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Sustainable land Management practices for Mitigation of on-farm salinity: A review

Salinization is one of the major land degradation processes, particularly in arid and semi-arid ecosystems, and the salinization process is further accelerated by unscientific soil and water management practices in irrigated agriculture. High concentrations of salts in the soil solution affect the physical, chemical, and biological properties of soils and thus lead to reduced crop productivity. The area under land degradation caused by salinity is increasing day by day as a result of global climate change, necessitating serious efforts to manage salinity at the farm level in order to meet the growing food demand of the world's growing population. The average yield of most of the crops remains between 20-50% of their potential yields, depending on the concentration and nature of the salts. A wide range of adaptations and mitigation strategies for salinity management at the farm level are required to cope with such impacts by enhancing crop and water productivity. Some of the on-farm salinity management options, viz., crop management, root zone salinity management using leaching requirements of salt, multi-quality and method on farm irrigation management, subsurface drainage technology, saline aquaculture, the introduction of salt-tolerant microbes, alternate land use and nutrient management strategies available for alleviating hazards, and sustainable salinity management based on available resources in salt-affected soil, can help to overcome salinity stress and maintain or restore soil health for better crop growth.

Key words: Agronomic strategies, On-farm salinity, Salinization, Sustainable productivity, Water management

Development of on-farm salinity management practices based on severity of problems and locally available resources are essential for sustainable utilization of land resources for meeting growing food demand.

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Introduction

Soil salinization is a common land degradation problem in arid and semi-arid regions of India, affecting productivity and socio-economic status of poor and marginal farmers. In irrigated lands, seepage from canals, excess irrigation, drainage congestion and irrigation with marginal quality saline and sodic waters induce salinization (Ambast *et al.,* 2006) and aggravated secondary salt enrichment in soil profiles affect water and nutrient transformations and reduce crop productivity. Initial osmotic stress followed by ion toxicities is the main limitation to plant growth in saline soils. In addition, salt uptake by plants leads to excess consumption of Na^+ and Cl^- levels which adversely affect the key metabolic processes such as photosynthesis. While in case of sodic soils, it is the excess of Na^+ on soil exchange site that adversely affects soil physical conditions followed by nutrient transformation and root respiration. As per estimates based on 2012-14 moving average data, India loses 16.84 million tonnes of farm production annually valued at Rs. 230.2 billion due to salt affected soils (Mandal *et al.,* 2010; Sharma *et al.,* 2015). Besides, use of poor quality water in different states varies from 32-84% (AICRP, 2014-16). These soils and waters threaten the livelihood security of farming community. Nearly 2.0 million ha salt affected lands have been reclaimed using technologies suggested by Central Soil Salinity Research Institute (CSSRI) (gypsum technology, subsurface drainage technology, introduction of salt tolerant varieties, sustainable use of saline/ sodic waters, land shaping techniques *etc*.) and put to productive use (CSSRI,

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2016-17; Barman *et al.*, 2021). This reclaimed area is estimated to contribute nearly 18 million tonnes food grains to the national food basket (CSSRI, 2016-17). But, the key challenges for addressing the problems of salt-affected soils (SAS) is to adopt preventive/ ameliorative measures to the areas with estimated increase of land with 16.2 million ha (an increase from 5% to 11% of total net sown area (141 Mha)) by 2050 (ICAR-CSSRI Vision 2050) under salt-affected regions.

Allocation of fresh water to agriculture sector has been reducing continuously due to expanding demand from other sectors which are inducing increase in the coverage of SAS, especially in the arid and semiarid regions. Sharma and Singh (2015) have suggested for adopting new approaches to mitigate salinity hazard, because of less availability of fresh water, required in the reclamation programmes. The recommended technologies such as sub-surface drainage, gypsum-based package, crop improvement programme and land shaping techniques showed significant potential in the productivity enhancement of salt-affected lands. But, reclamation of waterlogged saline soil based on surface and sub-surface drainage generates huge quantities of saline drainage water (Sharma and Minhas, 2005). The most important criterion for evaluating the salinity hazard by saline drainage water is the total concentration of salts in the water. Sharma and Rao (1998) reported the potential uses of saline drainage water in crop production, but many issues need to be addressed to make this practice environmentally viable and socially acceptable. Therefore, special on farm salinity management options are required to minimize the harmful effect of salts and to maintain/restore good physical condition of the soil for better crop growth. This review briefly outlines the crop management, root zone salinity management using leaching requirement of salt, multi quality and method of on farm irrigation management, subsurface drainage technology, using of saline aquaculture, introduction of salt tolerant microbes, alternate land use and nutrient strategies available for alleviating hazards and sustainable salinity management in salt affected soil of India.

Characteristics and extent

Saline soils at farm level are usually formed by the salt stored in soil profile and/or groundwater being mobilized by additional water provided by human activities such as irrigation. Application of additional water through irrigation pressurizes the water table for upward movement and this upward movement again exaggerates by soil surface evaporation which leads to the development of soil salinity by leaving salt behind. Therefore, quantity and quality of irrigation groundwater are most important factors for optimum crop production, but, poor quality groundwater resources are found in the water scarce areas. The maximum area under saline and brackish groundwater in India coincides with arid and semi-arid regions of Rajasthan, Haryana, Delhi, Punjab and Uttar Pradesh (Minhas and Tyagi, 1998; Minhas and Samra, 2003). In India, the problematic areas with high water table cover 2.6 million ha while 3.4 million ha suffer from surface water stagnation. Faulty management leads to increase the area of surface soil salinity. It was reported that surface soils with moderate (EC_e 8-30 dS m^{-1}) and strong (EC_e >30 dS m^{-1}) salinity covered 64.9 and 33.6 per cent area and the extent of soil salinity increased by 8.3 and 15.8 per cent (Table 1) from 2011-12 to 2017-18, respectively (CSSRI, 2017-18).

The typical characteristic features of saline pedons are presented in Table 2. A wide range of management options are available from field preparation to crop harvesting at farm level for control of salinity.

