BEST PRACTICES AND PROCEDURES OF SALINE SOIL RECLAMATION SYSTEMS IN SAARC COUNTRIES

SAARC AGRICULTURE CENTRE

Best practices and procedures of saline soil reclamation systems in Pakistan

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Introduction

Pakistan is located within the latitude and longitude of 30°N, 70ºE respectively. The Islamic Republic of Pakistan is located in South Asia and the Greater Middle East. In the southern side, Pakistan is surrounded by 1,046 kilometer coastline of the Arabian Sea, and is bordered by Afghanistan and Iran in the west, India in the east and China in the far northeast. Pakistan is predominantly a dryland country with 80% of its land consisting of arid and semi-arid regions which is provided with the largest contiguous surface irrigation system of the world. The salt affected soils in irrigated and non-irrigated areas of Pakistan are about 6 million hectares (Ansari *et. al.*, 2007). The surveys 2001-2003 by SCARPs Monitoring Organizations (SMO), WAPDA indicate that 27% soils have surface salinity while 39% profile salinity problem in Pakistan (WRPO and IWASRI, 2005). Low precipitation, high evapo-transpiration, low leaching of salts and the use of brackish waters for agricultural purposes are of serious concern in the area (Qadir and Oster, 2004). This leads to salt build up and depletion of Ca^{2+} from soil solution and exchange sites in the root zone through Ca^{2+}-Na^{+} exchange and precipitation as $CaCO_3$ or $CaSO_4$ (Berigari and Al-Any, 1994). Such soil conditions adversely affect many physical (Nadler, *et. al*., 1996) and chemical properties which hamper plant growth (Murtaza, *et. al*., 2009).The nature and properties of these soils are diverse. For any long term and sustainable solution, it is necessary to understand the mode of formation and origin of salt affected soils. The main source of salts is the primary minerals in exposed rocks and layers of the earth crust. Soil salinization may originate from a combination of frequently interrelated sources. However, weathering of rocks and minerals in the earth crust is the primary and chief source of all the soluble salts present in soil and sea. The main origin of salts for a particular area can be any one or combination of several sources as mentioned below:

Parent material and weathering process: As a result of weathering process, salts are formed in soils. Under humid conditions, salts leach through soil and are transported to nearby streams and river. But under the arid and semi-arid conditions, these weathering products accumulate in situ and result in the development of salinity and/ or sodicity. This process of formation of salt affected

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soils as a result of accumulation of salts released during weathering is called primary salinization/sodification.

Irrigation water: All the natural waters contain dissolved salts. Canal water in Pakistan is considered as the best quality water but does contain salts varying from 120-200 mg L^{-1}. Just its single irrigation of 10 cm will add salts in the range of 120-180 kg ha^{-1}. Ground waters in Pakistan are mostly brackish. On the average, GW in Pakistan contains 1250 mg L^{-1} of salts. .An irrigation of 10 cm with such water will add1.2 Mg salts ha^{-1} (Ghafoor, *et. al*., 2004).

Flood water and waste effluents: Flood water mostly transfer/redistributes the already present salts but many become important in some part of the world like during monsoon in Pakistan. Similar is the case with sewage water as a source of salts. Sewage water is being used to irrigate the crops mainly vegetable around the cities or is disposed into the irrigation channels.

Sea water: Sea water (EC= 45-60 dS m^{-1}, SAR = 50-55) intrusion as well as sea spray could contribute large quantities of salts but action is bit localized along the coast. Almost similar is the mode of inland saline seeps to contribute salts. In coastal area, soil generally gets enriched with salts from sea through:

i. Inundation of surface soil by sea water during high tide.

ii. Ingress of sea water through rivers, estuaries, etc.

iii. Ground water inflows.

iv. Salt laden aerosols, which can be transported even many kilometers inland from the sea coast and deposited as dry fall out or wash out by showers. Inland deposition of NaCl at a rate of 100-200 kg ha^{-1} $year^{-1}$ for nearby coastal area has been reported (Ghafoor, *et. al.*, 2004). Regular deposition over long period is leading toward salinization.

Lacustrine and marine deposits: According to geological information, whole of the sub-continent was under sea. Gradually sediments from Himalayas produced uplands which were later developed for agriculture. Hence some of the salts could be considered as fossil salts. As a result of irrigation, salts already present in soil profile are transported to the surface which is left behind upon evaporation. Thus over a longer period of time, salts that are previously evenly distributed may accumulate on soil surface and give rise to saline soil.

Causes of salinization/sodification

Successful and sustainable agriculture, especially in the irrigated dry regions mostly depends upon the salt balance (SB) and water balance (WB). Positive salt balance promotes formation of salt affected soils while negative salt balance induces desalination/de-sodification. Positive WB causes rise in GW table or even water logging which promotes the salt accumulation in the root zone and surface soil layers. A negative water balance, if continues for longer periods, causes draw down, sub-soil drying and crops need relatively more irrigation. As a result more and more GW will be pumped for irrigation bringing salts from deeper soil layers onto the surface since as a thumb rule, quality of ground water deteriorates with soil depth and distance from river.

Inappropriate salt balance: Under the agro-climatic conditions of Pakistan**,** SB remained positive, intensity of which increased during the recent years. Similarly WB also remained positive up to few years back because of which large areas were water logged. However, from 1999 onward, WB has become negative resulting in draw-down, sub-soil drawing and thus decreased drainage effluent has promoted soil salinization, sodification and increased irrigation demand. In turn increasingly more brackish GW (51 million acre feet (MAF) per annum) is being used for irrigation causing soil salinization.

Untreated municipal effluents: Continuous use of untreated sewer water or other drainage waters for longer period has the potential of inducing soil salinization followed by sodification if scientific management is not practiced.

Arid climate: Arid climate is generally accompanied by temperatures which induces high evaporation and capillary action causing salt accumulation on soil surface and precipitation of salts (gypsum and lime) in the root zone of crops. Accumulation of lime in soil layers give rise to dense layers in many soils of Pakistan.

Lack of land leveling: Land leveling is essential for uniform distribution of irrigation and rain water. Micro-level unevenness of fields results in differential percolation of water (rate and amount). After some years, lack of precision land leveling help the appearance of patchy salinity followed by sodicity just because of uneven distribution of irrigation and /or rain water.

Extra crop coverage: To meet the ever increasing food demand due to increase in population over years, give rise to salt build up in soil. For example, canal irrigation system supports 70% cropping intensity but in Pakistani Punjab cropping intensity almost touches 200%. To meet the crop water requirement, farmers are compelled to use ground waters, 70% of which is brackish in nature, thus causing salinity or sodicity.

Poor Groundwater quality: Pakistan has the largest irrigation system in the world but the availability of canal water does not commensurate to grow crops on the cultivable land, rather scarcity of good quality water is becoming severe day by day due to increased cropping intensity and non-agricultural demands. To overcome this shortage, 0.9 million tube wells have been installed and 70-80% of pumped water is of hazardous quality owing to high electrical conductivity (EC), sodium adsorption ratio (SAR) and/or residual sodium carbonate (RSC) and thus needs site-specific scientific management (Table 9).

Table 9. Quality of tube well-water samples

Status	Number of sample	Percentage
Fit	18605	45
Un-fit	22529	55
Unfit due to:		
EC	10547	47
SAR	2479	11
RSC	9503	42

Source: *Soil Fertility Research Institute, Punjab, 1981-96*

Inadequate availability of good quality water compels farmers to use ground water for irrigation. However, majority of the ground water sources contain high concentrations of $NaHCO_3$ (Minhas and Bajwa, 2001). Long-term use of such water for irrigation can lead to deterioration in soil physical and chemical properties and adversely affect yields of crops (Minhas and Bajwa, 2001). Excess of cations such as sodium and anions like carbonate and bicarbonate in water could increase soil pH, EC and SAR.

Shallow water table: Under inadequate drainage and inappropriate management of water, during both transport from dams and canals and on-farm use, the water table rises following introduction of irrigation water into an area. Mostly ground waters in arid regions are mineralized but to different extent and as a result of capillary effect, water continuously rise upward and enriches the surface soils with salts following evaporation and perhaps is the major cause of salty lands in irrigated areas.

Seepage from up-slopes containing salts: Under certain situation, seepage resulting from water inputs in the up-slope areas can cause severe salinity of the down-slope area especially when the sub-surface water flow takes place through the strata that are rich in salts and/or marine deposits. Soil salinization has seriously affected the crop productivity of large areas of Pakistan. About 40,000 hectares become saline each year due to secondary salinization (Ansari, *et. al.*, 2007).

Sea Water intrusion in Coastal areas: The coastal areas of Pakistan comprise southern part of Makran Division in Balochistan and southern part of Karachi, Thatta and Badin in Sindh. The region makes 40-60 km wide and about 1000 km long belt along the Arabian Sea. These soils are saline due to ingress of sea water through high tides, rise in water table and back flow into the rivers and estuaries.

Extent of salt affected lands in the country

In Pakistan, about 6.30 million hectares of land are salt-affected and of which 1.89 hectare is saline, 1.85 million hectare is permeable saline-sodic, 1.02 million is estimated that out of 1.89 million hectares saline patches, 0.45 million hectares present in Punjab, 0.94 million hectares in Sindh and 0.5 million hectares in NWFP. Out of 19.3 mha area available for farming, irrigated agriculture is practiced on about 16 mha. The irrigation water is mainly supplied through the world's largest canal system arranged through dams. Intensive and continuous use of surface irrigation has altered the hydrological balance of the irrigated areas,

and water logging in large areas of Sindh, Punjab, NWFP and Balochistan. The magnitude of the salinity problem can be gauged from the fact that more than

menace each year in early sixties (Ali, *et. al.*, 1997). For assessing the extent of

decades by several agencies. The first country wide soil salinity survey was conducted in 1953-1954 under Colombo Plan. The second survey was conducted by Master Planning & Review Division, WAPDA during 1977-79 covering 16.7 million hectare. The latest salinity survey has been carried out by SMO, WAPDA during 2001-2003. It covers an area of 16.8 million hectares. Table 3 shows surface salinity status of the Indus Basin during various surveys. The surface

sixties to 72 percent in 1977-1979 and 73 percent in 2001-03 at Pakistan level.

salinity was more in 2001-2003 as compared to 1977-79.

Table 10. Soils affected by various types of salinity and sodicity in Pakistan (000 ha)

Types of Soil	Punjab	Sindh	Khyber Pukhtoonkha	Balochistan	Pakistan
Soils with surface/patchy salinity and sodicity					
Irrigated	472.4	118.1	5.2	3.0	598.7
Un-irrigated	-	-	-	-	-
Gypsiferous saline/saline-sodic soils					
Irrigated	152.1	743.4	-	76.6	972.1
Un-irrigated	124.5	536.3	-	160.1	820.9
Porous saline sodic soils					
Irrigated	790.8	257.0	25.7	29.4	1102.9
Un-irrigated	501.0	150.1	7.8	364.0	1022.9
Dense saline sodic soils					
Irrigated	96.7	32.5	0.9	-	130.1
Un-irrigated	530.0	379.7	8.9	714.8	1633.4
Total	**2667.1**	**2217.1**	**48.5**	**1347.9**	**6281.0**

Source: S&R Directorate, SCARP Monitoring Organization, WAPDA Lahore, 2001-03

Table 11. Surface Salinity Status of Indus Basin (Percent of area surveyed)

Province/ Country	Survey Period	Salt free(S1)	Slightly Saline (S2)	Moderately Saline (S3)	Strongly Saline (S4)
Khyber Pukhtoonkha	2001-03	86	2	2	< 1
	1977-79	78	8	2	2
	1971-75	75	10	4	2
Punjab	2001-03	88	3	2	1
	1977-79	84	7	4	3
	1953-65	72	15	5	6
Sindh	2001-03	46	24	8	17
	1977-79	50	19	10	18
	1953-54	26	28	17	27
Balochistan	2001-03	67	15	9	7
	1977-79	74	17	5	4
	1953-54	69	15	7	9
Pakistan	2001-03	73	10	4	7
	1977-79	72	11	6	8
	1953-75	56	20	9	13

Table 11 shows soil profile salinity/sodicity status up to 1.5 m depth in Indus basin during various surveys. It can be depicted from the data that profile salinity also decreased in Pakistan as the salt free profile increased from 55 percent in 1962-65 to 61 percent in 1977-79 and remained unchanged in 2001-2003. However, profile salinity increased in 2001-03 as compared to 1977-79 in Sindh and Balochistan Provinces. The reduction in surface profile salinity is primarily due to increased irrigation water supply from surface and ground water sources, better water management, increased cropping intensity and measures taken by Government of Pakistan to reclaim the waterlogged and salt affected lands.

