of affected area, the Director of Land Records and Agriculture in his letter number 1247, dated 28 July 1888 informed the Secretary Board of Revenue that the area of *usar* in North-Western Provinces and Oudh was 3,129,053 acres (1,271,977 ha). This figure is almost of the same order as reported in later estimates of alkali lands in Uttar Pradesh (Tiwari *et al.,* 1989). The Punjab part of the Indus plains also suffered from soil salinity before any large scale canal irrigation was introduced in the province. The affected belt was reported to be 16 km x 4.8 km (Jameson, 1852). In view of the wide prevalence of soil salinity in the proposed new canal commands in the Punjab, the Government had, as a policy measure, kept apart large areas in each village settlement to give it in exchange to those settlers who happened to get a saline patch of land. Saline soils were also widespread in Sind part of the Indus plains. In 1906 the Government of India called for reports from experienced local irrigation and revenue officers regarding the prevalence of *kallar* or alkali in Sind.

Early agronomic research on secondary salinization in the subcontinent

It was in the Western-Yamuna canal command that the problem of land deterioration was brought to official notice through a complaint lodged in 1855 by a grower of village *Moonak* (now in Haryana very close to Karnal). This was probably the first well documented problem of soil salinity in relation to canal irrigation, which received considerable attention of British Government. Soil samples from village *Moonak* were collected in 1865 along with samples of canal water and dispatched for analyses to the Royal School of Mines in England forwarding a note that the purpose of soil and water analyses was to determine the correctness of the opinion about the origin of salts in question, as born by facts. After scientific analysis the first cause suggested, was the canal water. It is certain that the continual irrigation of land with water containing sulphates and chlorides, which the canal water has been shown to contain, and the removal of which is entirely due to evaporation, would inevitably have the effect of producing a *reh* soil in a time proportional to the quantity of water applied. This proved a very important point, which decided the line of future researches in secondary salinization. T.E. Brown, Chemical Examiner for Punjab, who had analyzed salt affected soils from Punjab in 1863, suggested that the cause of the problem in his view was the presence in soil of some minerals rich in alkaline substances, whose decomposition was accentuated by irrigation water. The impact of canal irrigation on secondary salinization of lands had also been felt in the peninsular India. The *Nira* Valley Irrigation Canal, opened in 1884, was one of the first attempts to irrigate deep black soils on a large scale. Within about 5 years of its opening, alarm was caused by the appearance of barren, salt-encrusted spots in some of the best and deepest lands in the valley (Mann and Tamhane, 1910).

Constitution of Reh committee: beginning of Indian salinity research

The *Reh* Committee, which sat in 1879, deliberated on the origin of salts in soils. The committee elaborated on two important sources of salts in soils, i.e. weathering of soil constituents and role of canal water. Regarding contribution of canal water, the committee was very emphatic that canal water was a perpetual source of salts. Another outcome was that a scheme of experimental work was drawn up, to be carried out mainly by the newly formed Agriculture Department. The scheme of experiments recommended by the *Reh* Committee was directed towards profitable cultivation of soil by (i) removal of salts, (ii) drainage, (iii) silting, (iv), deep cultivation, (v) manuring, and (vi) ploughing of green crops. A conference was held in 1879 at Aligarh, during which it was decided to set up a series of experiments for the reclamation of salt lands. The decisions of the conference have been systematically documented by Leather (1897). *Reh* maps were prepared to ascertain distribution of *Reh* throughout the provinces. The maps were accordingly prepared and the series of observations were made in 65 villages of Akbarabad *pargana* in Aligarh district. A surface drainage map was also prepared for the same villages of Akbarabad. A survey of sub-soil waters showing water-table depth was prepared for the whole province. A number of agricultural experiments were commenced at Awargarh, Aligarh and Kanpur. The effect of surface drainage was tested. But drainage experiments proved failure. In another experiment near Aligarh, reclamation of *usar* land was commenced with land enclosure and planting of trees. Greig (1883) has mentioned some of the experiences from Sikandra Rao in the Aligarh district and seven plantations near Awargarh. According to him good *usar* was the soil that could grow *Acacia* without any special soil treatment. His observations are forerunner of the auger-hole method of planting trees in alkali soils advocated by the Central Soil Salinity Research Institute, Karnal.