Management of on-farm salinity

The approaches used for management of salinity at farm level for sustainable crop production, in a salt affected environment can be grouped in to two categories *viz.*, modification of the growing environment to suit desired crop plants and improving the plant system to tolerate salt stress. Both these approaches may be used either singly or in combination (Sharma and Minhas, 2005), but the former approach has been used more extensively because it facilitates the use of alternative production inputs. The most of previous work was in the context of root zone salt stress management by the use of treated saline water, involving the application methods or withholding of irrigation to maintain an environment favorable for crop production. But all the management practices (conjunctive use, water table management, rain water conservation *etc.*) were developed at field level without considering their implications and effects of changing salt and water dynamics at farm/irrigation system/river-basin levels (Tyagi, 2003). The crop performance under the

Table 1: Changes of soil salinity over six years in the Nain experimental farm of CSSRI, Panipat

Soil properties	Range in property	Per cent of the total area (2011-12*)	Per cent of the total area (2017-18)	Δ_6% area
EC_e (dS m^{-1})	<4	8.7	0.01	8.69
	4 to 8	16.9	1.49	15.41
	8 to 15	25.4	15.4	10
	15–30	31.2	49.5	(+) 18.3
	>30	17.8	33.6	(+) 15.8

*Mandal *et al.*, 2013a

Table 2: Some characteristics of salt-affected soils representing different broad groups

Depth (cm)	pH	EC_e (dS m^{-1})	$CaCO_3$ (g Kg^{-1})	OC (g Kg^{-1})	Clay (%)	ESP
Aquic Natrustalf (Karnal, Haryana)						
0-10	10.6	22.3	51.0	1.4	12.5	96.0
10-48	10.2	6.3	89.0	1.0	18.9	91.0
48-76	9.8	4.2	94.0	0.7	22.7	88.0
76-104	9.5	2.3	126.0	0.5	21.2	85.0
104-163	9.6	1.3	138.0	0.4	31.8	69.0
Typic Natrustalf (Akbarpur, Kanpur)						
0-20	10.0	60.5	46.0	3.0	27.4	75.0
20-64	9.9	4.7	48.0	2.8	37.0	74.0
64-97	9.3	0.9	12.0	2.1	38.6	33.0
97-121	8.5	0.6	56.0	1.7	33.2	18.0
121-180	8.4	0.4	100.0	1.6	25.6	10.0
Typic Haplusterts (Barwaha, Madhya Pradesh)						
0-20	8.5	8.9	75.0	6.3	42.8	58.0
20-44	8.5	8.9	115.0	4.3	53.4	74.0
44-84	8.6	5.9	145.0	4.3	44.2	74.0
84-106	8.6	4.8	190.0	2.4	39.6	63.0
106-145	8.6	2.3	190.0	1.2	37.5	63.0
Typic Ustochrept (Sampla, Haryana)						
0-19	6.8	65.2	9.0	-	16.5	3.0
19-38	7.2	6.9	4.0	-	17.2	30.
38-79	7.3	4.2	18.0	-	18.2	4.0
79-119	7.4	3.4	38.0	-	16.5	3.0
119-147	7.4	4.0	20.0	-	17.2	3.0
Typic Natrargrids (Banaskantha,Gujrat)						
0-10	8.0	68.9	37.0	3.2	15.8	45.0
10-23	8.2	44.3	65.0	3.0	21.9	41.0
23-46	8.5	32.8	56.0	3.0	22.1	43.0
46-71	8.2	29.5	130.0	2.5	23.3	63.0
71-87	8.1	25.5	223.0	2.1	17.2	52.0
87-112	8.0	20.2	233.0	2.1	17.6	57.0
112-140	8.1	30.1	364.0	1.5	22.5	43.0
140-170	7.6	32.7	279.0	1.2	16.1	62.0

Taken from Dubey *et al.* (1998)

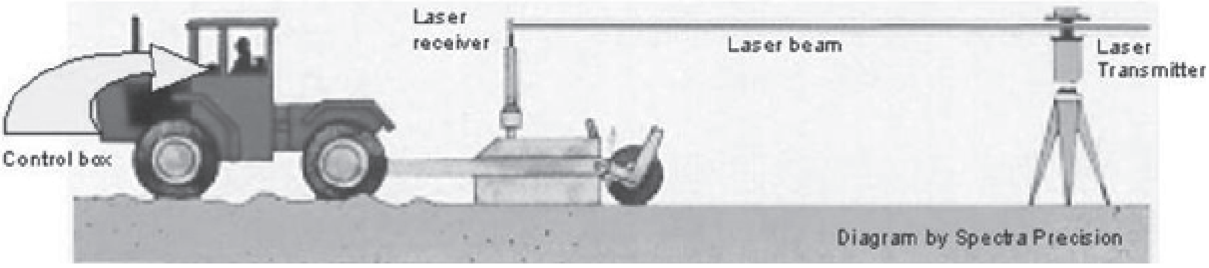
application of saline water for a long term and simultaneously salinity build-up in the soil depends on the interplay of several factors such as evaporative demand, salt content, soil type, rainfall, water table conditions and type of crop and water management practices (Minhas and Gupta, 1992). The available agronomic options are the management of crop, irrigation water, nutrient and cultural practices, but there seems to be no single management measure to control salinity of irrigated soils, but several practices interact with each other and should be considered in an integrated manner. Each management options starting from field preparation to crop harvest are described separately in the following sections.

Laser land levelling

Unevenness of the soil surface has a major impact on the germination, stand and yield of crops through nutrient water interaction and salt and soil moisture distribution pattern. Land levelling is a precursor to good agronomic, soil and crop management practices. Farmers recognize this and therefore devote considerable attention in levelling their fields properly. However, traditional methods of levelling land are not only more cumbersome and time consuming but more expensive as well.

Effective land leveling is meant to optimize water-use efficiency, improve crop establishment, reduce the irrigation time and effort required to manage crop. It is a common knowledge that most of the farmers apply irrigation water until all the parcels are fully wetted and covered with a thin sheet of water. Studies have indicated that a significant (20-25%) amount of irrigation water is lost during its application at the farm due to poor farm designing and unevenness of the fields.