Table 12. Soil Profile Salinity/Sodicity Status up to 1.5m Depth in Indus Basin (% of Profiles)

Province/ Country	Survey Period	Total Profiles	Non-Saline Non-Sodic	Saline	Saline Sodic	Non-Saline Sodic
Khyber Pukhtoonkha	2001-03	1253	83	9	6	2
	1977-79	1958	79	11	7	2
	1971-75	314	27	50	23	-
Punjab	2001-03	17294	68	6	16	10
	1977-79	39963	73	7	14	5
	1962-65	23662	55	6	27	11
Sindh	2001-03	5978	36	17	44	3
	1977-79	20543	38	17	42	2
Balochistan	2001-03	205	39	20	36	5
	1977-79	1402	35	26	38	1
Total	2001-03	24760	61	9	22	8
	1977-79	63866	61	11	24	3
	1962-65	23976	55	6	27	11

Source: Pakistan National Commission of ICID, 1991 and SCARPs Monitoring Organization (unpublished)

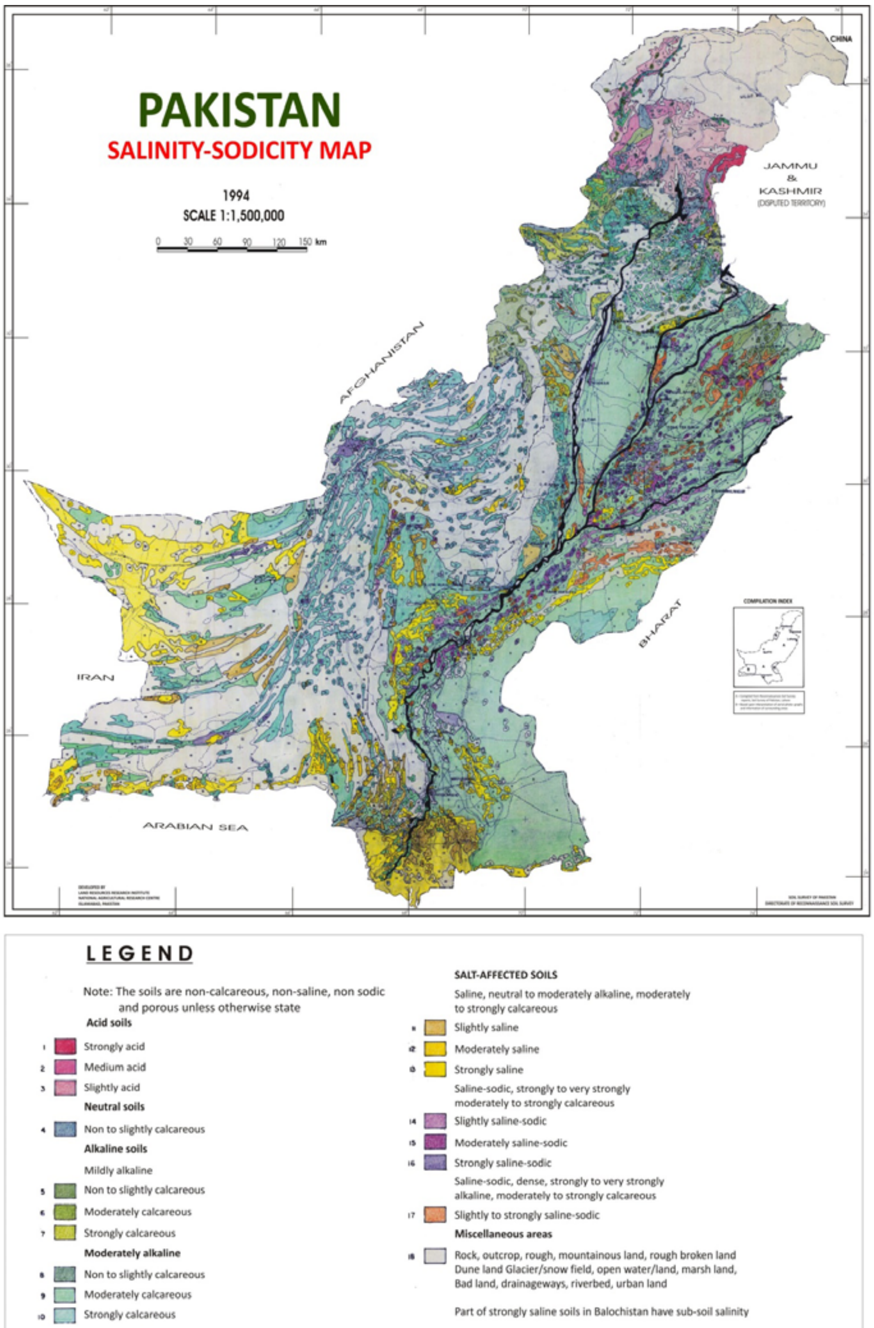
Types of saline and sodic soils

The saline and saline-sodic soils that occur can be classified on the basis of age, the nature of salinity/sodicity, the severity of the problem and the ease/economics of reclamation. The following general groupings have been adopted for easy understanding:

Soils with surface/patchy salinity and sodicity

These commonly occur in the form of scattered patches within cultivated fields. They are products of an incomplete natural process of salinization and sodification, which normally begins in small patches, occupying slightly higher, indistinctly convex shapes- these serve as shedding sites for scanty rainwater. The rainwater is absorbed by the adjoining lower areas, dissolving salts from the soil in its downward and lateral movement; the water rises through capillary action and evaporates from the convex sites, leaving behind a salt residue on the surface. This salinity is of relatively recent origin. While in some parts, this process has been reversed through reclamation efforts and intensive agricultural use, in other parts it has been accelerated through inadequate watering and a rising water-table after the introduction of the canal irrigation system.

The salinity/sodicity effect on most of these soils is restricted to the top 10-30 cm, while the subsoil is still non-saline. Although a significant portion of such saline soils do not have sodicity problems, for practical purposes all saline patches may be regarded as affected by both salinity and sodicity. The reclamation of these soils is relatively easy and does not, in most cases, require a drainage system. In some areas generally recognized as slick spots, salinity has affected soils to a greater (more than 1 meter) depth.



These soils require about 3-4 tons of gypsum per hectare for their effective reclamation. Soils with surface/patchy salinity and sodicity include those which have been misused by people. Such soils are commonly encountered in the SCARP areas and in some areas irrigated by low-quality tube well water. Many SCARP and private tube wells pump water with high electrical conductivity (EC), SAR or RSC values. Water with high EC value is used limitedly, as the emergence of salts on the soil surface alerts the farmer to the possible salinization of land.

What is more damaging and less apparent is the use of water with high SAR/RSC but low EC values, which is quite extensive. Salinity is not generally visible on the surface of soils irrigated by such water. But their use greatly favors the sodification process and results in the gradual deterioration of the soil structure, decreased soil permeability, and increased soil pH and exchangeable sodium percentage (ESP), which may reach alarming degrees and severely affect the growth of crops. Such deteriorated soils generally have a 2-3 mm thick, highly alkaline (sodic) crust on their surface, which severely hampers seed germination. The rehabilitation of these soils essentially requires the use of amendments i.e., 2-3 tons of gypsum per hectare.

Gypsiferous saline/saline-sodic soils

Soils included under this type are severely saline throughout their profile, generally have a 1-2cm-thick salt layer on the surface, mixed with some gypsum in powder or crystal form. These soils occur mainly in the central and southern parts of the Indus plains as uncultivated patches with moist surfaces. They are old soils formed under an arid climate on levees affected by water seepage from adjoining old streams and in basins collecting saline run-off. They contain adequate amounts of hygroscopic salts and therefore, remain moist for most of the year, except for those occurring in very dry areas (e.g. the Cholistan Desert). A small part of the area under these soils has recently been brought under irrigated cultivation resulting in their partial reclamation.

Porous saline-sodic soils

These soils occur mostly as large uncultivated patches with a sparse cover of natural grasses, shrubs and stunted trees. They are typical of a semi-arid climate, being formed mainly on levees affected by seepage from adjoining old streams or fluctuating past water tables in adjoining, relatively low areas. The salinization process is quite advanced so that the whole soil profile (to more than 150 cm depth) is affected by salinity and sodicity. Some of these soils have been brought under irrigated agriculture and support a few crops, mainly rice and wheat, that give moderate to low yields. These soils are sufficiently porous to be moderately to slowly permeable. They cannot be effectively reclaimed unless about 10-12tons of gypsum per hectare (or an equivalent amount of some other amendment) are added.

Dense saline-sodic soils

These soils have undergone severe sodication after salinization, which has caused structural instability and reduced water permeability. They are mostly formed in basins which have remained relatively moist due to run-off collection or intermittent flooding, a condition favoring the sodication process. These soils mostly occur in the form of large, uncultivated patches with almost no vegetation cover. Efforts have been made to bring a few of these areas under irrigated cultivation but they can support only rice and wheat, which give very low yields. Reclamation of these soils is extremely and saline agriculture approach is applied on these soils.

Methods of reclamation of salt affected lands

Saline soils: Reclamation is the easiest, least time consuming and the most economical of the three categories of salt affected soils. There are two site specific procedures which have been used for reclaiming saline soils in Pakistan. These are (i) leaching soluble salts with heavy irrigation and (ii) biological reduction of salts.

Reclamation of saline soil by leaching: The prevalent method of reclaiming saline soils in the Indus Plains consists of flooding and leaching soils without the use of any chemical amendments. Only soluble salts are leached with water to deeper soil layers. The quantity of water required to remove soluble salts depends primarily on the initial soil EC, the techniques of applying water, and the soil types as well as depth to be reclaimed. Although cropping is a common practice during reclamation process, only few crops can tolerate high EC, particularly during early stages of crop growth. Thus 2-3 irrigation before planting crops is advisable if EC is high in the upper layer.

Ground water if not deep should not rise beyond the critical depth. If the ground water table moves down freely to a considerable depth the chance of re-salinization is reduced. If ground water is shallow, the zone of salt accumulation does not move downward rather lead to formation of saline water logged soils. Kovda, 1961 proposed an equation, $Y = 170+8T\pm 15$, to estimate a safe ground water table where Y is the depth in cm of ground water table, T is mean annual temperature in ^{o}C. Considering 25 ^{o}C as mean annual temperature, a safe water table depth comes to 370 ± 15cm.

The above discussion indicates that the intermittent leaching method removed 75.23% of salts down from the top 0-60 cm soil depth, whereas the continuous leaching method removed only 64.01%. The main reason for the observed differences is due to the fact that the intermittent leaching method allows extra time for salts held in micropores to diffuse and then leached down with flowing water. This suggests that intermittent leaching method is more effective than that of continuous leaching method when leaching is carried out for more time. The statistical analysis of data showed highly significant ($p < 0.01$) decrease in EC of soil saturation extract of all plots after five months of the leaching (Tagar, *et. al.*, 2010).

Reclamation of saline soil through biological reduction of salts: Saline soil can be reclaimed by biologically reducing salts wherever possible. This method is suitable only for the bordering the desert which is frequented by dust storms. The best indication for the success of this method is to observe whether or not the vegetation in the particular area forms sand dunes. In the area where sand dune formation occurs, the blown soil apart from improving the texture and reducing salt concentration. In areas which are not under the influence of dust storms, reclamation of saline soil occur to a smaller extent through the removal of aerial part only for the local flora. Chaudri, *et. al.*, 1964 estimated about one tone acre^{-1} year^{-1}salt removal by a single harvest of aerial parts of shrubby seablite , (local name Lani) (*Suaeda fruiticosa)* (2668 kg ha^{-1}) in fall.

Management of coastal and deltaic saline soils: Management of these soils centers on preventing the ingress of sea water intrusion through high tides and back flow into the rivers and estuaries. High and structurally stable earthen dykes should be built to prevent the entry of sea water into the cropped area. In addition to this, back flow of sea water during off rainy season in the Indus river should be controlled with the help of flap gates in such a way that it does not salinize the ground water and raise the salinity of the soil. In these areas, ground water should be exploited carefully and only the good quality rain water should be skimmed from the shallow well. Over-exploitation of ground water will encourage ingress of sea water through the subsoil and result in salinization of the area.

Saline-sodic soils:

Saline-sodic soils are diverse in nature. These soils vary in horizon thickness and structure, EC and SAR levels, pH, texture, and clay mineralogy. Because of the differences in their chemical and physical properties and geographical as well as geochemical distribution, a suitable method of their reclamation is different. Such soils have been reclaimed by a number of methods in different parts of the world including Pakistan.

Reclamation of saline-sodic soil by chemical amendments: Chemical amendments used for reclamation of these soils are soluble Ca^{2+} salts like mind gypsum ($CaSO_4.2H_2O$), CaCl2 and phosphogypsum. Common examples of amendments those mobilize Ca^{2+} in calcareous soils by converting native $CaCO_3$ to more soluble $CaSO_4$, $Ca(HCO_3)$, Ca $(NO_3)_2$ or $CaCl_2$ include H_2SO_4, HCl, HNO_3 and S. Other amendments and by-products of certain industries, like press mud and molasses meal from sugar industry has been found effective but their extensive use is limited and localized. Addition of organic matter (farm manure, slaughter house waste, poultry excreta, green manure, vegetable/fruit market waste) alone is also used to reclaim these soils but at a slow rate. Some chemical fertilizers have also been tried to supply soluble calcium directly from $Ca(NO_3)_2$ and single superphosphate) or indirectly by producing physiological acidity within zone of their application [$(NH_4)_2SO_4$ and urea]. Application of such fertilizer at recommended dose cannot be expected to reduce the soil sodicity considerably (Hussain and Mian, 1983).