Early reclamation research experiments

The first reclamation experiments were carried out at *Mirpurkhas, Daulatpur and Sukkur* to cover two major soil types - the clayey soils near river Indus and its old branches and the coarse-textured soils. Henderson who took over charge in 1907 found that on a part of *Mirpurkhas* farm no crops would grow. The salt content of various plots varied from 0.08 to 0.98 per cent, sulphates being the dominant salts. In 1907 the plots were filled with water and kept filled with about 5 cm water for 4 to 5 months before *berseem* (Egyptian clover) was sown. This was followed by Egyptian cotton, pearl millet and Sindhi cotton in different years. At Sukkur site the soil was very salty. It was treated as at *Mirpurkhas*. The land became fertile after reclamation. The work was started at *Daulatpur* in the beginning of 1908. The site selected had rank bad *kallar,* as the salt content varied from 0.1 to 1.54 per cent with large presence of chloride salts. Henderson (1909) described results of initial years. According to Henderson, one point brought out in reclamation experiments in Sind was the importance of *berseem*. He noted that rice also owed its value as a reclamation crop because it could withstand large amount of water. Rice and *berseem* cultivation later became a standard practice for reclamation of salt-affected soils in Sind and Punjab.

The first complaint of soil salinity in canal commands of India originated from the Eastern part of the then Punjab. But it was the Western part of the province that was really threatened by the problem, so much so that the land allottees in Rangpur and Mailsi canal commands abandoned their lands when confronted with what they called '*white devil*'. The standard method of reclamation with rice-*berseem* crop rotation did not succeed everywhere. Even in some soils of Sind, application of gypsum was essential for their reclamation (Henderson, 1914). The distinction between saline and alkali soils for the purpose of treatment was made only on the basis of their physical traits like hardness and permeability to water. An important step was taken at the agricultural conference at Nagpur by formulating a small committee to ensure the proper coordination of the work on *reh,* which was being undertaken in most of the Provinces in India and the consequent acceleration of practical results from thorough scientific investigations.

As a follow-up of the recommendations of the 1903 Nira Valley Expert Committee, experiments on amelioration of salt lands of the Nira valley were initiated in 1908 under the supervision of Mann and Tamhane, who visited these experiments in 1909 (Mann and Tamhane, 1910). Open and covered drains had been used in the experiments. They concluded that salt land in the Nira canal area was due solely to the existence of the canal and to the rising of the water level in the area. Waterlogging and salt build up had also been noticed in the tank irrigated areas of Southern India. A series of experiments were carried out at *Saidapet* in Madras Presidency during 1880s. Stone and tile drains were used. Wood (1914) reported work on sub-soil drainage of rice lands under tank irrigation. Two kinds of drains were used: one of plain loose stones and the other made of bamboo tubes. Drains were laid in 1910 and by 1914 they still worked. In other experiments stone drains laid in alkaline rice land had run for 5 years and the land had become fertile.

Post-independence agronomic research on salt affected soils

It was in the post-Independence era that our country witnessed a spurt in researches on reclamation of salt affected soils. India embarked upon 5-year development plans, with strong emphasis on agriculture sector. The Indian Council of Agricultural Research (ICAR) took important steps by initiating research schemes during the second 5-year plan started All India Co-ordinated Research Project on Water Management and Soil Salinity (now All India Co-ordinated Research Project for Management of Salt-affected Soils and Use of Saline Water in Agriculture) and setting up the Central Soil Salinity Research Institute at Karnal in 1969.