The effect of laser land levelling in direct seeded rice with mulch and irrigation level under saline Vertisols was



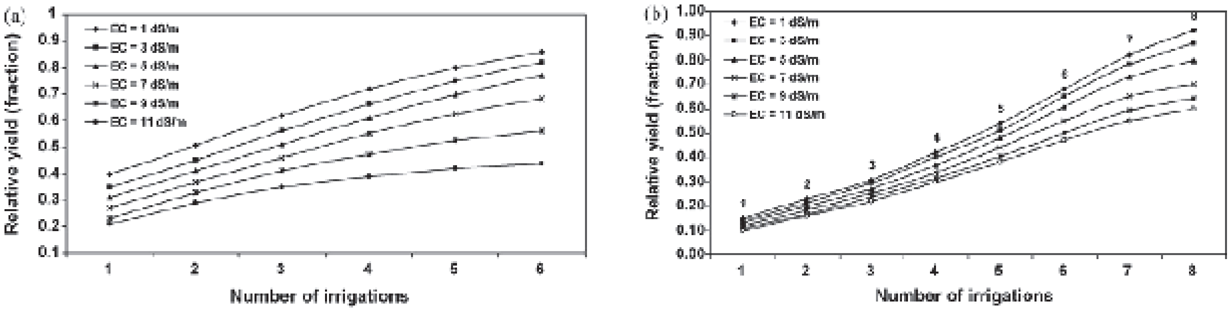


Fig. 1: Relative wheat yields (initial soil salinity = 5.5 dS m^{-1}) due to change in irrigation frequency (a) in conventionally levelled fields (6 cm $irrigation^{-1}$) and (b) in precision levelled fields (4 cm $irrigation^{-1}$).

initiated during *kharif* 2014 at ARS, Gangavati. The pooled data revealed that no significant yield difference was observed among laser leveling in DSR without mulch, laser leveling in DSR with mulch. However, the paddy grain yield differed significantly due to irrigation level treatments. Significantly higher grain yields under 1.5 ET compared to 1.0 ET in laser leveling treatment could be due to higher leaching of salts by applying higher level of irrigation (AICRP, 2014–2016). Laser land leveller helps in achieving precision land leveling (leveling index <1.5 cm) and thus provides the scope of applying shallow depth (4 cm) of irrigation water more frequently (Ambast *et al.,* 2004). Irrigation scheduling with application of 4 cm water was considered as an improvement option than application of 6 cm water (Mandare *et al.* 2008). It has been observed that, in case of 11 dS m^{-1} water, the relative yield increased significantly higher (from 0.45 to 0.60) in précised leveled field due to frequent irrigation as compared to good quality water, whereas, in case of conventionally levelled fields, relative yield may reduce to 0.4 (Fig. 1). Increase in relative yield has been seen as a result of frequent irrigations that reduced salinity build up in root zone depth before it reaches to threshold level.

Seed priming

In priming, seeds are exposed to restricted water availability under controlled conditions which allows some of the physiological processes of germination to occur, before germination is completed, the seeds are usually re-dried for short-term storage before sowing (Halmer, 2004). Several different priming methods have been employed to increase the germination and improve the uniformity in emergence of problematic seeds. *Hydropriming i.e.* soaking in water (Afzal *et al.*, 2002), *osmopriming i.e.* soaking in a solution of osmoticum (Rouhi *et al.* 2011), *halopriming i.e.* soaking in salt solution (Nawaz *et al.,* 2011) and *solid matrix priming* (SMP) *i.e.* priming using solid carriers (Khan, 1992) are most commonly used methods. It has been observed that certain physiological and biochemical beneficial changes are associated with priming of seeds (Basra *et al.*, 2005; Hu *et al.*, 2006).

Osmopriming contributes to significant improvement in seed germination and seedling growth in different plant species grown under saline conditions. For example, osmo conditioning of Bermuda grass (*Cynodon dactylon*) seed using PEG followed by immediate sowing improved germination and seedling growth under saline conditions. *Hydropriming* generally enhances seed germination and seedling emergence under saline conditions. Roy and Srivastava (1999) reported that soaking wheat kernels in water improved their germination rate under saline conditions. Presoaking treatment of wheat kernel with water resulted in significant increases in total chlorophyll, chlorophylls a and b, and chlorophyll a:b ratio compared with untreated seed under salt stress (Roy and Srivastava, 2000). Hydropriming eliminate the adverse effect of salinity on total and reducing sugars, lactose, maltose, and proline. Pre-sowing temperature treatment (*thermopriming*) of seed can also alleviate the adverse effects of abiotic stresses on germination and emergence. For example, chilling treatment of *Brassica juncea* seed for 5, 10, or 15 d (Fig. 2) resulted in

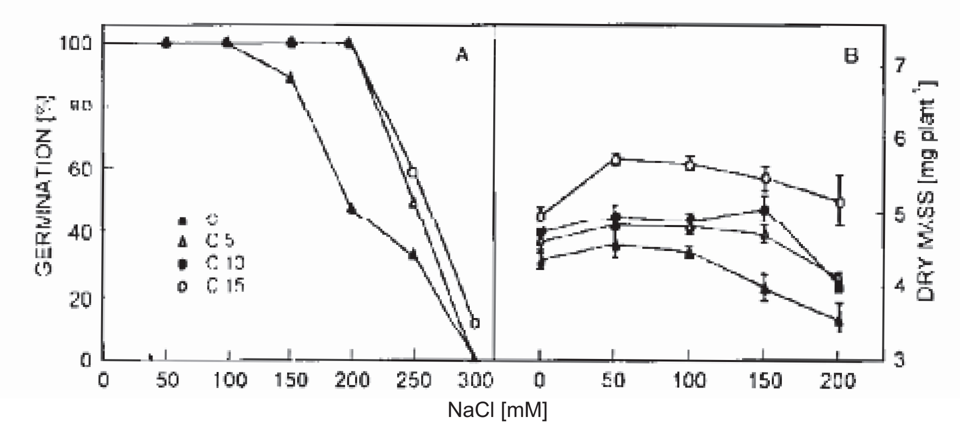


Fig. 2: Enhancement in germination percentage (A) and dry mass of 6-d-old Brassica Juncea seedlings (B) under salinity stress (0 – 300 mM NaCL) by pre sowing chilling treatments to seeds. (C-water soaked non-chilled controls; C-5, 10 and 15 represents chilling treatments for 5, 10 and 15 d (Error bar: Mean±SE)

enhanced germination under salt stress (Sharma and Kumar, 1999).