Chemical amendments: The choice of an amendment at any place depends upon its relative effectiveness as judged from improvement of soil properties and crop growth, its availability, cost, handling and application difficulties and the time required to react in the soil and to replace the adsorbed Na+. However, nature of the sodic soil is overriding factor. Amendments have shown different level of effectiveness in reclaiming sodic and saline-sodic soils (Table 13). Acids (H_2SO_4, HCl and HNO_3) were found efficient in decreasing SAR than that with gypsum when applied to a calcareous saline-sodic clay loam soil under laboratory conditions. Their application equivalent to 75% gypsum proved similar to gypsum @ 100 % GR (Ghafoor and Muhammad, 1981).

Better paddy yield was obtained from a calcareous saline-sodic field (EC 6.6dS/m, SAR 70.5) with HCl than gypsum when both the amendments were applied at equivalent rate (Ahmad et. al, 1986). After two years of studies on a moderately saline sodic soil (EC 4.2 -8.2 dS/m, ESP 20-48), Shad and Hashmi, 1970 found the ameliorative effect in the order: Gypsum> H_2SO_4> S> Press mud> manure. Similarly superiority of gypsum over other amendments (H_2SO_4, HCl and $CaCl_2$) noted during the reclamation of a calcareous saline-sodic sub-soiled sandy clay loam field (EC 13.9 dS/m; SAR 119.8) by Ghafoor, *et. al.*, 1986.

Table 13. Reclamation of saline-sodic soils as affected by different amendments

Amendment	Rate %GR	Soil Texture	Crop	Duration (years)	Decrease over control %		Source
Gypsum	100	SiL	R-W	2	48	76	Zaidi, et. al,1968
Gypsum	100	SCL	R-W	3	81	79	Ghafoor, et. al, 1985a
Gypsum	100	SCL	R-W	3	74	80	Ghafoor, et. al, 1985b
H_2SO_4	75	SCL	R-W	1	56	74	Ghafoor, et. al, 1986
HCl	75	SCL	R-W	1	55	68	Ghafoor, et. al, 1986
$CaCl_2$	75	SCL	R-W	1	65	75	Ghafoor, et. al, 1986
Gypsum	50	SiCL	KG	2	85	80	Hamid, et. al, 1990
Manure	25	SCL	R-W	3	52	60	Qadir, et. al, 1998a
Gypsum	100	SCL	R-W	3	61	58	Qadir, et. al, 1998a

Conjunctive use of amendments: An amendment when applied in combination with some other amendment(s) may expedite some improvement. In a laboratory experiment, a number of amendments and their combinations were used for the reclamation of loam and clay loam saline-sodic soils. The reclamation efficiency of the amendments was found in the order: S + manure> gypsum + manure> S > gypsum> press mud + manure> manure> press mud> simple leaching (Muhammed and Khaliq, 1975). Field experiments on a saline-sodic soil (EC_e= 4.8-10.0 dS m^{-1}, SAR = 41.8-105·.2) involving the application of gypsum, sulphur, manure and press mud alone and in various combinations indicated the superiority of combined application of amendments in terms of speedy reclamation. Gypsum @ 100 % GR + manure @ 50 t ha^{-1} were the best combination. Although combination of amendments was more efficient yet it was less economical compared to gypsum @ 50 % GR + manure @ 50 t ha^{-1} (Chaudhry *et. al.*, 1982). Similar observations were obtained in another field experiment where several amendments were used for the reclamation of a fine-textured saline-sodic soil. The best combination comprised manure with gypsum @ 50 % GR that increased the soil infiltration rate from 0.5 to 11.2 cm day^{-1} after 4 years (Hussain, *et. al.*, 1988).

Particle-size of amendments: Effect of particle size of gypsum powder is crucial regarding its dissolution to supply Ca^{2+}. In lysimeter experiments, gypsum grades ranging 5 to 100 meshes were applied @ 100 % soil gypsum requirement (SGR) to saline-sodic soil columns. There was greater reduction in EC_e and SAR with increasing gypsum fineness (Rashid, *et. al.*, 1986; Ghafoor, *et. al.*, 1989). A sharp initial increase followed by a sudden decline in the hydraulic conductivity of soil was observed with finer grades of gypsum. With coarser grades, hydraulic conductivity was lower but a more steady-state persisted. The possibility of $CaCO_3$ formation as well as mechanical plugging of soil pores with finer gypsum particles was responsible for sudden decline in hydraulic conductivity of the soil (Haq, 1984). Coarser gypsum gave lower initial electrolyte concentration which was maintained or increased with time. It is better to use a mixture of particles, with a 2 mm upper limit, to obtain the dual benefit of initial rapid dissolution of fine gypsum followed by a sustained release of Ca^{2+} from coarser particles. In a lysimeter experiment, Ghafoor and Salam, 1993 found Ca^{2+} concentration of 6-8 $mmol_c$ L^{-1} in irrigation water (a level commonly achieved with soil-applied gypsum) as the most efficient to promote Na^+- Ca^{2+} exchange to reclaim a number of saline-sodic soils (CEC =8- 1 2 $cmol_c$ kg^{-1}) in a reasonable period of time.

The review on choice of amendment(s), their conjunctive use, methods of application, and gypsum particle size indicates that a bit inconsistent results have been reported from time to time on the effectiveness of various amendments for the reclamation of sodic/saline-sodic soils. Generally, gypsum and H_2S0_4 were found the most effective reclamant. Because of low price and freight, general availability and easy application, gypsum is the most commonly used and highly cost-effective Ca^{2+} source for reclaiming both the calcareous and non-calcareous sodic/saline-sodic soils.

Bio-saline approach: The term "biological reclamation" is used to describe the reclamation of a salt-affected soil by growing salt tolerant or salt resistant crops. The below-ground parts (roots) can modify conditions at root-soil interface (rhizosphere) in many ways. Roots can decrease soil pH (Kumar and Abrol, 1984; Qadir, *et. al.*, 1996b), lower oxygen concentration, release organic compounds and complex energy sources such as exudates, secretions, and mucilages (Dormaar, 1988), increase CO_2 partial pressure (Robbins, 1986), upon decay provide channels for soil solution movement (Elkins, 1985), increase microbial activity and influence numerous physical and chemical properties (Hamid, et. al, 1990; Ahmad, *et. al.*, 1990; Qadir, *et. al.*, 1996c; Ilyas, *et. al.*, 1997). The above-ground plant parts provide shade to soil, lower soil temperature, have a mulching effect, decrease evaporation from soil surface and thus check upward movement of salts through capillaries (Sandhu and Qureshi, 1986; Ahmad, *et. al.*, 1990; Qadir, *et. al.*, 1996b). After harvest of crops, the remains of the below-ground parts (large and small roots, rhizomes) plus the plant litter all add organic matter to soils.

Plants growing in saline/sodic environment may face certain limitations for biomass production. A judicious selection of plant species capable to yield under inhospitable soil conditions during reclamation of sodic/saline-sodic soils is vital (Qadir, *et. al.*, 1996c). The effectiveness of plant species in soil reclamation is highly variable (Ahmad, *et. al.*, 1990) because of differences in their tolerance to soil EC, SAR and irrigation requirement. Generally, high water-requirement crops get the benefit of salt dilution, while salt tolerant crops enjoy the facility of their natural as well as adaptive mechanisms of salt tolerance in a saline and/or sodic soil environment.

Effect of plants on soil properties: Plants influence physical and chemical characteristics of soils. After growing Kallargrass *(Leptoehloa fusca)* for four consecutive years in a highly saline-sodic clay loam field (pH, = 10.3, EC_c= 20.2 dSm^{-1}, SAR = 170, ESP = 71) a marked decrease in soil pH, EC and SAR was observed (Akhtar, *et. al.*, 1988). In another experiment, Kallar grass, sesbania*(Sesbania aculeata),* swank *(Eehinoehloa colona)* and mandal *(Eluesinee oraeana)* were planted on a calcareous saline-sodic field (EC_c= 8.9-9.4 dS m^{-1}, SAR = 54.8-61.2). The effectiveness of these species after one season in terms of soil amelioration was in the order: sesbania>Kallargrass>swank>mandal, though SAR did not decrease below critical level of 13.2. Biomass production by the plant species was found directly proportional to their reclamation efficiency (Qadir, *et. al.*, 1996b).

Different crop rotations (Sesbania-barley, rice-wheat, and Kallar grass-alfalfa) were employed for reclaiming a strongly calcareous moderately saline-sodic silt loam soil. All the crop rotations reclaimed the soil after one year. The leaching of salts by irrigation and rain waters, valence dilution, Na' uptake by plants, Ca^{2+}supplied in irrigation water, dissolution of soil lime under the action of root respiration and microbial activity were the factors considered responsible for ameliorating soil (Qadir, *et. al.*, 1992). Under dense saline-sodic conditions, considerable soil improvement was observed when sesbania-wheat-sesbania rotation was followed for one year (Ilyas, *et. al.*, 1997).

Choice of plant species for saline-sodic/sodic soils

Plants suitable to colonize salt-affected soils are important for stabilization and reclamation of the growth medium. The ability of some plant species to grow in a wide range of stress conditions could render them suitable. Some workers favored the inclusion of Kallar grass (Haq and Khan, 1971; Sandhu and Malik, 1975; Abdullah, 1985; Malik, *et. al.*, 1986; Qadir, *et. al.*, 1992) or sesbania (Ahmad, 1968; Ahmad, *et. al.*, 1990; Qadir, *et. al.*, 1996b) as the first crop to start reclamation of saline-sodic/sodic soils. Ahmad, *et. al.*, 1990 found greater leaching of salts from a calcareous saline-sodic field with sesbania and Kallar grass grown for two seasons. They attributed this effect to the deeper and extensive root system of the former species that improved soil porosity. Qureshi and Qadir,1992 ; Ghafoor, 2002b proposed inclusion of sesbania in a rice-wheat rotation on a dense saline-sodic soil to increase soil porosity.

Salt tolerant forage plant species generally performed better in calcareous saline-sodic/sodic soils than non-calcareous ones. In some experiments, salt tolerant crops resulted in soluble Ca^2+ in calcareous sodic soils to cause a considerable decrease in EC_e and SAR (Chaudhry and Abaidullah, 1988; Ahmad, *et. al.*, 1990; Qadir, *et. al.*, 1996b). Several salt tolerant forage species from the genera Atriplex, Malreana and *Echinochloa crusgalli* (Aslam, *et. al.*, 1987) have been found useful. However, their role in soil reclamation has yet to be studied. Some tree species like *Eucalyptus camaldlensis, Leucaena leucocephla* and *Tamarixa phyla* were found suitable for utilization of salt-affected soils but with a little reclamation effect. Apart from producing a good amount of wood, these species reduced soil EC/SAR after 7 years (Qureshi, *et. al.*, 1993).

Chemical vs. **biological reclamation of saline-sodic/ sodic soils:** The initial investment to purchase chemical amendments has focused the attention of scientists towards the economic utilization of saline-sodic/sodic soils by growing certain salt tolerant forage plants with national level reservations that up to what extent soil could be taken out of food crops. Research work on the comparative efficiency of chemical and biological methods for soil reclamation is limited, particularly under field conditions. During a lysimeter experiment, gypsum @ 100 % SGR reclaimed two saline-sodic soils (pHs= 8.4 and 8.1, EC_e= 48 and 39, ESP = 62 and 53) in much shorter time than the biological method (growing of Kallar grass) and the control (Kausar and Muhammed, 1972). However, in this study, there were some problems of growing Kallar grass a bit out of season. In another lysimeter experiment, a saline-sodic sandy clay loam soil (pHs= 9.1, EC_c = 9.8 dS m^{-1}, SAR = 103, $CaC0_3$= 9.4 %, CEC = 122 $cmol_ckg^{-1}$) was subjected to reclamation. Four treatments, one cropped (Kallar grass) and three non-cropped (control, gypsum @ 50 %, 100 % GR) were leached with four leaching cycles using canal water (EC = 0.28 dS m^{-1}, SAR = 0.8) at different time intervals. Two leaching cycles were completed during the peak growth of Kallar grass (summer) and the remaining two were completed during winter when its growth was very slow. The 100 % SGR treatment removed the greatest amount of soluble salts including Na^+ from the soil columns. Kallar grass removed more Na^+ during summer than that during winter. Effectiveness of the treatments for soil reclamation was found in the order: 100 % GR >Kallar grass>50 % GR >control (Qadir, et. al, 1996b). Ilyas, et. al, 1997 compared perennial alfalfa, sesbania-wheat-sesbania rotation, incorporated wheat straw @ 7.5 Mg ha-^{1}, and a fallow (control) on a slowly permeable saline-sodic field (pHs= 8.8, EC_c= 5.6 dS m^{-1}, SAR = 49). Each treatment was also combined with gypsum applied @ 75 % SGR of the upper 20 cm depth (25 Mg ha^{-1}). Combination of gypsum and crops was the best treatment.

Chemical and biological methods have been compared on cost benefit ratio in few experiments. From the results of an experiment on a slightly saline-sodic field (pHs= 8.6-8.7, EC_c= 5.3-6.6 dSm^{-1}, SAR = 16.3-17.4), Chaudhry and Abaidullah,1988 placed the treatments for profitability in the order: Kallar grass>gypsum @ 50 % SGR + rice-wheat>sesbania (green manure)-barley. All the treatments had completely reclaimed the soil up to 30 cm depth within a period of two years. Muhammed, et. al, 1990 compared biological (rice-wheat rotation), physical + biological (sub soiling + rice-wheat rotation), chemical + biological (gypsum @ 100 % GR + rice-wheat rotation), and chemical + physical + biological (gypsum + sub soiling + rice-wheat rotation) methods for the reclamation of two saline-sodic soils (Typic Halorthids and Halic Camborthids). Combination of gypsum + crops was the best for economical soil reclamation. In another study, the budget of a private farmer raising buffaloes on Kallar grass was found to be economically viable by Sandhu and Qureshi, 1986. The area under grass was 40 ha with 100 buffaloes. They calculated a net income of Rs. 2000 per ha under grass. However, efficiency of grass and its comparison with some chemical amendments for the economic reclamation was investigated.