Besides the ICAR projects, researches on reclamation of alkali soils were carried out by the National Botanical Research Institute, Lucknow, state owned Universities, research institutes and the state departments of agriculture. During the second 5-year plan the ICAR research projects on land reclamation were located at Ludhiana and Allahabad. The researchers at Ludhiana centre were concerned with comparison of different chemical amendments like gypsum, press-mud, commercial acids, aluminum sulphate, ferrous sulphate and organic amendments like molasses, farmyard manure *etc*. Agronomic researches were carried out using plant residues, *Sesbania* green-manure, different crop rotations, deep tillage and nutrient use at Kamma and Nilokheri research stations in Ludhiana and Karnal. The research results of Ludhiana centre were -later extended to the field through an Operational Research Project situated in District Kapurthala and through field demonstrations elsewhere in Punjab. The centre at Allahabad mainly conducted research on organic amendments.

Research in network mode started in the All-India Coordinated Research Project, involving research centres located in different states with considerable area of salt affected lands and problems of brackish ground water. Presently the centres exist in Uttar Pradesh, Rajasthan, Madhya Pradesh, Kanataka, Tamil Nadu and Andhra Pradesh. The research under this project besides tackling the problem of brackish water use, concerns with the use of different chemical and organic soil amendments, their dose, method of application, nutrient use, and choice of crops and crop rotations in salt-affected soils. The research at the Central Soil Salinity Research Institute, Karnal, probed into the physics and chemistry of alkali soils of the Indo-Gangetic plains. A number of refinements in the technology of alkali-soil reclamation have been introduced by the Institute.

Establishment of Central Soil Salinity Research Institute (CSSRI)

The Central Soil Salinity Research Institute, Karnal was established by the Indian Council of Agricultural Research (ICAR) during IV Five Year Plan as a follow up of recommendations of an Indo-American team on water management constituted by the Government of India in 1967. This committee *inter alia* recommended the establishment of a National centre for research on salinity and alkalinity problems. The Govt. of India accepted these recommendations, which led to the establishment of CSSRI as a plan project in March 1969 at Hisar. However, in October 1969 it was shifted to Karnal, where problematic areas representing the sodic soils of the Indo-Gangetic plains were extensive. Research work was initially carried out at Karnal farm, where alkalinity problem was extensive. As this farm had been recently reclaimed, a new farm at Gudha near Karnal was taken-up during 1978. For research on sub-surface drainage technology of saline waterlogged soils, a farm was established at Sampla in Rohtak district of Haryana in 1982.

The Institute quickly won the confidence of the farming community through ORP demonstrations, lab-to-land programme and attracted the attention of planners. By the end of 1980s CSSRI received attention of International scientific community engaged in salinity research and established linkages with many International organizations. Over the years, the Institute addressed various issues of salt affected soils and their management through outreach programmes by establishing its research farms at Gudha, Sampla, Mundlana, Bhaini Majra, Bichhian, Hisar and now at Nain. The Institute has three regional research stations located at Canning Town (West Bengal) to address the problems of coastal salinity, Bharuch (Gujarat) to address the problems of salt affected Vertisols and at Lucknow (U.P.) to address the problems of alkali soils of IGP. Since its inception, the institute has been pursuing interdisciplinary research on reclamation and management of salt affected soils and has now grown into an internationally recognized centre of excellence in salinity research.

Basic researches on salt affected soils and their properties

The basic and strategic research on soil-water-plant relationships was given priority during 1970s and 1980s in India. Moisture retention characteristics were extensively studied (Acharya and Abrol 1975, Khosla *et al.,* 1982). In sodic soils with varying ESP and pH, studies on water transmission characteristics received considerable attention (Abrol *et al.,* 1978, Acharya and Abrol 1991, Chawla and Abrol 1980). By this time, agronomists and soil scientists very well understood that cation exchange equilibrium is the vital factor, which decides the response of salt affected soils to reclamation technologies (Poonia *et al.,* 1979, Poonia *et al.,* 1984, Rao *et al.,* 1968). Besides cation exchange phenomena, the clay mineralogy plays an important role in controlling cation exchange equilibrium as well as the different soil processes (Bhargava *et al.,* 1981, Kapoor *et al.,* 1981, Raj Kumar *et al.,* 1983). Simultaneously, research was initiated on microbiological processes and their impact on micro-flora and fauna in salt affected soils. The researchers identified the microbial diversity, biological activity and role of microbes in bioamelioration of salt affected soils (Bhardwaj, 1974, Rao and Pathak, 1996, Rao *et al.,* 1995). Research on soil fertility management started advancing throughout the country on salt affected soils with major researchable issues of electrochemical changes during rice growth (Chhabra and Abrol, 1977, Swarup and Singh, 1989), nutrient dynamics and management (Rao and Batra, 1983, Singandhupe and Rajput, 1989) and integrated use of organics with mineral fertilizers (Agarwal *et al.,* 1979, Dargan and Chhiller, 1980).