Leaching requirements (LR) for salt balances

Minimal fraction of total applied water which passes through the root zone to prevent reductions in crop yield below the acceptable level is known as LR for salt balance. In very low rainfall area where steady state flow occurs, the concept of LR shows practical importance at that area. However, under continental monsoonal climate, concentration of rains in a short span of 2–3 months is the most uncontrolled factor causing non-steady state salinity. Under such situations, salt tolerances of crop plants, especially at critical stages may vary with patterns of salinization and initial distributions of salinity in soils (Minhas and Gupta, 1992). The leaching requirement proportionately related with salinity of the irrigation water and the sensitivity of the crop for salinity (Kijne, 2003). Reduction in water application amount from high saline source slower the process of salinization. However, more and more amount of good quality water needs to be applied to the crop to control the root zone salinity at an acceptable level. This may be achieved through diversion of good-quality canal water from head to tail reaches to improve the blend of irrigation water available in tail reaches (Kuper, 1997). As the requirement of fresh water for leaching is governed by initial salinity, water requirements can be reduced if initially the soil is leached with saline waters. Removal of 80% salts would require 1.5, 1.1, and 0.4 cm water per cm soil depth in fine, medium, and coarse textured soils, respectively (Minhas, 1998). In other words, if the surface 50 cm soil is to be leached, water requirement of respective soils would be 75, 55, and 22 cm (Fig. 3).

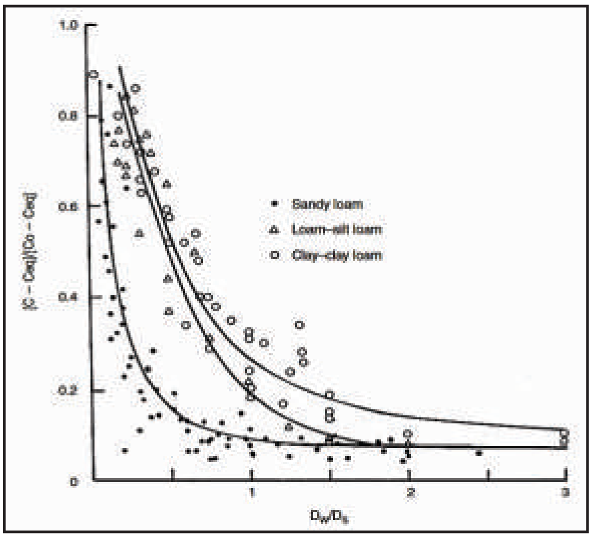


Fig. 3: Leaching curves for different textured soils.

Drainage practices in waterlogged saline soil

Reversing the water flux for salt leaching is the primary requirement for successful crop production in saline soils. This is achieved by natural or artificial drainage for maintaining the root zone free from salt and control of water table. The following surface and subsurface (vertical, horizontal) drainage techniques are pursued in India.

Surface Drainage

Land leveling and shaping is done for proper surface water flow over the surface to furrows or ditches and ultimately into groundwater through the main drain. The recharge of groundwater through surface drain depends on soil permeability and depth of water table, but, use of surface drains suffers from the disadvantages of loss of land, hindrance to farming operations, heavy maintenance costs in terms of weed control and overland instability of banks. However, surface drainage technique in an agricultural farm can provide adequate drainage to reduce water stagnation problems during monsoon season. The surface drainage water can be stored for irrigation during the dry spells.

Sub-Surface Drainage

Two man made systems of sub-surface drainage, *viz*., vertical and horizontal are in vogue. Vertical drainage is mainly achieved by pumping out groundwater through the tubewells and the horizontal drainage involves engineering structures laid parallel to the ground surface. Both types of drainage systems aim at lowering the water table in response to recharge caused by rainfall, irrigation, leaching water, etc.

Vertical Drainage

The success of a vertical drainage system has not been feasible in saline areas due to their poor aquifer yields and saline ground waters. Thus, the water tables are rising at an alarming rates leading to secondary salinization. For such areas, a multiple well point system has been devised to lower water table by skimming fresh water floating over saline water (Shakya *et al.,* 1995). The system consists of a number of well points arranged in a line, interconnected to each other through a horizontal pipe line (lateral) buried at 70 to 100 cm below the ground level which is pumped by a centrally located sump. In the latter case, it is known as a multiple well-point syphon system. Similarly, Singh *et al.* (1994) have tried installation of open wells placed at 150-300 m grid for skimming of good quality water. These systems improve multiple farms simultaneously.

Shallow water table management

The conjunctive use of surface water and groundwater resources can easily control the rising water tables by increasing the groundwater utilization (Sharma *et al*., 1994; Kazmi *et al.,* 2012). The reduction in percolation of irrigation water is a major challenge in rice-dominated cropping systems, as more than half of the total water applied to a rice field gets percolated, and thus contributes to the rise in water table. A reduction in rice area against other crops could reduce the percolation rates significantly (Singh *et al.,* 2010). While implementing poor quality groundwater for controlling the rising water table, the adaptation of salt tolerant crops is also suggested as it reduces the harmful effects of salts on plant growth. Though, the increased use of poor quality groundwater can control the waterlogging problem up to some extent, its excessive use can lead to higher concentrations of salts in the soil and thus to salinity. In coastal areas, the lowering of water tables can lead to seawater intrusion and can degrade groundwater quality, making it unsuitable for irrigation in coastal farm.

Sub-surface drainage helps to manage water table depth and also leaches away the harmful salts (Datta *et al.,* 2000; Manjunatha *et al.,* 2004). About 60,000 ha waterlogged saline areas have been reclaimed using this technology (CSSRI, 2018). The water table depth and salinity of sub-surface water has direct implications on the use of groundwater by crops (Shannon and Grieve, 2000). The provision of sub-surface drainage allows the use of higher salinity water through surface applications (Minhas, 1993; Sharma *et al.,* 1994). Yield reductions were much smaller in fields having a sub-surface drainage system than in fields with a deep water table and the differences were larger at applied water salinities of more than 10 dS m^{-1} (Table 3).