Table 14. Reclamation of saline-sodic soil through chemical and biological mean

Plant species/ Amendment	Soil texture	Duration	Decrease over Initial level (%)		Source
			ECe	SAR	
Kallar Grass	SCL	225 days	0	67	Kausar and Muhammed, 1972
Gypsum (100% SGR)	CL	79 days	94	91	Kausar and Muhammed, 1972
Gypsum (50% SGR)	SCL	3 years	63	58	Chaudhry and Abaidullah, 1988
Sesbania-barley	SCL	3 years	48	51	Chaudhry and Abaidullah, 1988
Kallar grass	SCL	3 years	26	24	Chaudhry and Abaidullah, 1988
Gypsum (100% SGR)	SiL	3 years	24	66	Ahmad, et. al, 1990
Sordan	SiL	15 month	23	36	Ahmad, et. al,1990
Gypsum (50% SGR)	SCL	15 month	60	77	Qadir, et. al, 1996a
Gypsum (100% SGR)	CL	16 month	83	86	Qadir, et. al, 1996a
Gypsum (100% SGR)	CL	16 month	18	4	Qadir, et. al, 1996b
Sesbania	CL	5 month	39	40	Qadir, et. al, 1996b
Kallar grass	SCL	5 month	31	34	Qadir, et. al, 1996b
Swank	SCL	5 month	26	25	Qadir, et. al, 1996b
Mandal	SCL	5 month	10	18	Qadir, et. al, 1996b
Gypsum (75% SGR)	CL	1 year	23	39	Ilyas, et. al, 1997
Alfalfa	CL	1 year	25	63	Ilyas, et. al, 1997
S-wheat-S	L	1 year	25	57	Ilyas, et. al, 1997

Reclamation of saline-sodic/sodic soils by physical methods: Physical methods of soil reclamation include deep ploughing, sub-soiling, sanding, hauling and horizon mixing. These techniques aim at increasing soil permeability directly by mixing fine and coarse textured layers. Deep ploughing consists of ploughing to a depth from about 40 to 150 cm and is beneficial for stratified soils having impermeable layers to speed up soil reclamation, particularly if the subsoil is gypsiferous. Sub-soiling consists of pulling vertical strips through soil to shatter compact layer to improve soil permeability. Beneficial effects of sub soiling may continue for several years if the lime layer is broken, otherwise might persist only for a single crop season. Among the physical methods, sub soiling (50 ± 5 cm crosswise furrows 120-150 cm apart) with rice-wheat crop rotation successfully reclaimed two calcareous saline-sodic soil series (Khurrianwala- Typic Halorthids; Gandhra- Halic Camborthids) within a period of three years. It was concluded that only sub soiling of some medium textured soils, like the Khurrianwala series, may produce a good crop of rice (Ghafoor, 1984; Muhammed and Ghafoor, 1986).

Data presented in Table3. 6 showed that the grain yield significantly increased with all the soil treatments over control crop yield of 2495 kg ha^{-1}. This yield increase ranged from 21.64 to 59.87% with different soil treatments. The highest yield increase of 59.87 % was recorded in the treatment of deep tillage + 100% gypsum application showing significant increase than all other inputs applied alone. This yield increase might be attributed to increase in grains $spike^{-1}$ and 1000 grains weight with soil treatments. These results are in line with the findings of Wasif, et. al, 1995, Rashid and Majid, 1983 and Haq, et. al, 2007. The findings of this study revealed that deep tillage can improve the efficiency of gypsum application in terms of combating salts effects on plants growth and increased crop production. Thus it can be concluded that combined application of deep tillage + 100 % gypsum can be recommended to end users for adoption to achieve production potential of wheat in salt affected soil of Pakistan.

Table 15. Grain yield data of wheat affected by soil amendments during 2007-08

Treatment	Grain yield (kg ha^{-1})	% increase over control
T1 Control	2495	-
T2 Deep tillage	3035	21.64
T3 100% GR application 3515	3515	40.88
T4 Deep tillage+ 100% GR	3989	59.57
T5 Acid application	3183	27.57
LSD (0.005)	146	

Reclamation of saline-sodic/sodic soils by high-salt water method: Like many other countries, Pakistan is also falling short of good-quality water for agriculture due to increased cropping intensity as well as more pressing demands of the non-agricultural sector (Mohtadullah, et. al, 1992; Ghafoor, et. al, 2002a). Most of the ground or drainage water is of poor quality (Ghafoor, et. al, 1991, 2002b; Ghafoor and Qadir, 1993). This fact suggests technology development and adoption for using poor quality water at or near source for crops and/or reclamation of salt-affected soils for vertical and horizontal production along with eliminating the environmental risks. Hydro-technical/high-salt water method initially makes use of high electrolyte concentration of water to improve soil permeability and subsequently the "valence-dilution" effect to favor the adsorption of divalent cations at the cost of mono-valents. In a soil-water system where soluble cations are in equilibrium with the solid phase, addition of water (dilution) favors the adsorption of Ca^{2+} at the cost of Na" while reverse is true when soil solution concentrates. Muhammed, et. al, (1969) reclaimed a sodic soil with successive dilutions of high-salt water.

Soil reclamation with amended brackish water: The ratio of divalent to total cations of water (mmol L^{-1}) should be at least 0.3 greater it is the lesser the depth of water for effective reclamation (Reeve and Doering, 1966). Some natural waters meet this ratio, but in many cases additional Ca^{2+} is required. Ca^{2+}can be introduced by placing gypsum stones in water channels or by soil applied gypsum in powder followed by leaching with high salt water .Improvements ratio have been found in the quality of brackish water after passing through gypsum stone-lined water courses (Hanif, et. al, 1975; Qureshi, et. al, 1975, Qureshi and Anjum, 1977; Ahmad, et. al, 1979; Hussain, et. al, 1986; Ghafoor, et. al, 1987) which are summarized in Table 3.8. Ahmad, et. al, 1979 passed a saline-sodic tube well water (TSS = 1600 ppm, SAR= 16) over baffled gypsum stones of 5 to 20 kg in water course. The dissolution rate of gypsum stones was proportional to the square root of the velocity of water, while the rate of increase in water EC was by the square root of the size of gypsum stone. In a field experiment, Ghafoor, et. al, (1987) irrigated a saline-sodic soil (pHs = 8.6-9.5, EC_e = 12.1-21.3 dSm^{-1}, SAR = 114.5-143.9) with a saline-sodic tube well water (EC = 1.6 dS m^{-1}, SAR= 10.2, RSC = 7.1 $mmol_cL^{-1}$ passed through a 183 m long water course lined with gypsum stones of 5 to 30 kg. The amended water was applied to 3 wheat and 2 rice crops on sub soiled and/or gypsum treated (@ 75 % SGR) soil. Reclamation efficiency was found in the order: sub soiling + gypsum> gypsum> sub soiling> control.

Table 16. Water Quality after passing through gypsum stone line water course

Un-amended water			Amended water			Source
EC dS m^{-1}	**SAR**	**RSC ($mmol_c L^{-1}$)**	**EC dS m^{-1}**	**SAR**	**RSC ($mmol_c L^{-1}$)**	
3.6	21.0	11.5	4.0	15.8	6.0	Qureshi, et. al, 1975
3.5	19.5	12.9	3.9	12.0	6.5	Qureshi and Anjum, 1977
1.7	9.3	7.1	1.2	6.0	4.0	Hussain, et. al, 1986
1.8	10.2	7.1	2.1	8.7	4.6	Ghafoor, et. al, 1987
1.2	14.4	5.0	1.6	6.8	00	Chaudhry, et. al, 1984

Use of untreated brackish water for soil reclamation: Studies have been carried out on amendment-applied saline-sodic soils followed by leaching with un-amended high-salt water by a number of workers (Haider and Hussain, 1976; Haq and Dabin, 1981; Ghafoor, et. al, 1985a, 1986a, b, 1997a, b, 2002b; Muhammed and Ghafoor, 1986; Bhatti, 1986; Muhammed, et. al, 1990; Qadir *et. al.*, 1996a, 1998a). Haider and Hussain, 1976 reported that press mud application to a saline-sodic soil followed by leaching with brackish water significantly reduced the soil SAR accompanied by an increase in soil infiltration rate. A considerable increase in wheat, cotton, sorghum, maize, alfalfa and clover yields was obtained from the press mud-treated soil irrigated with high-SAR water. Similarly, Haq and Dabin, 1981 found alfalfa green manure as a good soil amendment since soil infiltration increased as a result of Ca^{2+} release from $CaCO_3$ dissolution in response to CO_2 evolution during the decay process and countered the adverse effects of marginal quality irrigation water. In other laboratory experiments, Ghafoor, et. al, 1989 reclaimed a gypsum-treated (16-25 mesh @ 100 % SGR) saline-sodic loamy clay soil (pHs= 9.1, EC_c= 14.0 dS m^{-1}, SAR = 59) with brackish waters (EC = 0.6-4.0 dS m^{-1}, SAR = 6-30).

Table 17. Effect of un-treated brackish water irrigation on chemical properties of salt affected soils

Irrigation water			Soil Texture	Crop	Amendment	Decrease over initial level %		Source
EC	SAR	RSC				EC	SAR	
1.8	10	7.2	SiL	R-W	Gypsum	81	79	Ghafoor, 1984
1.8	10	7.2	SCL	R-W	Gypsum	74	80	Ghafoor, 1984
1.8	10	7.2	SCL	R-W		44	06	Ghafoor, *et. al.*, 1986b
1.8	10	7.2	SCL	R-W	Gypsum	63	79	Ghafoor, *et. al.*, 1986b
1.8	10	7.2	SCL	R-W	H2SO4	56	74	Ghafoor, *et. al.*, 1986b
1.8	10	7.2	SCL	R-W	HCl	55	68	Ghafoor, *et. al.*, 1986b
1.8	10	7.2	SCL	R-W	CaCl2	65	75	Ghafoor, *et. al.*, 1986b
4.0	1.6	-	SiL	-	-	46	69	Javaid, *et. al.*, 1993
3.2	15.7	7.3	SCL	R-W	-	40	45	Qadir, *et. al.*, 1998 a
3.2	15.7	7.3	SCL	R-W	Gypsum	61	58	Qadir, *et. al.*, 1998 a
3.2	15.7	7.3	SCL	R-W	H_2SO_4	39	38	Qadir, *et. al.*, 1998 a
3.2	15.7	7.3	SCL	R-W	Manure	52	60	Qadir, *et. al.*, 1998 a

SiL= Silt loam, SCL- Sandy clay loam, R-W = Rice-wheat, EC as dS m^{-1} and RSC as $mmol_c$ L^{-1}

The results of field studies have also shown promise regarding reclamation of amendment receiving saline-sodic soils using brackish water irrigation. A saline-sodic water (EC= 1.8 dSm^{-1}, SAR = 10.0, RSC = 7.2 $mmol_c\ L^{-1}$) was applied to a calcareous saline-sodic sandy clay loam soil (pHs = 8.9, EC_c = 13.9 dS m^{-I}, SAR = 120) treated with gypsum, HCl, $CaCl_2$ or H_2S0_4, The amendments except gypsum were applied equivalent to 75 % SGR of the soil. Gypsum was applied at two rates (75 and 100 % SGR). The 100 % SGR treatment caused maximum decrease in soil EC and SAR and produced better rice and wheat yields than other treatments (Ghafoor, et. al, 1986b). A saline-sodic silt loam field (EC_e= 16.8 dS m^{-1} SAR = 16.5) was irrigated for three years with a saline tube well water (EC = 4.0 dS m^{-1}, Ca^{2+}= 33.5 $mmol_c\ L^1$, SAR= 1.6). Four heavy irrigations each of 12.5 cm were applied before planting alfalfa and Kallar grass. The high Ca^{2+} water, under both the crops, was able to decrease soil EC and SAR below the critical limits of 4 dS m^l and 13, respectively (Javaid, et. al, 1993). An effort was made by using tile drain water (EC = 2.9-3.4 dS m^{-1}, SAR= 12.0-19.4, RSC = 4.6-10.0 $mmol_c\ L^{-1}$) to irrigate rice and wheat crops on a saline-sodic field (EC_e= 24.3-32.3 dS m^{-1},SAR = 56.6-77.5). The overall treatment effectiveness to decrease the EC_e and SAR of soil after 3 years was in the decreasing order of gypsum> farm manure> sulfuric acid> tile drain water (Qadir, et. al, 1998a). In studies (Ghafoor, 2002b, 2003) at different locations of Punjab, it has been observed that brackish waters reclaimed a number of saline-sodic soils receiving gypsum @ 50 % SGR applied in two equal splits to the first rice and following wheat crops. In these studies, it was also observed that application of gypsum @ WRSC reclaimed saline-sodic soils. However, it is yet to be concluded that when the next gypsum application will be required if brackish water irrigation is continued after reclamation of soils for sustainable crop production.