By 1980s many of the basic characteristics of salt affected soils had been studied. Later the researchers diverted their efforts to understand the solute transport processes (Dahiya and Abrol, 1974; Minhas and Gupta, 1992), solute transport modelling (Dahiya *et al.,* 1981, Gupta, 1983; Gupta, 1985) and hydro-salinity modelling (Kamra *et al.,* 1991a,b, Rao *et al.,* 1992).

Crop response to salinity

The knowledge of vegetation types on the salt affected soils was initiated to find out the effective and inexpensive solutions of salinity problems through biological means. This issue received considerable attention after 1980. Plant adaptation against high salinity was major researchable issue (Dagar *et al.,* 1993). Eco-physiology and biochemical adjustment of various plant species against salinity (Sen 1982) was studied across the country. Researchers observed that seed germination was better in soils with low osmotic potential and was adversely affected beyond 13 bars. Germination enhanced with decreasing osmotic potential. This indicated sufficient ion toxicity across the seeds when exposed to various plants was in the following descending order: $NaHCO_3 > Na_2CO_3 > NaCl > CaCl_2$. Environmental and genetic adaptations were studied by some of the research workers to recognize fundamental concepts of salt affected soils (Ramakrishanan 1960 and 1973). Natural coastal vegetation and their ability to tolerate high levels of salinity were thoroughly studied. Researchers at CSSRI and other parts of the country explored physiological trials to understand salt tolerance mechanisms in plant species and crop responses to salt stress (Qadar, 1991; Qadar *et al.* 1981; Rao and Rao 1979). These responses included anatomic, bio-chemical, ion consumption and their expressions in terms of crop growth and yield.

Reclamation and management of salt affected soils

There have been two approaches in reclamation and management of salt affected soils: (i) reclamation of sodic soils by chemical amendments and (ii) reclamation of saline and waterlogged-saline soils by surface and sub-surface drainage. Research on reclamation of sodic soils in India was started before independence (Dhar 1934, Talati, 1947). Different chemical compounds with appreciable soluble calcium content were tried in varying agro-ecological situations (Kanwar and Bhumbla, 1957, Yadav and Agarwal, 1959). Soil-specific gypsum requirements were quantified and relationships developed between pH and gypsum requirement; and ESP and gypsum requirement (Abrol *et al.,* 1981). These basic research were directed towards enhanced effectiveness of chemical compounds (Hira *et al.,* 1981). Gypsum technology for sodic land reclamation proved to be a magical weapon, which spread like a wildfire and influenced the stakeholders and policy makers in different states. The technology was very simple and consisted of land leveling and bunding for rainwater storage and uniform distribution of irrigation water, determination of gypsum requirement, uniform application of gypsum (10 to 15 tonnes per hectare) followed by mixing of surface (10 cm) soil, ponding water for minimum one week before transplanting of rice and adopting proper agronomic practices. CSSRI implemented an Operational Research Project to demonstrate the technology on farmers' fields in rural areas of Haryana, Punjab and Uttar Pradesh. Hand-on field demonstrations, trainings to the farmers, women, youths, farm labourers and subsequent collaboration with governmental departments helped in rapid spread of the technology. Rural poor experienced the effectiveness of the technology so much so that the traditionally migrating tribes (Bazigars) purchased sodic lands at low cost and started a settled life at their farms. The success story was replicated in village Gurusikaran in District Aligarh of Uttar Pradesh. Popularity and success of the technology amongst the farmers proved to be an eye-opener for many of the policy makers and state governments. Impact of this mega success led to setting-up of Land Reclamation Corporations in many of the states. World Bank, European Union and many International funding agencies are now funding the land reclamation programmes in the country.