Sub-surface drainage helped in maintaining a more favorable moisture regime in the root zone, which lead to higher productivity and exhibit improvements in soil properties. In spite of tangible improvements in soil and environmental quality, higher incomes to the adopters and generation of farm employment, the slow penetration of SSD technology is a cause for concern. In addition, safe disposal of saline drainage water in landlocked regions is another hindrance to the implementation of SSD projects. Measures such as use of evaporation ponds (Tripathi *et al.,* 2008), blended or cyclic use of saline and fresh (Datta *et al.,* 1998) and the use of salt tolerant cultivars (Sharma and Rao, 1998) are suggested for enhancing the acceptability of this technology at farmers' fields. The slow penetration of SSD technology has also enhanced the interest in bio-drainage through salt tolerant trees (Ram *et al.,* 2011).

Crop management

For satisfactory higher yields under given levels of root zone salinity, the intergenic differences of crop genotype to the salinity tolerance can be exploited for screening purpose (Minhas and Gupta, 1992; Koyama *et al.,* 2001). Less water demanding crops like oilseed crops can tolerate higher levels of irrigation water salinity over salinity sensitive pulses and vegetables. Monocropping is recommended in arid and semi-arid zone (rainfall <400 mm) for maintaining salt balance. Minhas *et al.* (2004) recommended the use of semi-tolerant to tolerant (mustards, wheat, cotton) crops for successful use of saline waters, whereas, crops like rice,

Table 3: Relative yield of wheat with saline irrigation under conditions of a deep water table and a shallow water table but provided with sub-surface drainage

Irrigation water salinity (dS m^{-1})	Relative yield (%)	
	Deep water table	Shallow water table
0.6	95	100
4.0	90	94
8.0	83	86
12.0	60	78
16.0	42	74

sugarcane, and forages, those require liberal water use, should be avoided. Tolerance limits to the use of saline waters and salt accumulation in soil may vary under different soil texture (mainly), annual rainfall and ionic constituents of salinity. Water with EC more than 12 dS m^{-1}, can be used for growing tolerant and semi-tolerant crops in coarse textured soils, whereas, EC more than 2 dS m^{-1} may hamper the crop growth due to osmotic stress in fine textured soils (Sharma and Minhas, 2005). Other factors *i.e.* ageing, crop cultivars and presence of toxic constituents along with salinity can change in tolerance of crops to osmotic stress (Minhas, 1996; Katerji *et al.,* 2000).

On-farm irrigation management

Saline water can be directly applied where a crop can be grown within acceptable yield levels without adversely effecting soil quality and health. Boumans *et al.* (1988) reported less than 20% average yield reductions for crops like cotton, millet, mustard and wheat under saline waters with EC of 4–6 dS m^{-1} in light textured soils of Haryana, India. Mungbean, sorghum and mustard crops could tolerate higher salinity once the non-saline water was substituted for pre-sowing irrigation to leach out the salts of seeding zone to enhance germination which markedly increase the crop growth and yields and also resulted in better utilization of soil-water even from the lower soil layers.

Multi-quality irrigation practices

Sharma and Rao (1996) in a field study used drainage water for wheat in different modes without substantial yield reduction. Conjunctive use of saline drainage water can be more beneficial in areas where fresh water is available during the early growth stage of the plants because plants are more sensitive to salinity during germination and early growth stages. For example, Chauhan *et al.* (2008) reported a higher germination percentage of wheat under saline water use conditions where the pre-sowing irrigation was done with good quality water. The conjunctive use of good and poor quality water is practiced in many water-scarce areas having twin problems of waterlogging and salinity (Yadav *et al.,* 2007). In India the poor quality water utilization in different states ranges between 32% and 84% (Table 3) (Tyagi and Minhas, 2002). To practice conjunctive use of saline and fresh water, the available options are blending and cyclic mode. Blending is promising in areas where freshwater can be made available in adequate quantities on demand. The potential for blending two different supplies depends on the crops to be grown, salinities and quantities of the two water supplies and the economically acceptable yield reductions. Cyclic use is most common and offers several advantages over blending (Rhoades *et al.*, 1992). Kumar *et al.* (1996) recorded better plant growth of cereal crops with cyclic treatment of conjunctive use as compared to blending. Various researchers also confirmed the superiority of cyclic application over the

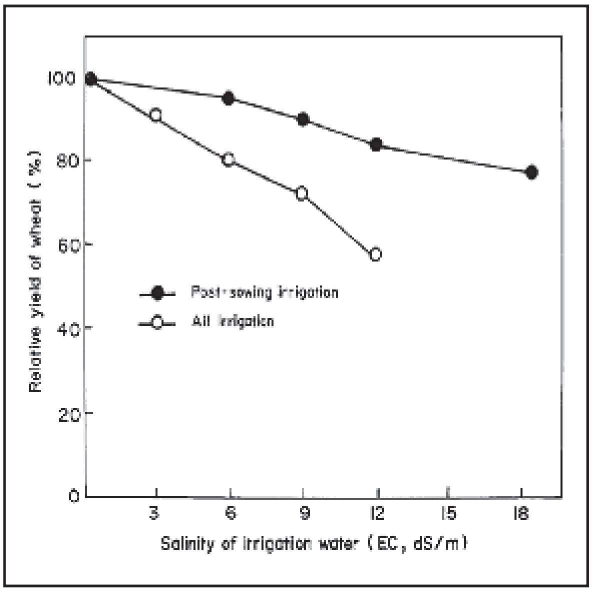


Fig. 4: Effect of pre-plant and post-plant irrigations with blended drainage water of different salinities on relative yield (%) of wheat

blending showing that for similar salt input, cyclic applications have an advantage over blending the water supplies especially when the better quality water is used initially at crop establishment (Minhas and Gupta, 1992; Naresh *et al.,* 1992; Sharma and Minhas, 2005; Minhas *et al.,* 2007). Minhas and Tyagi (1998) analysed a large number of experiments and showed at the same level of EC_{iw} (Weighted average salinity of the irrigation water), the yields for different cyclic use modes were higher than the estimated yields for mixing. Further studies (Naresh *et al.,* 1992; Minhas *et al.,* 1998) have confirmed the beneficial effects of cyclic uses especially when canal waters are applied during the initial stages of crop establishment. Sharma and Tyagi (2004) reported non-significant reduction in wheat yield after the use of blended drainage water of different salinity levels in one sector of the drainage project for six years; the seventh wheat crop was irrigated with non-saline canal water at different growth stages (Fig. 4). This practice will also prevent salt accumulation in the lower layers.