Using brackish water with different Ca^{2+}:Mg^{2+} ratios: Ground water in the Indus Plain, Punjab in particular, in addition to high EC and SAR, also contains Mg^{2+}> Ca^{2+}. Irrigation with high Mg^{2+} water has shown increased dispersion/crusting and decreased hydraulic conductivity of normal productive soils (Khan, 1975; Chaudhry, et. al, 1986). In pot experiments with leaching provision, synthetic brackish water (EC = 2 dS m^{-1}, SAR= 12, RSC = 3 $mmol_c\ L^{-1}$) with Ca^{2+} : Mg^{2+} ratios of 4: 1, 2: 1, 1:1, 1:4, and 1:6, were applied to a calcareous saline-sodic sandy loam soil (pHs = 8.6, EC_e = 21 dS m^{-1}, SAR = 183) receiving uniform rate of Ca-sources to grow wheat and rice crops while canal water (Ca^{2+} level same as in brackish water) served as the control. Soil reclamation was found maximum with canal water while there was less but almost similar soil improvement with the brackish water treatments. This indicated a feasibility of using brackish waters with Ca^{2+}: Mg^{2+} ratios of 4: 1 to 1:6 during reclamation of coarse textured saline-sodic soils. Wheat yield was not affected by the applied treatments while paddy yield decreased significantly with a decrease in Ca^{2+}:Mg^{2+}ratio in the applied brackish water (Ghafoor, et. al, 1990, 1991). In another experiment, synthetic brackish water of similar composition, with Ca^{2+}:

Mg^{2+}ratios of 1:4 and 1 :6, was applied to the same soil and crops in the presence of soil-applied phosphogypsum (50 or 100 % GR) or farm yard manure (5 or 50 t ha^{-1}). Soil reclamation was found more with phosphogypsum than that with farm yard manure. Application of phosphor-gypsum at both the rates and with both the Ca^{2+}:Mg^{2+}ratio waters countered the adverse effects of Mg^{2+} in water better than farm yard manure. High Mg^{2+} irrigation water without soil-applied amendments adversely affected growth components of both the crops (Ghafoor, et. al, 1992a, 1992b). Most of the native ground waters have Ca^{2+}:Mg^{2+} ratios less than 1:6. These waters can be extensively used on gypsum-treated soils for reclamation to save canal water for good soils.

Reclamation of hard saline-sodic/sodic soils by horizontal flushing: Water percolates in fine-textured soils mostly through pores having diameter> 0.1 mm. These soils contain more total pore space but have fewer macro-pores than the coarse-textured soils. Soil solution in micro-pores remains largely immobile under steady-state flow conditions, since the micro-pores do not take much part in water conduction. The traditional reclamation scheme "gypsum application followed by irrigation" is less effective to reclaim such soils (Rafiq, 1975; Qureshi, *et. al.*, 1992; Ahmad and Qadir, 1995). A technique involved mixing of gypsum with soil in standing water with cultivator followed by horizontal flushing of the standing water to a nearby drain and a second flushing after 12 h (G FF) followed by a rice-wheat crop rotation. The technique proved better than the conventional practice of gypsum + vertical leaching (GVL) for rice yield but treatment differences for wheat yield and soil reclamation was not so prominent. In another field study (Qadir, *et. al.*, 1998b), the GFF technique was modified by applying gypsum in between the two water flushing (FGF) and it was compared to the above mentioned treatments with GVL and GFF or without gypsum (VL and FF). The FGF treatment remained better for both soil EC/SAR amelioration and crops (Table 18). However, enough land slope and a nearby drain are pre-requisites which make the approach site-specific.

Table 18. Reclamation treatment effect on salinity and sodicity of the 0-15 cm soil depth.

Treatment	Before treatment	Post Flushing I	Post Flushing II	Post rice	Post wheat
ECe (dS m^{-1})					
Vertical leaching (VL)	8.8	8.9 b	8.7 b	8.5 b	8.3 a
Two horizontal flushing (FF)	9.1	8.5 c	8.1 c	7.4 c	7.2 b
Gypsum +VL (GVL)	9.2	10.0 a	9.7 a	9.0 a	8.6 a
Gypsum +FF (GFF)	8.9	9.2 b	8.5 b	7.8 c	7.4 b
Gypsum between flushing (FGF)	9.3	8.2 c	8.3 bc	6.6 d	5.9 c
SAR					
Vertical leaching (VL)	54.3	53.4a	50.1 a	47.1 a	51.3 a
Two horizontal flushing (FF)	53.6	46.6 b	41.8 b	40.9 b	39.4 b
Gypsum +VL (GVL)	48.2	43.7 b	36.7 c	33.33 c	31.6 c
Gypsum +FF (GFF)	49.9	36.1 c	29.9 d	23.7 d	21.3 d
Gypsum between flushing (FGF)	56.0	44.2 b	24.6 e	16.5 e	12.5 e

(Qadir, *et. al.*, 1998b)

Engineering Approach

The engineering approach assumes that salinity in irrigated areas can be reversed using drainage schemes that lower water tables. Over 7.8 million hectares have so for been treated through Salinity Control and Reclamation Project (SCARPs) in Pakistan. Measures taken for combating waterlogging and salinity in Pakistan were very helpful for controlling waterlogging and its allied secondary salinization but still many salt-affected soils are not treatable and the sustainability of the approach for tackling the problem of salinity/sodicity is questionable. The International Commission on Irrigation and Drainage during 1991 has reported that the waterlogging has generally been controlled in the SCARPs but at the same time the effect has been found diminishing due to reduction in the pumping capacity of tube wells with time or non-operation of tube wells due to some reasons or use of excess surface supplies etc. Despite of all drainage efforts, waterlogging and salinity is not being controlled as envisaged during the planning of the projects. This is mainly due to availability of inadequate funds for the running and maintenance of these projects.

Best Management Practices in salt affected lands

Saline soil

Reclamation of saline soil is the easiest, least time consuming and most economical of the three categories of salt affected soils. Since saline soils contain excess soluble salts (EC_e>4 dS m^{-1}). Generally osmotic effects are the major cause of yield reduction or crop failure. There are three methods to reduce the salt contents of saline soil i.e. scraping, flushing and leaching. Methods commonly adopted to accomplish this include the following:

Picture 9. Layer of soluble salts after water evaporation can be seen on saline soil in Balochistan

Scraping and precision land leveling

Removing the salts those have accumulated on the soil surface by mechanical means has had only a limited success although many farmers have resorted to this procedure. Although this method might temporarily improve crop growth, the ultimate disposal of salts still poses a major problem. Precision land leveling is major step towards the management of saline soil and evenly irrigates the field. Government of Punjab took the task of precision land leveling through on-farm water management program and other development projects. Through this program millions of acres have been leveled using laser leveler developed by Pakistan Atomic Energy Commission. Farmers were provided with subsidy or the purchase of laser land leveler. This step is being considered utmost important among farming community regarding salinity control, irrigation management and improvement in crop productivity.

Picture 10. Precision land leveling activity in Balochistan Province

Flushing: Washing away the surface accumulated salts by flushing water over the surface is sometimes used to desalinize soils having surface salt crusts. Because the amount of salts that can be flushed from a soil is rather small, this method does not have much practical significance.

Leaching: This is by far the most effective procedure for removing salts from the root zone of soils. Leaching is most often accomplished by ponding fresh water on the soil surface and allowing it to infiltrate. Leaching is effective when the salty drainage water is discharged through subsurface drains that carry the leached salts out of the area under reclamation. Leaching may reduce salinity levels in the absence of artificial drains when there is sufficient natural drainage, i.e. the ponded water drains without raising the water table. Leaching should preferably be done when the soil moisture content is low and the groundwater table is deep. Leaching during the summer months is, as a rule, less effective because large quantities of water are lost by evaporation. The actual choice will however depend on the availability of water and other considerations.

The results of average ECe before and after leaching with continuous (CL) and intermittent leaching (IL) methods for five months are plotted in Figure 19. It is apparent from figure that the average ECe of the soil profile after five months of the experiment work with intermittent leaching (IL) method was remarkably decreased to 1.48 dS/m as compared to the continuous leaching (CL) method in which the ECe decreased to 2.16 dS/m.(Tagar, *et. al.*, 2010).

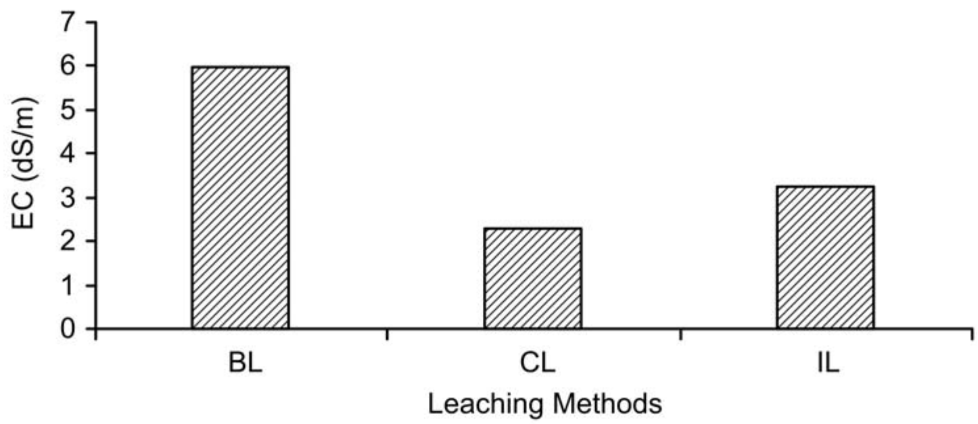


Figure 19. Comparison of electrical conductivity of soil saturation extract before and after two months of leaching with continuous (CL) and intermittent leaching (IL) methods.

The above discussion indicates that the intermittent leaching method removed 75.23% of salts down from the top 0-60 cm soil depth, whereas the continuous leaching method removed only 64.01%. The main reason for the observed differences is due to the fact that the intermittent leaching method allows extra time for salts held in micropores to diffuse and then leached down with flowing water. This suggests that intermittent leaching method is more effective than that of continuous leaching method when leaching is carried out for more time. The statistical analysis of data showed highly significant ($p < 0.01$) decrease in EC of soil saturation extract of all plots after five months of the leaching (Tagar, *et. al.*, 2010).

Choice of crop and cropping pattern: Cultivation of salinity tolerant crops helps reclamation of moderately saline soil in shorter time and could provide reasonable income. Phyto-extraction of salts by glycophytes is small (Qadir, et. al, 2003) hence leaching of salt remains the principal method of their reclamation. Inclusion of high water requirement crops in rotation proved better. Rice and sesbania crops are being grown for the purpose. This vegetative reclamation strategy is generally known as bio-remediation, phyto-remediation and biological reclamation. The principal contributing mechanisms include: (1). Enhanced CO_2 partial pressure in the root zone because of root and microbial respiration, which increase the solubility of calcite, and (2) improved soil physical properties due to root growth. Vegetative bioremediation provide financial benefits from the crops growth which help to support forming operations; to some extent bioremediation.

Use of aged seedlings. The mortality of seedlings in salt-affected soils can be substantially reduced if the seedlings are somewhat older (40-45 days) than normal when they are transplanted into the field (Akbar, *et. al.*, 1972).

High-density planting. Crop stands can be improved by planting four seedlings per hill in salt-affected soils, compared with two seedlings per hill, as usually recommended for non-saline soils (Aslam, *et. al.*, 1990).

Irrigation. Rice is least sensitive to salinity during germination and early vegetative growth and more sensitive during grain filling. If good quality irrigation water is in short supply, then the poor quality water should be used during establishment and vegetative growth when it will have the least damaging effects on the crop (Aslam, *et. al.*, 1993).

Alternate irrigation of canal and brackish ground water: brackish water irrigation followed by canal water irrigation helps in salt leach down efficiently away from root zone and hence good crop growth and reduction in soil ECe. Furthermore, avoiding brackish water application at sensitive crop growth stage also helps in more productivity.

Frequency of irrigation: If the crop depletes soil water and suffers water stress between irrigations. One obvious solution is to irrigate more frequently. More frequent irrigation could maintain better water availability and help decrease soil EC to which the crop is exposed. With regard to permeability, this strategy will also maintain a lower SAR, since dilution favors the adsorption of Ca^{2+} and Mg^{2+} over Na and losses of Ca^{2+} due to precipitation is reduced.

Age of nursery: Since younger plants are more sensitive and become better tolerant to salinity as ages, the relatively aged seedlings results in higher plant population and growth performance, e.g. rice has been found to yield better if the age of nursery is increased from 40-45 to 55-60 days.

Use of mulches: During germination and early growth stage, there is much unproductive evaporation leaving salts on soil surface to affect direct soil toxicity, osmotic effects and development of hard crust. Such adverse effects can be checked by providing mulch at the surface. Mulch materials include crop residues, plastic material and loose natural soil. Mulching also maintain proper temperature of soil during winter and indirectly could help expedite the germination.

Drainage: Mostly more water is applied to crops on saline soils to avoid salt stress to plants and salt buildup in soils. In order to counter such hazards, good drainage is essential to sustain the crop production and salt balance and to decrease the chances of oxygen stress.