Besides gypsum, calcium chloride, press mud, acids, acid-formers, fly ash and organic materials were extensively explored. However, organic amendments did not prove much effective as compared to mineral amendments (Chhabra and Abrol, 1977). Crop production in alkali soils demands agronomic skills tuned to physico-chemical properties of the soil. Thus, efforts were diverted to evaluate various agronomic practices keeping pace with reclamation measures (Sharma *et al.,* 1985, 1990). One of the major processes, degrading the soil productivity in canal commands of arid and semi–arid India was rising water-table resulting in accumulation of excess salts on the soil surface. With the scientific advancements, the basic principles to produce crops in saline environments were applied and management practices were evolved (Abrol *et al.,* 1988, Minhas and Gupta 1992, Rao *et al.,* 1995).

Reclamation of saline and saline-waterlogged soils needs drainage for eluviating excess water and salts from the crop root zone. Thus, the drainage remained a major researchable issue in saline soil reclamation and management. Drainage related problems were extensively studied and water-table control maps of different states were prepared. Both surface and sub-surface drainage received attention for reclamation of saline soils. Subsurface drainage technology provided boost to control waterlogging and associated soil salinity by maintaining water-table below a specific depth. It had remarkable impact on crop yield, farm income and employment. The technology initially got impetus in Haryana, which was subsequently widely adopted and replicated in Rajasthan, Gujarat, Punjab, Andhra Pradesh, Maharashtra and Karnataka. Indo-Dutch Network Project transformed drainage research and development from micro to macro scale and involved drainage programmes in several states and a number of researchers contributed in the effort (K.V.G.K. Rao, N.K. Tyagi, S.K. Gupta, O.P. Singh, P.S. Kumbhare, S.K. Kamra, M.J. Kaledhonkar). Sampla experience of CSSRI proved to be a blessing in spreading sub-surface drainage technology. The sub-surface drainage technology helped in increasing cropping intensity from 0% to 200% in the very first year of implementation. Encouraged by the results of demonstrations and Pilot Projects, the state of Haryana prepared a Drainage Master Plan for 45,000 hectare area. Another 15,000 hectare in Chambal Command area of Rajasthan was treated successfully. These and many other success stories reached the planners and it helped the process of providing subsidy for drainage projects by the Ministry of Water Resources. Considerable success was achieved in the field of drainage management by vertical drainage, multiple-well point drainage, skimming open well, horizontal drainage and filter material used for drainage pipes. Recycling of drainage effluent was given due attention for meaningful use of drainage effluent in crop production. Besides drainage, research was carried out for improvement in irrigation system for salinity control in canal irrigation commands. The issue included control of salinity through system improvement, institutional measures and economic measures leading to cost effective improvement in irrigation system (Tyagi *et al.,* 1993, Tyagi, 1986). Despite all the positive points associated with drainage of salt affected areas, the drainage technology could gain momentum only with the support from Government, mainly due to high costs. Researchers therefore explored the possibility of bio-drainage in waterlogged saline areas, mainly along the irrigation canals (Jeet Ram *et al.,* 2008, Chaudhari *et al.,* 2012a, b) with considerable success.

One of the major areas of research in salt affected soils, which received attention of scientists, policy makers and Government Departments, was developing salt tolerant cultivars of potentially important crops. Thus, agronomists and plant breeders (R.S. Rana, B. Mishra, R.K. Singh, K.N. Singh, N. Kulashrestha) joined hands together to develop multiple stress tolerant crop varieties. Some of the most important crop varieties include CSR-10, CSR-13, CSR-23, CSR-27, CSR-30, CSR-36, Sumati and Bhutnath of rice, KRL-1-4, KRL-19, KRL-210 and KRL-213 of wheat and CS-52 and CS-54 of mustard. These varieties are being grown widely in salt affected areas of Punjab, Haryana, U.P, Gujarat, Maharashtra, West Bengal and many other states and are contributing immensely to the food basket of salt affected areas. CSR 30 is the first salt tolerant Basmati type rice variety of the country.