Method of irrigation

Favorable salt and water regimes in the root zone should be maintained by the application of irrigation water such that water is made readily available to plants for their growth without any reduction in yield. High energy pressurized irrigation methods like sprinkler and drip are typically more efficient than surface irrigation for the adequately controlled water application. Sprinklers help in uniform distribution of water even on undulating land surfaces and increase the efficiency of salt leaching (Sharma, 2001). However, it may cause leaf burn in some sensitive crops particularly during periods of high evaporative demands.

As regular and frequent water supply is possible with drip irrigation, it has been observed to enhance the threshold limits of their salt tolerance by modifying the patterns of salt distribution and maintenance of constantly higher matric potentials. Use of poor-quality water through drip, however, requires some changes from standard irrigation practices such as selection of appropriately salt tolerant crops. When using low quality water, drip irrigation has several advantages over other irrigation methods because it does not wet the foliage, and because of its high application frequency, concentrations of salts in the rooting zone remain manageable (Mmolawa and Or, 2000). Therefore, drip irrigation is an important technique to manage salt and moisture in the root zone. AICRP Hisar center conducted an experiment on comparing drip irrigation frequency treatments and reported that there was 2.67 and 11.57 per cent yield reduction in case of alternate irrigation compared to daily irrigation, in canal and saline water irrigation (7.5 dS m^{-1}), respectively (CSSRI, 2016-17). Vegetables yield was 20-30 per cent higher in drip method as compared to the conventional irrigation method (CSSRI, 2016-17). Fruit yield of tomato and bitter gourd was 2.5 times higher in drip as compared to surface irrigation with saving of about 30% irrigation water (CSSRI, 2015-16). However, accumulated salts cause difficulties in the planting of subsequent crops and the use of flood or sprinkler irrigation can be more effective in leaching those salts. Another problem is frequent clogging of drippers due to salt precipitation.

Root-zone salinity management

The utilization of poor quality water for the management of root-zone salinity is most challenging task for saline water farmers, because, the scarcity of good-quality water in the arid and semi-arid regions is increasing at a higher rate by pumping of groundwater for irrigation purpose in agriculture field. Salinity in the upper level of root zone has a major influence on plant growth and yield than lower level in absence of suitable management practices to maintain root zone salinity (Minhas and Gupta, 1993). The indiscriminate use of poor-quality waters without proper soil-water-crop-livestock management practices not only poses a serious risk to the health of soil, animal, human and environment, but also creates the problem of salinity and toxicity, simultaneously. It reduces crop productivity and many times effects become so severe that lands even go out of cultivation. Percentage use of poor-quality groundwater resources in different states varies from 25 (Madhya Pradesh) to 84 (Rajasthan). Based on the research and experience in different agro-ecological regions of India, irrigation water resources were categorized as good, marginally saline, saline and High-SAR saline (Gupta *et al.,* 1994) for irrigation in India. The degree of restrictions based, saline water uses guideline is given in Table 4. This classification serves the purpose of planning in the utility of saline water at farm level based on different soil texture and rainfall region for the development and management of specific treatments and practices at micro niche level.

However, different states are following different classification of groundwater salinity for irrigation purposes, *i.e.* the upper limit of salinity for irrigation water in Haryana, Punjab, Delhi, Rajasthan (Western, Eastern), Gujarat and Uttar Pradesh are 6, 4, 3, 8, 6, 3.46 and 2.25 dS m^{-1}, respectively (Singh, 2009). The most of salinity management research in India has focused on keeping the root zone salinity under control through appropriate leaching requirements, conjunctive use of multi-quality irrigation waters, appropriate scheduling of irrigation, replacement of surface irrigation methods with efficient techniques such as sprinkler and drip irrigation,

Table 4: Guidelines for using poor-quality groundwater (Subbaiah *et al.,* 2020)

Soil texture % clay	Guidelines for using saline waters			
	Crop tolerance	Upper limits of EC_{iw} (dS m^{-1}) in rainfall region		
		350 mm	350–550 mm	550–750 mm
Fine (<30)	S	1.0	1.0	1.5
	ST	1.5	2.0	3.0
	T	2.0	3.0	4.5
Moderately fine (20–30)	S	1.5	2.0	2.5
	ST	2.0	3.0	4.5
	T	4.0	6.0	8.0
Moderately coarse (10–20)	S	2.0	2.5	3.0
	ST	4.0	6.0	8.0
	T	6.0	8.0	10.0
Coarse (>10)	S	–	3.0	3.0
	ST	6.0	7.5	9.0
	T	1.0	10.0	12.5

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and application of sub-surface and bio-drainage practices (Kijne, 1998). The use of saline drainage water in reclaimed soils will reduce the pressure on fresh water reserves and the environmental impacts of effluent disposal (Sharma and Tyagi, 2004).

Land shaping technologies

Soils having good water and air movements are amenable to land-use intensification through practices such as early sowing, use of high yielding cultivars and integration of crop and other high value components. Multiple cropping and increase in crop yield literally translate into enhanced availability of food, feed and energy from the same land unit. A combination of crops and other components increase the availability of diverse food resources to the farm families. The usefulness of a few simple and economically viable land shaping techniques including farm ponds and paddy-cum-fish model for enhancing the productivity of degraded waterlogged saline lands has been demonstrated. Soils having poor water permeability often suffer from the problems of water inundation and salinity. Rain water harvesting in such man-made structures serves twin purposes of salinity mitigation and enhanced availability of irrigation water during the dry season. Establishment of the farm ponds involves the excavation of about 20 per cent of the farm soil from a depth of about 3 m. The excess rainwater is harvested in these ponds for irrigating the crops grown on embankments round the year. In paddy-cum-fish model, trenches (3 m top width × 1.5 m bottom width × 1.5 m depth) are dug around the periphery of the farm land leaving about 3.5m wide outer from boundary and the dugout soil is used for making dikes (about 1.5 m top width ×1.5 m height × 3 m bottom width) to protect free flow of water from the field and harvesting more rain water in the field and trench. While dykes are used to grow vegetables throughout the year, the remainder of the farm land including the trenches is used for integrated rice-fish culture (Mandal *et al*., 2013b).