Use of plant nutrients: Nutritional disorders can accentuate the yield losses imposed by osmotic effects. Shallow water table and poor aeration could limit root growth and their absorbing area and this way may restrict ability of roots to absorb nutrients in required amounts. It is also known that metabolism of absorbed nutrients is adversely affected. The harmful effects of moderate levels of EC can be alleviated by the judicious use of fertilizers. Specific effects of Cl and SO_4 can be minimized by proper application of P and N fertilizers. Many times, leaching losses could be high and necessitate application of fertilizers higher than the normal soils. In fact, lack of essential nutrients may be responsible for reduced yields in many saline soils. However, research is required to establish the nutrient requirements of crops in saline soils.

Continuous cropping: Under arid and semi-arid climates, saline soils should be kept under crops to alleviate the upward salt movement to accumulate at soils surface. If crop is not possible to grow, then soil must be ploughed frequently to break the capillaries through which soil solution moves.

Growing crops

The most important conventional food and cash crops cultivated on salt-affected soils in Pakistan are rice, wheat, cotton, and oilseed. These are cultivated on a total of 3.5 million hectares of land with patches of salinity covering about 20% or more of the area. Overall yields on such land are therefore determined by growth in the non-saline and saline parts of the field.

The salt-affected patches of such fields are usually highly saline-sodic, and impervious to water, and these conditions severely affect germination and growth of plants. Most of this type of salt-affected land is irrigated and is therefore regularly cultivated. The use of such land is of great concern and it has serious economic impacts at the national level. A simple answer to the problem of these lands is to develop salt-tolerant crop varieties that may outperform the currently prevalent varieties. However, cultural practices can also be modified to help the particular crops give higher yields in saline fields. Farmers are generally well informed about the agronomy of conventional crops and it is not necessary to repeat details of all these practices. Therefore, we discuss here only those aspects of the growth of rice, wheat and cotton that are expected to improve yield compared with the normal practice.

Rice

Picture 11. Rice varieties (SarShar, IRRI-8, KS-282 and Kanwal) being tested under saline condition in Nasirabad, Balochistan Province

Varieties

Rice is a moderately salt-tolerant species, although there are differences between cultivars. On moderately salt-affected soils, the cultivars KS-282 and NIAB-6 produce about 30-35% more paddy than ordinary varieties (Aslam, *et. al.*, 1993).

Wheat

Varieties selected for high salt tolerance do not always perform better than recommended varieties in salt affected soils. This is because the extent and degree of salinity varies a great deal under field conditions. Moreover, climatic factors and cultural practices also affect performance. Nevertheless, we expect that salt tolerant varieties will have 'an edge' over non-tolerant varieties under most saline field conditions. A lot of effort has gone into selecting salt-tolerant varieties of wheat by the Saline Agriculture Research Cell at the University of Agriculture Faisalabad. Selections that have performed well under field conditions include SARC-I, SARC-II, SARC-III and SARC-IV. Seeds of SARC-I has been multiplied and distributed among farmers within the area of the Joint Satiana Pilot Project. These farmers have generally reported favorably on its performance in salt-affected fields. A new line (234-1) has recently been identified as being highly water logging tolerant, but trials in farmers' fields are not yet complete.

Planting techniques

The choice of method for planting wheat depends on the soil texture and its permeability characteristics as detailed below. There were clear benefits of raised beds on the yield of wheat in an experiment on saline-sodic soil (ECe 8.3 dS m^{-1}, SAR 23, pH 8.9) loamy clay at Sadhoke. Wheat grown with conventional cultivation yielded 0.60 tons per hectare. However, wheat grown on 15· 30, 45 or 60 cm high beds had yields of 1.07, 1.06 and 1.20 tons per hectare (Qureshi and Aslam, 1988).

Freely draining soils. For freely draining soils, the land should be well prepared. Seed should be sown into almost dry soil, which is then heavily irrigated to leach salts into the subsoil. Subsequent irrigation is given soon after the crop has established (i.e. 7-15 days after germination). Nitrogen and phosphorus fertilizers should be applied at this stage.

Poorly drained soil. Soils that are clayey, low-lying, sodic and/or used for rice generally have drainage problems, and after irrigation or rain, water can stand on the soil surface for a long time, causing waterlogging. In this situation dry sowing is hazardous. Instead, the land should be prepared in the form of raised beds, about 75-100 cm wide, and 20-30 cm high, separated by irrigation channels. After a heavy irrigation and the addition of the first dose of the nitrogen and phosphorus fertilizers, the crop is sown in the beds in rows about 15 cm apart.

Cotton

Cotton is a relatively salt-tolerant crop. Furthermore, water logging can seriously affect its growth. Recently developed BT cotton varieties IR-1524, FH-113, Ali Akbar-802, Neelam-121 are performing well.

Planting and managing the crop

Cotton is a summer (kharif) crop. It should be planted on ridges or raised beds about 30 cm high and 75 cm wide. These beds should be 75 cm apart. The sequence of events in building these beds is as follows.

Cultivate the soil and then apply gypsum. Use a bedding plough to construct the furrows and raised beds. These beds will be 75 cm wide, alternating with irrigation furrows 75 cm wide. Plant seeds in rows on either side of the beds. Instead of evenly spacing the seeds, there is improved emergence of broad-leaved crops like cotton through crusting soils by planting three to four seeds in a clump, with about 15 cm between clumps. Seedlings in these clumps can then be thinned about 45 days after sowing when the plants are about 15-20 cm high.

Oil seeds

According to the international literature, rapeseed is moderately tolerant to salinity whereas sunflower is moderately sensitive to salinity. However the outcomes of pot experiments suggest that sunflower may have greater tolerance to salinity than rapeseed. In two experiments, the rapeseed cultivar Gobhi Sarsoon had a 50% decrease in growth at a salinity (ECw) of 12 dS m^{-1}. In contrast, the sunflower cultivar Shamas had a 50% decrease in growth at a salinity (ECw) of 19 dS m^{-1}. So sunflower can be successfully grown on salt affected lands as compared to rapeseed.

Grasses and tree species

Bio-saline agriculture was successfully demonstrated to restore the productivity of about 400 hectares of salt-affected lands by planting river red gum tree (*E. camaldulensis var. camaldulensis)*. and saltbushes (*Atriplex amnicola* and *Atriplex lentiformis*).

After growing Kallargrass *(Leptochloa fusca)* for four consecutive years in a highly saline-sodic clay loam field (pH, = 10.3, EC_c= 20.2 dSm^{-1}, SAR = 170, ESP = 71) a marked decrease in soil pH, EC and SAR was observed (Akhtar *et. al.*, 1988). In another experiment, Kallargrass, sesbania *(Sesbania aculeata),* swank *(Eehinoehloa colona)* and mandal *(Eluesineeo raeana)* were planted on a calcareous saline-sodic field (EC_c= 8.9-9.4 dS m^{-1}, SAR = 54.8-61.2). The effectiveness of these species after one season in terms of soil amelioration was in the order: sesbania>Kallargrass>swank>mandal, though SAR did not decrease below critical level of 13.2. Biomass production by the plant species was found directly proportional to their reclamation efficiency (Qadir, *et. al.*, 1996b).

Different crop rotations (Sesbania-barley, rice-wheat, and Kallar grass-alfalfa) were employed for reclaiming a strongly calcareous moderately saline-sodic silt loam soil. All the crop rotations reclaimed the soil after one year. The leaching of salts by irrigation and rain waters, valence dilution, Na^+ uptake by plants, Ca^{2+}supplied in irrigation water, dissolution of soil lime under the action of root respiration and microbial activity were the factors considered responsible for ameliorating soil (Qadir, *et. al.*, 1992).

Picture 12. Salt tolerant Trees for Fuel and Forage Production

Acacia ampliceps : In Pakistan, 2-year-old plants had 25 and 50% reductions in dry weight at 17 and 20 dS m^{-1} (calculated from the data of Ansari, et. al, 1994). In an adaptation trial on a saline site in Sind (ECe values of 5-40 dS m^{-1}), there was 77-98% survival after 2 years, but 3 months of flooding eliminated survivors in three provenances and caused substantial mortality in a fourth (Ansari, *et. al.*, 1994).

Acacia nilotica **(L.)**: In a trial in Sind, 80% of 2-year-old established plants survived a 3-month period of flooding (Ansari, *et. al.*, 1994). In longer-term field experiments near Faisalabad, it produced more wood per plant than Prosop is cineraria on a saline soil, and on a dense saline soil its production was more highly ranked than Leucaena leucocephala, Terminalia arjuna or Dalbergia sisoo (Qureshi, *et. al.*, 1993).

Albizzia lebbek **(L). :** A. lebbek tolerates moderate salinity, sodicity and high pH (8.7-9.4).

Casuarina equisetifolia: C. equisetifolia grows in calcareous and slightly alkaline soils, where it withstands salinity but not waterlogging. In Pakistan, irrigation with water of electrical conductivity of 9-10 dS m^{-1} caused 16-18 % decreases in height and stem diameter. In an adaptation trial on a saline site in Sind (ECe values of 5-40 dS m^{-1}), there was 60% survival after 2 years, but 3 months of flooding eliminated all survivors (Ansari, *et. al.*, 1994).

Eucalyptus camaldulensis: *E. camaldulensis* grows in slightly alkaline soils, where it can withstand some salinity and waterlogging. The situation regarding the salt and waterlogging tolerance of the species is confused. This may be because of the enormous variation between provenances. In irrigated sand culture, plant height and stem diameter decreased by 36 and 55% respectively, when water with an assuming that fuelwood has a market value of 0.50 PKR per kg (Qureshi, *et. al.*, 1993).

Picture 13. Eucalyptus grown in salt affected lands of Pindi Bhattian area

***Leucaena leucocephala* (Lam.)**

Tolerance to salt and waterlogging: *L. leucocephala* grows well on light-textured saline soils that are well drained. However, it is sensitive to water logging. In irrigated sand and gravel cultures, water with electrical conductivities of 9-10 dSm^{-1} did not adversely affect growth (Ahmad,1987). Two field experiments examined the adaptation of the species to saline soils at Faisalabad. The first of these examined the effects on survival of 3 months flooding of the soil surface. Under drained conditions there was 80-100% survival, but under flooded conditions there was no survival (Qureshi, *et. al.*, 1993,). In a longer-term adaptation experiment on a saline-sodic soil, leucaena produced 90 kilograms of timber per plant over a seven-and-a-half -year period (Qureshi, *et. al.*, 1993).

***Parkinsonia aculeata* L.:** *P. aculeata* grows well under conditions of high salinity, but is sensitive to waterlogged conditions.

Sesbania bispinosa

Tolerance to salt and waterlogging : *S. bispinosa* is commonly grown for the reclamation of salt-affected soils. It is adapted to a variety of soil conditions, varying from waterlogged to saline, and from sands to clays. It has a 50% decrease in growth in soils with an ECe of 13 dS m^{-1} (Sandhu and Haq, 1981).

Salt Tolerant Fruit Trees

Grewia asiatica L.

Description: *Grewia asiatica* L. is a member of the Tiliaceae family, and is known locally as phalsa (falsa).

Picture 14. Phoeuix dactylifera L.

Tolerance to salt and waterlogging: *G. asiatica* had excellent survival under saline-sodic conditions in a five-and-a-half-year field trial near Faisalabad (Qureshi, *et. al.*, 1993),

Description: *Phoenix dactyfifera* L. is a member of the Arecaceae family. Its common name is the date palm, and it is known locally as khajoor or khajji.

Tolerance to salt and waterlogging: According to the criteria of Maas and Hoffman dates are 'tolerant' to salinity. Their salinity (ECe) threshold for reduction in yield is 4 dS m^{-1}, and they have a 50% reduction in yield at 17.9 dS m^{-1}).

***Psidium guajava* L.**

Description: *Psidium guaiava* L. is a member of the Myrtaceae family. Its English name is the common guava, and it is known locally as amrood (amrud).

Tolerance to salt and waterlogging

Guava can be successfully grown in wet and moderately saline soils. Guava survived well but with reduced growth under saline-sodic conditions in a seven-and-a-half-year field trial near Faisalabad (Qureshi, *et. al.*, 1993). Major guava growing area in Pakistan is Sheikhupura, Nankana Sahib and Larkana districts.

***Ziziphus mauritiana* Lam.**

Description: *Ziziphus mauritiana* Lam. is a member of the Rhamnaceae family. Its common name is Indian jujube, and it is known locally as ber (Urdu), beri or mallah (Punjabi).

Tolerance to salt and waterlogging: Indian jujube can tolerate moderate to high salinity and sodicity.

Picture 15. Ziziphus mauritiana Lam.

Management of Sodic Soils

Reclamation and Amendments:

Any organic and inorganic material which could be used to accelerate the Na-Ca exchange in sodic soil is called amendments or reclamant or ameliorant for such soils. Amendment could be direct source of Ca or could make calcium available indirectly by solubilizing the native reserve, Calcite.