Devising alternate land use systems for salt affected soils

Productivity of conventional crops and cropping systems remains at a sub-optimum level and never touches the potential production level in salt affected soils. Also in severely degraded salt affected areas, crop production is limited by several factors including salinity stress. Under such conditions, research workers observed that forestry and agro-forestry are the better options, which help in bio-amelioration of marginal lands. Research workers across the country studied tolerance of tree species (Tomar and Gupta 1984-1994) and developed planting techniques (Ghosh 1977, Gill and Abrol 1986, Yadav and Singh 1970), and various cultural practices to be adopted for afforestation on salt affected soils. Singh and Gill (1990) demonstrated the ameliorating effects of different tree species on a degraded sodic soil and demonstrated their effectiveness in reducing soil pH and increasing soil fertility. For community lands, different agro-forestry models such as silvi-pasture, silvi-agriculture, silvi-multi-pasture and agri-horti models were evaluated on varying degree of salinity (Singh and Dagar 1998). An auger hole technology for raising forest and fruit tree plantation in salt affected soils has been developed and standardized. By adopting this technology, state forest departments have raised successful tree plantations on salt affected village community lands, Govt. lands adjoining roads, railway lines and canals etc. Pit-cum-auger hole technology was developed to raise fruit trees like aonla (*Emblica officinalis*), karaunda (*Carissa carandus*) and guava (*Psydium guajava*) in soils having pH 10 and above, where nothing was possible to grow. Silvi-pastoral model for bio-reclamation of sodic soil (pH > 10) was developed for production of fuel wood, fodder, pods and honey besides reducing runoff volume, increasing infiltration, reducing soil alkalinity and improving soil fertility. The process involves planting of *Prosopis juliflora* and Karnal grass (*Leptochloa fusca*) together for 5 years. After that

Karnal grass is replaced with *Berseem* or *Shaftal*. This is a non-chemical based eco-friendly technology for the rehabilitation of salt-affected village Panchayat lands. Different agroforestry models have been developed by the researchers. This technology has been adopted by the farmers and the forest department for remediation of salt affected soils. Similarly, research workers demonstrated usefulness of agro-forestry systems for commercial farms on alkali soils. Forage cultivation and research on salt affected soils also received considerable attention because forages not only provide fodder for the livestock but also help in rapid reclamation of salt affected soils. Salt tolerance of forages and grasses were evaluated by Ashok Kumar and Abrol (1986), Ashok Kumar and Gill (1994) and Ashok Kumar and Sharma (1995) and many other researchers.

Agronomic research on salt affected Vertisols

Salt affected Vertisols (Black soils) cover an area of about 1.21 million hectare in Gujarat. Problem is increasing in Karnataka, Maharashtra and Rajasthan. Due to high clay content, soils are adversely affected even at low salt and exchangeable sodium contents. Further, with the introduction of mega irrigation projects, the extent of salt affliction is increasing at a rapid rate. Restoring the productivity of these lands, once they become salinized is much more difficult as compared to alluvial sandy loam soils of Indo-Gangetic Plains. Researchers made consistent efforts to study the basic, strategic and applied aspects of salt affected Vertisols (Chaudhari *et al.*, 2006, Nayak *et al.*, 2004, Rao, *et al.,* 2004, Singh *et al.,* 1994). Technologies like cultivation of *Salvadora* (tolerates salinity up to 50 dS/m) for the restoration of highly saline (>40 dS/m) soils and *Dill* (tolerates salinity of 4-6 dS/m) 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.

Agronomic research on coastal saline soils

Coastal salinity research was given due importance and various researchable issues of salt affected soils have been taken on priority (Bandyopadhyay *et al.,* 1985, Maji and Bandyopadhyay, 1991, Sen *et al.,* 2000). An innovative 'Dorovu' technology has gained immense popularity in coastal regions of the country. Several other technologies developed by CSSRI regional research station, Canning Town and transferred through their Institute–Village-Linkage-Programme (IVLP) have contributed towards higher food grain production in coastal regions. These technologies include *rabi* cropping in mono-cropped coastal saline soils, rainwater harvesting in dugout farm ponds, reduction of arsenic uptake by higher application (10-15 kg ha^{-1}) of Fe and Zn, salt tolerant rice varieties 'Sumati' and 'Bhootnath' released for coastal saline soils, rice-Azolla interaction for higher rice yields, efficient nutrient management, rice-fish multi-cropping for higher income besides higher rice production with lime (3-4 t ha^{-1}) and rock phosphate (2 t ha^{-1}) for acid sulphate soils.