Alternative land use systems in degraded farm

Best use of degraded land in a farm is to retire to permanent vegetation, because, use of highly saline waters for crop production in such area is neither feasible nor economical. Due to poor survival percentage under saline environments Tomar *et al*. (2002) devised 'SPFIM' (sub-surface planting and furrow irrigation method) system of planting to establish good plantations and to improve biomass production from such lands. In this method, saplings are planted in furrows and raised beds act as micro-catchments. This improved method not only saves irrigation time and labor but also leads to lesser salts in the soil profile. Irrigation is provided only to sapling-planted furrows covering one-fifth to one-tenth of the total area. Quantities equaling 10% of open pan evaporation sufficed for the optimal growth of several tree species of arid and semi-arid areas (Minhas *et al.,* 1997). In addition to creating favorable water regimes in the rooting zone during irrigations to furrow planted saplings, this method had an added advantage as a consequence of salt movement towards the inter-row areas caused by infiltration of rainfall during the monsoon season. Preferred choices for tree species are; *Tamarix articulate, Prosopis juliflora, Acacia nilotica, Acacia tortilis, Fironia limonia, Acacia farnesiana*, and *Melia azadirach* (Tomar *et al.,* 2002). Halophytic species like Salvadora, Sueda, *etc*. have been identified for bio-saline agriculture. Fruit crops also showed greater potential to salinity tolerance. Fruit tree-based agri-horti systems like *Aegle marmelos*, *Emblica officinallis* and *Carissa congesta* as main components and cluster bean and barley as subsidiary components have been identified for areas having marginal quality water (EC_{iw} 6 – 10 dS m^{-1}) (Dagar *et al.,* 2008). Experiments conducted under shallow saline watertable conditions have shown the possibility of commercial cultivation of guava (cv. Allahabad Safeda) and bael (cv. NB-5) in saline soils irrigated with saline water (3.0–4.0 dS m^{-1}) (CSSRI, 2016-17).

Moreover, the degraded lands in arid and semi-arid regions are traditionally left for pastures but their forage productivity is low, unstable and un-remunerative. Usually there are acute shortages of fodder during winters/post monsoon periods. When the limited saline ground water resources were utilized to supplement rain water supplies, the forage grasses like *Panicum laevifolium* followed by *P. maximum* (both local wild and cultivated) out-performed other grasses (Tomar *et al.,* 2003). Saline irrigation not only improved their productivity by 3–4 fold but fodder (about 30%) could also be made available during scarce periods of April–June, when the most pastoral nomads are forced to move towards the adjoining irrigated areas in search of fodder. This brackish water based agro-forestry systems have also emerged as eco-friendly phyto-remediation crops for the degraded soils (Qadir and Oster, 2002). Beside this, a number of medicinal and aromatic crops have been screened for salinity tolerance in India. Crops like Isabgol (*Plantago ovata*) and Matricaria can be successfully cultivated in soils having EC between 8 and 10 dS m^{-1} (Dagar *et al.,* 2004, 2006). Similarly, dill (*A. graveolens*), a spice crop and Salvadora, a non-edible oil tree can be grown in salt-affected vertisols very successfully. Tomar and Minhas (2004) reported that, *Aloe barbadensis* and *Andrographis paniculata* perform and yield well under saline irrigation. Industrial species like *Euphorbia* and *mulathi (Glycyrrhiza glabra*) also have good scope for cultivation in salty environments of farm.

Use of salt tolerant microbes

There has huge potential in the use of salt tolerant soil micro-organisms to promote plant growth in salt affected soils (Arora *et al.,* 2014) at farm level. Kannan *et al.* (2015) observed that endophytic bacteria enhanced the salt tolerance in the farm of polyembryonic mango rootstocks which was attributed to higher activity of extracellular enzymes such as amylase, protease, cellulase and lipase. The basic physiological mechanisms of these microorganisms in salinity mitigation include higher uptake of K^+ ions, improvement in water absorption and leaf water relations, stability of chlorophyll pigments and increase in photosynthesis, elevated levels of antioxidant enzymes and expression of genes involved in salt tolerance (Ruzzi and Aroca, 2015). Use of microbial inoculants in alleviating salt stress in crops is limited due to higher costs and lack of technical know-how. To overcome these constraints, a low-cost microbial bio-formulation 'CSR-BIO', based on a consortium of *Bacillus pumilus*, *Bacillus thuringenesis* and *Trichoderma harzianum* on dynamic media, has been developed. It acts as a soil conditioner and nutrient mobilizer and significantly increases the productivity of rice, banana, vegetables and gladiolus in salt affected soils of farmer field (Damodaran *et al.,* 2013).

Plant growth promoting rhizobacteria (PGPRs), endo- and ectomycorrhizal fungi, and many other useful microscopic organisms led to improved nutrient uptake, plant growth, and plant tolerance to salt stress. Upadhyay *et al.* (2009) isolated a total of 130 rhizobacteria from a saline infested zone of wheat rhizosphere, and screened for plant growth promoting (PGP) traits at higher salt (NaCl) concentrations (2, 4, 6, and 8%). Out of these, Bacillus and Bacillus-derived genera were dominant which showed PGP attributes at 8% NaCl concentration. Only two isolates, SU18 (*Arthrobacter* sp.) and SU48 (unidentified) showed the nitrogen fixing ability (nif H gene) and found to tolerate 8% NaCl. Another isolates SU47 (*Bacillus subtilis*) also showed the tolerance upto 8% NaCl. Wheat co-inoculated with these two PGPR strains, *i.e.,* SU18 and SU47, and grown under different salinity regimes (2–6 dS m^{-1}), showed an increase in dry biomass, total soluble sugars and proline content (Upadhyay *et al.,* 2012). Upadhyay *et al.* (2011) also screened to identify the bacterial exopolysaccharide (EPS) producing salt-tolerant rhizobacteria with plant growth-promoting traits which showed the potential to mitigate salinity stress (tolerance up to 80 g L^{-1} NaCl) by reducing the content of Na^+ available for plant uptake. The use of arbuscular mycorrhiza (AM) has been shown to be able to alleviate salt stress in tomato and lettuce (Latef and Chaoxing, 2011; Aroca *et al.,* 2013) farmer field.