- Direct source of Calcium: material having Ca which release into soil solution upon dissolution. e.g. Gypsum ($CaSO_4.2H_2O$). Saturated gypsum solution contains 28-30 mmolc L^{-1} (14-15 mmolL^{-1} or 600 mgL^{-1}) of Ca.
- $CaCl_2$ and $Ca(NO_3)_2$, $CaCO_3$.
- Indirect sources of Calcium: most common material is commercial H_2SO_4 (90-94 % pure, specific gravity 1.84) and rapid in reaction, crude S forming H_2SO_4 after long time that reacts with soil lime to release soluble Ca. $FeSO_4$ and $Al_2(SO_4)_3$ also form H_2SO_4 and release Ca.
- Organic amendments: FYM, green manure, press mud, solid waste, upon bio-chemical decomposition, they release organic acids and CO_2 both help dissolve native $CaCO_3$

Industrial Byproducts as Amendments

Industrial byproducts like phosphogypsum, press mud, molasses, acid wash, and effluents from milk plants are being used to provide soluble Ca directly or indirectly by dissolving soil lime, for reclamation purposes. As these materials are cheap and locally available, their use is being encouraged.

Amendments are useful where soil permeability is less because of low salinity, when electrolyte concentration of the leaching water is less than the threshold electrolyte concentration, excess exchangeable Na+, or $C0_3^{2-}$, $HC0_3^-$ in the water. But these are not helpful if the poor permeability is due to soil texture, soil compaction, restricted layers (hardpan, clay pan), or high water table.

Quantity of Amendment

The amount of an amendment needed for sodic soil reclamation depends upon the amount of exchangeable sodium to be replaced, which in turn is governed by the amount of sodium adsorbed on to the soil (ESP and CEC), Sodicity tolerance and the rooting depth of the crop to be raised.

pH and the Gypsum Requirement

As discussed earlier, there exists a good relationship between pH of 1:2 soil water suspensions (pH2), pH of the saturation paste (pHs), and ESP of the soil. It has been observed that for soils of the Indo-Gangetic plains such a relationship can form a sound basis for calculating approximate gypsum requirement of the soils varying in texture and thus CEC. Similar relationships for different soils can be established for quick recommendations of their amendment needs.

Efficiency of Gypsum in conjunction with organic amendments

Haq, et. al, 2001 concluded that the most effective treatment noted was the combination of gypsum, press mud and farmyard manure (94% increases in yield over control) followed by press mud alone (60%) or in combination with FYM (57%). Of all the treatments, gypsum proved the best in reclaiming the soil with regards to pH and gypsum requirement as it reduced pH and gypsum requirement (GR) at 14-18% and GR 88-100%, respectively. Zaka, et. al, 2003 conducted a field experiment to reclaim sodic soil through the gypsum application @ 25 % GR alone and in combination with FYM, rice straw, sesbania @ 10 t ha^{-1} and crust scraping. A standard treatment of 100 % GR was also included. Rice and wheat crops were grown in rotation for two years. Crops were harvested at maturity and soil status was monitored after the harvest of each crop. The rice straw and sesbania coupled with 25 % GR were found to be superior to other treatments but were comparable with 100 % GR as far paddy yield of first rice crop was concerned. But in subsequent wheat, the treatment of 100 % GR became inferior.

Gypsum Application method

Traditionally, gypsum is applied to the soil surface to reclaim saline-sodic soils. The lower soil profile is left untreated. Therefore, the salts do not leach much to deeper depths, particularly in heavy textured soils. Raza, et, al, 2001 conducted a field study in which gypsum was applied in slots for the reclamation of abandoned saline-sodic soils was conducted. The excavated soil was mixed with gypsum and slots were refilled. The results showed that maximum increase in soil permeability by 220% occurred in slotted area; whereas, the infiltration rate increased by 152% with gypsum application by broadcast method. The electrical conductivity of soil (EC_c) decreased by 49 and 15% at 0-30 and 30-60 cm depths, respectively with gypsum applied by broadcasting. On the other hand, application of gypsum in slots reduced EC_c of slotted area by 51 % at 0-30 and 25% at 30-60 cm depths. In case of slotting method, lesser salts were accumulated at 60-90 cm depth than that of broadcast method. Similarly, gypsum application by broadcast method reduced sodium adsorption ratio (SAR) of soil by 59% at 0-30 cm depth and 8% at 30-60 cm depth. At lower depth of 6090 cm, SAR was increased by 24%. But gypsum application in slots decreased SAR by 72 and 46% at 0-30 and 30-60 cm depths, respectively. But SAR increased only by 11 % at 60-90 cm depth. The gypsum application in slots also decreased the salinity and sodicity in inter slot area. Maximum crop yields were recorded from slotted area.

Table 19. Effect of treatment on crop yields (kg ha^{-1})

Treatments	Wheat 1998-99	Cotton 1999	Wheat 1999-2000
Gypsum application by broadcast	1106	439	1293
Control	638	229	719
Gypsum application by slotting methods	4233	863	4625
Inter slot area	437	-	813

(Raza, *et. al.*, 2001)

Niazi, et. al, 2000 reported maximum increase in the yield of 132% by the application of gypsum @ 100% GR in one shot. A significant decrease in pH was noted with the application of gypsum @ 100% GR. A maximum of 8% decrease in pH was observed by gypsum application @ 100% GR. The ECe of the soil was linearly decreased with time. Maximum decrease in ECe was noted in treatment receiving 100% GR in one shot. The cumulative decrease in ECe at the end of experiment was 66% compared to control. A 45% decrease in SAR was recorded during the experiment in gypsum treated plots @ 100% GR in two splits.

Cultural Practices

To ensure successful reclamation of sodic soils, the following practices should be adopted.

Land leveling and shaping: To ensure proper water management and uniform leaching of salts, the field should be leveled properly. To avoid major earthwork, the big fields should be divided into small parcels and leveled. Drastic removal of the surface soil will expose the subsoil containing $CaCO_3$, which can pose difficulties in reclamation and cropping of the area.

Flushing: Flushing of soil followed by the chemical amendment is utmost desirable to get rid of excess soluble salts as well as sodium ion replaced from the exchangeable site as a result availability of calcium. Qadir, et. al, (1998) developed a technique to ameliorate the sodicity problem by horizontal flushing which involved mixing of gypsum with the soil in standing water with a cultivator followed by horizontal flushing of the standing water from the soil surface to a nearby drain and a second flushing repeated after 12h (GFF). Rice production responded positively to the GFF technology compared to the conventional GVL practice.

Hussain, *et. al.*, 2000c conducted a study in saline sodic soil on farmer field at Pindi Bhattian to reclaim it under restricted infiltration and drainage during 1995-97. The original soil had an ECe 5.25 dS m-1, SAR 49.1 and pH 9.8. Gypsum was applied at 100% GR, while the irrigation water was flushed out at different time periods (12, 24 and 36 hours) of gypsum application except control. Wheat yield significantly increased (38, 48 and 70%) with the increase in flushing time compared to control. A 26% decrease in SAR of the soil was recorded at the time of wheat harvest. While increase in the ECe resulted when water was flushed after 12 hours of gypsum application. A delay in the water flushing 24 and 36 hours decreased the ECe significantly. A further decrease in SAR and ECe has been observed after second and third crop of rice and wheat, respectively. Horizontal flushing 36 hours after gypsum application proved to be the best intervention as it significantly improved soil physical properties as well as wheat yields.

Plant Population: Because of the hard crust on the surface, germination percentage is often low in sodic soils. Plant population further decreases because of high rate of mortality, especially during early stages of plant growth. This together with poor tillering can reduce crop yield. Crop stand in sodic soils can be improved by increasing the seed rate and reducing the planting distance. In the case of rice, better plant population can be achieved by increasing the number of seedlings per hill and by gap-filling so as to replace the dead plants.

Tillage: Cultivation increases the infiltration rate and helps in leaching the salts and reclaiming the saline soil. Pratharper and Qureshi, 1999 evaluated the effect of pre-monsoon surface cultivation for the reclamation of saline soil by using a numerical model SWAP-93. It was found that with a water table at one meter or below, abandoned saline soil could be reclaimed by pre-monsoon surface cultivation within few years. However, deep ploughing and chiseling alone are not helpful to reclaim saline sodic soil. Therefore, gypsum application in combination with sub-soil proved to be the best intervention (Azhar, *et. al.*, 2001).

Picture 16. Appropriate tillage practice in sodic soil

Phyto-remediation of Sodic Soils

Qadir, et. al, 1996 reported that amelioration of sodic and sodic soils by chemical amendments requires high capital input. Cultivation of salt tolerant grasses may mobilize the native lime ($CaCO_3$) in these soils through root action to substitute the chemical approach. A sodic soil (pH_s = 9.1, EC_e = 9.8 dS m^{-1}, SAR = 103, $CaCO_3$ = 9.4%, CEC = 122 $mmol_c$ L^{-1}, texture = sandy clay loam) was experimented for reclamation. Concrete cylinders (60 cm long, 30 cm internal diameter) were used to prepare the soil columns. The bottom of each column was padded with a 5 cm layer of gravel and sand to facilitate leaching. In each lysimeter, soil was added in small increments to obtain a uniform soil column. The soil was packed to a height of 40 cm, making the soil depth in each column 35 cm. Four treatments, one cropped i.e. kallar grass (*Leptochloa fusca*) and three non-cropped (control, gypsum @ 50%, and 100% gypsum requirement) were leached with four leaching cycles (LC_1 to LC_4) at different time intervals. Canal water (EC =0.28 dS m^{-1}, SAR = 0.8) was used for leaching. Two leaching cycles, LC_2 and LC_3, were completed during the peak growth of kallar grass (summer) and the remaining two, LC_1 and LC_4, were completed during winter when its growth was very slow. After the completion of LC_4, soil samples were collected from the lysimeters at 0–15 and 15–30 cm depths. The treatment receiving gypsum at higher rate (100% GR) removed the greatest amount of Na^+ from the soil columns and caused a substantial decrease in soil salinity (EC) and sodicity (SAR). Performance of the grass treatment in enhancing the leaching of Na^+ was between the gypsum treatments. Kallar grass removed more Na^+ during summer than during winter. Effectiveness of the treatments for soil reclamation was in the order: 100% GR > kallar grass > 50% GR > control.

The results of Akhtar, et. al, 2007 confirmed that cropping of kallar-grass on a highly saline, sodic soil, irrigated with brackish water improved appreciably the soil physical (AW, Kfs, SI, BD and P), chemical (ECe, pH, SAR and OM) and mineralogical properties, within a period of three years. Kallar grass maintained its growth without addition of any fertilizer for a long time. The proportion of clay mineral component found in soil-clay fraction and significant evidences available confirmed that uncropped soils are highly unstable, very soft when wet and very hard when dry, due to greater amount of illite clay. The growth of kallar grass accelerated the rate of weathering, with transformation of mica to 2:1 expansible clay, and the soil attained an appreciable improvement in soil-aggregate stability, hydraulic permeability, available water, soil-porosity or bulk density, due to increase in organic matter and leaching of soluble ions from surface to lower depths.

The soil maintained the improved characteristics with further growth of grass up to five years. The results confirmed the sustainability of biological approach i.e. amelioration of saline lands by growing salt tolerant plant species with brackish underground water.

Green manuring

Application of green manure can help to enhance OM content, increase partial pressure of C02, lower pH, enhance solubility of native $CaC0_3$, and add a considerable amount of plant nutrients in the soil. For this, *Sesbania,* which is tolerant to both high ESP and waterlogging, is an ideal crop. As it grows during the summer (May-June), a lean period for rice and wheat, it also fits into the cropping pattern to be followed in Sodic soils.

Normally, 45-day-old *Sesbania* crop that attains a height of 1.5 to 1.8m is ideal for incorporation as green manure crop. Being succulent and having a narrow C:N ratio (about 25), it decomposes very easily and quickly. The standing water in rice fields hastens the decay without any harm to rice crop. So there is no need to allow any time for the decomposition of the organic matter and rice seedlings can be transplanted immediately after the incorporation of *Sesbania* in the soil. Since about 50 per cent of the organic nitrogen contained in the green manure crop is converted into the readily available ammoniacal form within 4 to 6 days and the rest within 10 to 20 days of incorporation (under the temperature conditions prevailing in the main rice-growing season), it helps ensure a steady supply of N to the rice crop.

A growth period of 45 days and "no decomposition period" results in better rice yields and a saving of 10 to 15 days for cultivation and decomposition of green-manuring crop. A longer growth period renders the plants hardy and difficult to decompose, whereas allowing more time for decomposition of a succulent crop like *Sesbania* in Sodic soils results in greater losses of N through volatilization and less N recovery by rice crop. It has been observed that yield increase in rice crop due to green manuring can be equivalent to about 80 kg of N applied through chemical fertilizers.

Continuous cropping

On application of amendment, leaching (especially during growth of rice), and cropping, replaced Na+ keeps moving downwards and there is continuous reduction in the exchangeable sodium of the soil throughout the soil profile.

Drainage

As the sodic soils basically have low infiltration rate, all the rain water accumulates to create surface water logging. Even a low intensity shower or a normal irrigation may create temporary water logging and anaerobic conditions. Because of this, plants normally suffer oxygen stress in Sodic soils. To avoid the problem, surface drainage, especially during the rainy season, is a must. During early stages of reclamation, surface runoff water that contains high concentration of soluble Na_2CO_3 and $NaHCO_3$ should not be allowed to pass on to the adjacent fields; it can cause sodication of the good quality land.