Agronomic research on sodic soils of IGP

Outstanding agronomic research has been and is being carried-out on the sodic soils of Indo-Gangetic Plains (IGP), mostly in the irrigation commands. One of the regional research centres (Lucknow) of CSSRI is completely devoted to the cause of reclamation and management of these soils. The centre has proved that the Phospho-gypsum (a byproduct of the phosphate fertilizer industry) can be an alternative to the mineral gypsum without much radiation and heavy metal hazards (Sharma *et al.,* 2011). Agronomic research on resource conservation showed that zero tillage wheat is a cost effective practice as compared to the conventional method and saves 20 % water (Sharma *et al.,* 2009). In another study Mishra *et al.,* (2009) evaluated the effect of tillage and crop residue management and reported that the combined effect of crop residue and tillage enhances rice yield in comparison to the individual effect of crop residue and tillage. Results of agronomic research on multi-enterprise agriculture, crop diversification and land re-shaping have been encouraging.

Impact of agronomic research on salt affected soils

Research efforts made during the last 3-4 decades has made a great impact. Amongst all, the reclamation technology received the highest priority and equally vibrant

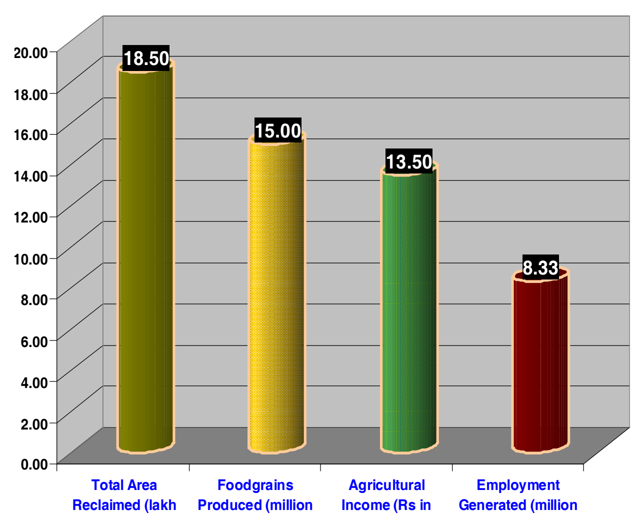

Fig. 1. Overall impact of land reclamation technology on food grain production, agricultural income and employment generation.

response from the farming community in various parts of the country. So far, the country has reclaimed 1.5 million ha salt affected soils in various states (Fig. 1). The reclaimed land every year adds about 15 million tonnes of foodgrains to the National food basket and provides additional income worth Rs 13.50 billion. The technology also provides on-farm and off-farm rural employment opportunities worth 8.5 million mandays every year. Based on 10 per cent discount rate, the economics of sodic land reclamation shows that the present net worth of reclaimed lands is Rs 56000/ha with B:C of 1.52, internal rate of return 21.4 per cent and payback period is 3 years (Sharma *et al.,* 2011). This shows the strength of the land reclamation programmes and justifies the National investment in soil salinity research.

Similarly, more than 50,000 ha waterlogged saline soils have been reclaimed in different states of India where the cropping intensity has increased by 25 to more than 100% and crop yields by up to 45% in rice, 111% in wheat and 215% in cotton. The sub-surface drainage technology generated around 128 man-days additional employment per hectare per annum. Its net present worth estimated to Rs. 45,000/ha, with B:C of 1.5 and internal rate of return of 13 per cent and payback period of five years (Sharma *et al.,* 2011). The technology reduced flood hazards and water-logging, improved resource use efficiency, reduced poverty, minimized inequity and improved quality of life of the people in the affected areas.