Fertilization

Fertilizer application is one of the sources of salinization of soils (Maas and Grattan, 1999). The extent of salinization due to fertilization depends on the fertilizer characteristics, the method of fertilizer application, irrigation water quality, and fertilization scheduling, *etc.* Excessive nutrient applications must be avoided, and high-purity, chloride-free, low-saline fertilizers should be selected. The application of fertilizers through irrigation water (fertigation) can reduce soil salinization and mitigate salt stress effects because it improves the efficiency of fertilizer use, increases nutrient availability and timing of application, and the concentration of fertilizers can be easily controlled. The solutions applied in fertigation should generate low additions of EC_w and should not exceed the EC_t (electrical conductivity threshold) tolerated by the crops, which varies with the irrigation water and with the fertilizer used (Machado *et al.,* 2014). Nitric acid with fertigation reduces chloride salinity in the root zone, because the nitrate can counterbalance the excess of chloride (Patel *et al.,* 2009). Application of nitrate and ammonium containing fertilizer would decrease chloride uptake and its accumulation due to negative interaction between them (Flores *et al.,* 2001; Patel *et al.,* 2009; Ghanem *et al.,* 2011). The NH_4^+ feed plants were more sensitive to salinity than NO_3^- feed plants in nutrient solutions (Grattan and Grieve, 1999). Although deemed a “non-essential” mineral nutrient, Si has been shown to be effective in mitigating salinity effects (Al-Aghabary *et al.,* 2004; Romero-Aranda *et al.,* 2006) by the reduction of root-to-shoot translocations of Na^+, Cl^-, in tomato crop. The majority of these results, obtained under controlled condition, need to be confirmed under farmer field condition. Humic substances can ameliorate the deleterious effects of salt stress by increasing root growth, altering mineral uptake, and decreasing membrane damage, thus inducing salt tolerance (Ouni *et al.,* 2014) of bean (Aydin *et al.,* 2012) and Okra (Paksoy *et al.,* 2010) crops. Biofertilizers application reduce soil salinization by reducing fertilizers application, improving soil fertility by fixing atmospheric N_2, both in association with plant roots and independent of roots, solubilizing insoluble soil phosphates, and producing plant growth substances in the soil. Biodegradable municipal solid waste also has huge potential for enhancing crop productivity in saline soils. Three years of field experimentation on mustard-pearl millet cropping system in a saline soil with integrated use of organic amendments *viz.,* municipal solid waste compost (MSWC), rice straw compost (RSC) and gypsum enriched compost (GEC) along with 25 per cent recommended dose of fertilizers (RDF) resulted in significant increase (32% higher over 100% RDF) in microbial biomass carbon, decrease in soil salinity (one unit over control) and increase in crop yields (25% higher over 100% RDF) in both mustard and pearl millet than use of organic amendments and mineral fertilizers alone (CSSRI 2016-17; Sheoran *et al.,* 2022). Improved fertilizer management such as additional doses of phosphorous and organic manures may help to alleviate Cl^- toxicity and improved nitrogen use efficiency, respectively (Minhas, 1996).

Conclusion

Saline waters constitute an important resource for agricultural production in water-scarce regions. But indiscriminate use of saline water in the absence of proper soil-water-crop management practices may lead to degraded soils and environments. Researchers and practitioners have tried either to modify the plant to suit the saline environment or modify the environment to suit the plant. Past research has mainly focused on root zone salinity management, with little consideration given to its implications and practicability at farm, irrigation system, or river basin levels. The available management options mediated through the management of crops, irrigation water, and cultural practices should be considered in an integrated manner to evolve sustainable practices and improved yields. Advanced irrigation (drip, sprinkler, soil moisture probe base, sub-surface planting and furrow for brackish-water based agro-forestry, etc.) and drainage (subsurface) systems can help to alleviate the salinity hazards at field level. These advanced systems, with the adoption of different agronomic interventions such as the use of salt-tolerant microorganisms, balanced fertilizer use with an emphasis on organic inputs, the cultivation of low-water-requiring crops, and resource conservation technologies, present viable options for achieving sustainable returns from reclaimed saline soil.

खेती की जोत के स्तर पर लवणता के शमन के लिए सतत् भूमि प्रबंधन विधियां- एक समीक्षा

अरिजीत बर्मन, सुरभि होता, कृष्ण कुमार मौर्य, परविंदर श्योरण, आर. एस. मीणा और यू. एस. सैकिया

सारांश

लवणीकरण भूमि क्षरण प्रक्रियाओं में से एक है, जो कि सिंचित कृषि में अवैज्ञानिक मिट्टी और जल प्रबंधन प्रक्रियाओं से तेजी से बढ़ती है। मृदा में लवण की उच्च सांद्रता, मिट्टी के भौतिक, रासायनिक और जैविक गुणों को प्रभावित करती है और इस प्रकार फसल उत्पादकता को कम करती है। वैश्विक जलवायु परिवर्तन के परिणामस्वरूप लवणता के कारण भूमि गिरावट का क्षेत्र दिन -प्रतिदिन बढ़ रहा है। दुनिया की बढ़ती आबादी की बढ़ती भोजन की मांग को पूरा करने के लिए खेती की जोत के स्तर पर लवणता का प्रबंधन करने के लिए गंभीर प्रयासों की आवश्यकता है। लवणता के कारण अधिकांश फसलों की औसत उपज उनकी संभावित पैदावार के 20-50 प्रतिशत के बीच रहती है, जो लवण की सांद्रता और प्रकृति पर निर्भर करती है। खेती की जोत के स्तर पर लवणता का प्रबंधन फसल और पानी की उत्पादकता बढ़ाकर किया जा सकता है। खेती की जोत के स्तर पर लवणता प्रबंधन के अनेक विकल्प उपलब्ध हैं जैसे कि फसल प्रबंधन, रूट जोन लवणता प्रबंधन, आधुनिक गुणवत्ता परक सिंचाई प्रबंधन, उपसतह जल निकासी प्रौद्योगिकी, लवणीय पानी में मछली पालन, लवण-सहिष्णु सूक्ष्मजीवों की शुरूआत, वैकल्पिक भूमि उपयोग और पोषक तत्व प्रबंधन इत्यादि को अपना कर लवणता के प्रभाव को कम किया जा सकता है तथा उसके विस्तार को भी रोका जा सकता है साथ ही मिट्टी के स्वास्थ्य को बनाए रखते हुए बेहतर फसल उपज प्राप्त की जा सकती है।

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