Agronomic research on other aspects of salt affected soils viz; alternate land-use systems, salt tolerant crop varieties, salt affected Vertisols, coastal salinity, salt affected soils of IGP etc proved highly impactful by influencing food and nutritional security, women empowerment, involvement of landless labourers and minimizing rural migration. Salinity research helped restore the ecological balance in affected area by its positive impact on environment.

Future issues in agronomic research on salt affected soils of India

- *Re-sodification of reclaimed sodic soils:* This is a growing concern in the areas where sodic soil reclamation took place before 2-3 decades. Though the causes of re-sodification are identified, yet concerted research efforts are to be made to avoid it.
- *Need for alternative to gypsum:* Gypsum being mineral in nature and mined from limited area, its availability in future will no longer be the same as it was in the past. Already there is a crisis and several judicial and social issues involved in gypsum mining. Therefore there is an urgent need to find out an alternative to mineral gypsum and standardize the agro-techniques for its use on sodic soils.
- *Harnessing synergy from modern science:* There are opportunities and avenues of reclamation and remediation of both salt affected soils and poor quality waters; and agronomic research in the area of nano-technology applications in salt affected soils.
- *Bio- and phyto-remediation:* Bio-remediation and phyto-remediation of waste waters / poor quality waters and their use in salt affected soils need to be explored on a major scale. This area has a great potential for agronomic research in future with limiting water availability for irrigation.
- *Bio-saline agriculture:* Agro-forestry offers a very good solution to the bio-amelioration of saline lands. It is possible to go for bio-fuels and bio-energy plantations on moderately degraded and severely degraded salt affected soils. This requires extensive research involving multi-disciplinary teams and addressing core researchable issues. Financial support for such research is now available within the country as well as outside the country.
- *Micro-irrigation for enhanced resource use efficiency:* Till now cereal systems are dominant on salt affected as well as reclaimed salt affected soils. These soils are not exposed to high value horticulture production. Since these areas are affected by multiple stresses of salt, water and nutrients. Therefore, research efforts need to be diverted for enhancing the use efficiency of water and nutrients on salt affected soils. For this, micro-irrigation, drip fertigation, drip chemigation and use of liquid bio-fertilizer along with automized irrigation need to be explored.
- *Resource conservation:* Entire Indo-Gangetic Plain and Trans-Indo-Gangetic Plain is engaged in rice-wheat cultivation for several decades. Exhaustive nature of rice-wheat cropping system depleted the natural resources and there is resource crunch disturbing agro-ecology of the area. The problem is aggravated in salt affected soils because of multiple stresses. This compels adaptation of resource conservation technology and therefore conservation agriculture options need to be thoroughly evaluated for reclaimed as well as non-reclaimed salt affected soils.
- *Multi enterprise agriculture:* For small and marginal land holdings, multi enterprise agriculture provides an assurance of regular income as well as on-farm employment. Results of the research carried out at CSSRI, Karnal are encouraging. Thus, the multi enterprise agriculture involving subsidiary components with conventional crop components in a synergy based recycling manner needs to be evaluated in different agro-eco systems on salt affected soils.

- *Integrated nutrient management:* It is well proved that higher nutrient application is beneficial in salt affected soils as compared to normal soils. But after reclamation soil pH of surface 30 cm layer is within the range of 7.5-8.5, therefore nutrient supply as per the recommended doses of fertilizer is advisable. However, in Haryana, Punjab and Western Uttar Pradesh, farmers use very high amount of nitrogen fertilizers than the recommended one. On the contrary, they do not use potassium fertilizers leading to imbalance nutrition for the crop, which affects soil health and quality. These issues need a fresh relook and to be critically addressed by location-specific research. Therefore, integrated nutrient management prescriptions need to be developed for different types of salt affected soils.

Agronomists in future can do their best by giving inputs in reclamation research that involves hydrological, chemical and biological aspects; water management research that involves nutrient, crop and human resource dimensions. Also agronomists need to continue their support in crop improvement research to develop salt tolerant varieties of important crops.

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