After the first few showers, the quality of the surface runoff water is generally very good. Instead of letting it go waste and contribute to the flood waters it may be stored in shallow ponds dug out at the lowest place at the farm. This stored water can be used for irrigation in the lean period. If water table is high, which is the case in most soils, and then sub-surface drainage has to be installed. However, because of low hydraulic conductivity, conventional sub-surface drainage to lower the water table is neither possible nor required in these soils. Normally, in Sodic soils, the groundwater is of good quality and can be exploited for irrigation. For this, as many shallow cavity tube wells as possible should be installed to act as a source of irrigation and to provide vertical drainage. This has proved to be the most effective and economical way of controlling the water table and providing a source of irrigation.

Because of the poor hydraulic conductivity of these soils, natural recharge of the groundwater even during the rainy season is low. And as a result of vertical drainage through tube wells the water table goes down very fast in many areas. This sometimes even necessitates lowering of the motor for obtaining effective discharge and thus costs money to the farmers and exposes them to the poisonous gases that may accumulate in the pits. To boost groundwater recharge, vertical bores with appropriate filters may be provided. This will also minimize runoff and conserve the rain water right in the area.

Irrigation

Hussain, et. al, 2000a conducted a study to evaluate the effectiveness of gypsum application and soil ripping to manage saline-sodic soil irrigated with brackish ground water in Pindi Bhattian area, district Hafizabad. The soil was clay loam in texture. The original pH, EC_e and SAR of the soil were 8.9, 5.25dS m^{-I} and 49.9, respectively and the brackish water had EC_w 1.4 dS m-1, SA.R. 8.7 (m molc $L^{-1})^{-1/2}$and RSC 4.8me L^{-1}.Two gypsum levels i.e. control and gypsum @100% GR and no ripping, single ripping and double ripping were tested in farmer's fields. Reduction in EC_e and SAR were treated as the indicators to evaluate the effectiveness of different treatments. Significantly higher wheat grain yield was recorded when double ripping along with 100% GR was applied. Increase in wheat yield over control was 55% during the year 1996-97. Highest paddy yield (1.52 Mg ha^{-I}) was recorded when single ripping along with gypsum @ 100% GR was applied. Gypsum x ripping interaction significantly ($P<0.05$) decreased the EC_e below salinity threshold in all the treatments except control. SAR was significantly decreased below 15 in treatments which received double ripping+ gypsum application and single ripping + gypsum application. Crop yield data indicated that gypsum application in conjunction with ripping is much more effective than either of the two treatments alone.

Hussain, et. al, 2000b conducted a study in the field on a normal soil. Brackish tube well water was used for irrigating wheat and rice crops without any amendment and with gypsum (equal to sodium contents of irrigation water; and two times its sodium contents). Wheat and rice crops were grown from Rabi 1995-96 to Rabi 1998-99. Use of brackish water without any amendment resulted in an increase in EC and SAR of the soil and caused a decrease in crop yield. Use of the same water in combination with two times its sodium contents resulted in normal yield of both the crops without any harmful effect on the soil. Gypsum equal to sodium contents of the irrigation water proved comparatively less effective.

Table 20. Brackish water affects saline-sodic soil (0-30 cm) and income (Rs. Ha^{-1}) after 3 rice + 3 wheat crops, field studies at Dijkot, Faisalabad.

Treatment	pHs	ECe (dS m^{-1})	SAR	Net income
Original soil (Khurrianwala series	7.9-8.4	8.5-32.2	21-77.5	-
SIB9 sump water alone	8.4	9.8	22.9	28427
Soil applied gypsum @ 50 SGR	8.4	8.4	21.8	28380
Water applied H2SO4@50% @WRSC	8.4	10.3	23.9	-11719
Soil applied gypsum @ 100 SGR	8.3	8.5	20.9	35714
FYM @ 25 Mg/ha/annum	8.4	10.1	16.4	35713

* EC_{iw}, 2.93-3. 21 dS m^{-1} SAR $_{iw}$, 12-18.2, RSCiw 3.7-10.0 $mmol_c$ L^{-1} (Ghafoor, et. al, 1997 b)

Economic Considerations of Soil Reclamation

The success of any technology is dependent upon its cost: benefit and is considered a key factor for adoption by farmers. In most of the studies, economic evaluation of treatments is overlooked. If it is computed, then only on the basis of variable costs and produce only. The long term benefits like appreciation in land value, improved environment; farm-level employment opportunities and waste water disposal issues etc. are not included in economic analysis. Apart from these concerns, mostly gypsum passed through 30 mesh sieve having 70-80 % purity with or without organic materials has proved highly cost-effective than acids or acidulates for native soils.

Acids and acid formers for the treatment of native salt-affected soils are not suitable because of clay mineralogy concerns since considerable chlorite is present in clay fraction. However, organic matter has no substitute regarding health of normal as well as salt-affected soils. The biological reclamation approach, although is cost-effective than the chemical amendments, but time and amount of irrigation water required to achieve soil reclamation make it impractical for most of the farmers except landlords. Small land holdings (70 % farmers own land less than 5 ha) are another issue to be kept in mind while recommending reclamation technologies. It must be kept in mind that reclamation of all the types of salt-affected soils will start as soon as farmer starts agricultural operation(s) in his field with or without any reclamation treatment. All the soil reclamation endeavors aim at to expedite the amelioration process which will bring more benefit to the farmer during early phase (first year) when expenses have been incurred. Secondly, appreciation in land value, farm employment, saving of foreign exchange, environment cleaning effect, i.e. CO_2 consumption along with replenishing the O_2 in atmosphere, aesthetic value of green crops and food security like aspects are important considerations to promote soil reclamation. Following studies are indicative of economics of various amendments.

Sulphurus Acid Generator Technology

This technology was introduced in the country by an American firm "Sweet Water" in collaboration with different governmental departments and universities. The technology was widely tested in irrigated area having brackish water zone. Generator treated water just reduced RSC of the water while EC of water increased. Total soluble salts of treated water became more hazardous to crops as compared to treated water (Table 21). However, economically this technology was much more costly due to initial cost of the generator, cost of sulfur and its burning as compared to other sodic water management options. Therefore, presently no sulphurus acid generator is functional in the country. The data given in table 14 is indicative of usefulness of FYM and Gypsum application. Application of FYM @ 15 Mg/ha/yr before rice transplanting gave net benefit of Rs. 93181 and Soil applied gyp to each crop equal to WGR (decrease in RSC equal to that of SAG water) gave benefit of Rs. 81110 while SAG treated T/W of all irrigation (1/10 water passing through SAG and mixed with remaining T/W gave benefit of Rs. 49472 (Table 22).

Table 21. Quality of tube well water treated with sulphurus acid generator

Treatments	TDS (mg L^{-1})	EC (dS m^{-1})	pH	SAR	RSC
Un-treated Tube wells water	1209	1.9	8.5	14.2	2.7
Generator treated water	1440	2.3	2.8-4.0	10.1	Nil
Mixed (one part treated and 4 parts untreated water)	1261	2.0	7	11.5	0.6

Source: Kahloon and Gill, 2003

Table 22. Economic of sulphurus acid generator (SAG) treatment of brackish water, Faisalabad (2 rice and 1 wheat crops)

Treatment	Total income	Variable cost	Net benefit
Control (all irrigation with un-treated T/W water*	74336	-	74336
All irrig. With SAG treated T/W(1/10 water passing through SAG and mixed with remaining T/W	88578	39106	49472
Alternate irrig. of SAG treated & untreated T/W	87102	19889	67213
One irrig. with SAG treated water and 2 with untreated TW	90266	13125	77144
FYM @ 15 Mg/ha/yr before rice transplanting	96931	3750	93181
Soil applied gyp to each crop equal to WGR (decrease in RSC equal to that of SAG water)	88360	7250	81110
Sulphuric acid fertigation equal to water RSC (decrease in RSC equal to that of SAG water)	89640	37939	51661

*ECw=3.3 dS m^{-1}, SAR $_{iw}$=16.6, RSC- 5.7 $mmol_c$ L^{-1}, Zia, *et. al.*, (2006)

The cost effectiveness of different amendments was investigated by Ghafoor and Muhammad, 1981 and concluded that gypsum is much economical than the other treatments (Table 23).

Table 23. Economic evaluation of gypsum and acids for soil and water improvements (pot studies)

Treatment	GR (T/ha -15 cm)	Cost (Rs. ha^{-1})
Gypsum @ 100 % soil GR	11.0	3864
Sulfuric acid @ 100% soil GR	11.0	9953
Hydrochloric acid @ 100 % soil GR	11.0	9619
Nitric acid @ 100 Soil GR	11	55350

(Ghafoor and Muhammad, 1981)

Ghafoor, 2003 concluded from a study that application of gypsum equivalent to 100 water gypsum requirements proved to be the economical dose for reclamation of brackish waters (Table 24).

Table 24. Economics (Rs ha^{-1}) of brackish water treatment during reclamation of saline sodic soils on the basis of 2 rice + 2 wheat crops (Ghafoor, 2003)

Treatment	Chak 147 RB, Punjab		Chak 123 GB, Punjab	
	Total cost	Net income	Total cost	Net income
Control T/W brackish water	4979	36907	3346	12618
Gyp @ 25% SGR to twice	7722	43565	6639	13116
FYM @ 10 Mg/ha/ye	6543	36424	4255	11668
Combination of gypsum +FYM	7888	36762	7378	17891
Gyp@ 50% WGR+ 1 augar hole $(50\ m)^{-2}$ filled with soil:RH::1:1	8503	19800	-	-
Gyp@ 50% WGR+ 1 augar hole $(50\ m)^{-2}$ filled with soil::gyp::1:1	8010	20675	-	-
Gyp@ 50% WGR+ 1 augar hole $(50\ m)^{-2}$ filled with soil:RH:gyp::1:1:1	8101	27935	-	-
Gyp@ 50% WGR+ wheat seed soaking for three hours	7268	31744	5956	32176
Gyp@ 50% WGR+ wheat seed soaking for six hours	7971	25372	6151	33707
Gyp@ 50% WGR+ wheat seed soaking for 12 hours	6818	21852	5514	28528

The EC_{iw}, SAR $_{iw}$, SAR $_{adj,}$ RSC were 3.92 dS m^{-1}, 16.33, 18.30 and 8.9 $mmol_c\ L^{-1}$ at Chak 147/RB and 2.55 dS m^{-1}, 7.76, 9.0 and 0.9 $mmol_c\ L^{-1}$at chak 123/G.B, respectively.

*Soaking in 15 $mmol_c\ L^{-1}$ gyp solution, RH= Rice Husk

Conclusions

Precision land leveling is the major step forward for saline soil reclamation. The intermittent leaching method removed 75% of salts down from the top 60 cm soil depth, whereas the continuous leaching method removed only 64%. High and structurally stable earthen dykes should be built to prevent the entry of sea water into the cropped area. Flap gates should be constructed to stop back flow of sea water during off rainy season in the Indus River. In coastal areas, ground water should be exploited carefully and only the good quality rain water should be skimmed from the shallow well. Salt tolerant cultivars of wheat, rice, cotton and oilseed may be bred to raise farm income of lands having suitability for saline agriculture.

The conjunctive use of manure with gypsum @ 50 % GR increased the soil infiltration rate from 0.5 to 11.2 cm day^{-1} after 4 years. Horizontal flushing of water 48 hours after the reaction of gypsum with soil properties proved to be an effective practice. Superiority of gypsum over other amendments (H_2SO_4, HCl and $CaCl_2$) proved extensively during the reclamation of a calcareous saline-sodic. Growing Kallargrass *(Leptoehloa fusca)* in a highly saline-sodic clay loam field (pH, = 10.3, EC_c= 20.2 dSm^{-1}, SAR = 170, ESP = 71) markedly decreased the soil pH, EC and SAR. Effectiveness of the gypsum and kallar grass treatments for soil reclamation was found in the order: 100 % GR >Kallar grass>50 % GR >control.

Adapting saline agriculture approach, salt tolerant crops like rice, wheat, cotton and oil seed can be planted to raise farm income and earn livelihood of farming community. Similar grasses and tree and fruit tree species perform well in extremely salt affected soil without any reclamation effort. Reclamation efficiency of saline-sodic soils was found in the order: sub soiling + gypsum> gypsum> sub soiling> control. Rice and sesbania crops are being grown as vegetation reclamation strategy to reclaim salt affected lands as well as raising farm income. Conjunctive use of gypsum, press mud and farmyard manure increased 94% yield over control followed by press mud alone (60%) or in combination with FYM (57%). Of all the treatments, gypsum proved the best in reclaiming the soil with regards to pH and gypsum requirement as it reduced pH and GR at 14-18% and GR 88-100%, respectively. Normally, 45-day-old *Sesbania* crop that attains a height of 1.5 to 1.8 m is ideal for incorporation as green manure crop. Gypsum application in conjunction with ripping is much more effective in soil reclamation than either of the two treatments alone. Gypsum application equivalent to 50% WGR proved to the economical dose to manage brackish water having high RSC and SAR.

Recommendations

Use of gypsum for saline sodic soils and waters should be given due attention and be made popular through media (scientific, public and electronic etc.). Use of gypsum is encouraged along with FYM/green manure/ press mud to sustain the irrigated agriculture in the country. Research on gypsum should be continued to investigate various aspects of saline-sodic soil reclamation and brackish water management, pumpage of which is creating mess in cropped area.

Quality and purity (not less than 70%) of gypsum should be ensured by effective implementation of Fertilizer control ordinance (FCO) 1973 (amended in 1999). Ground water quality mapping be done on district basis. Since subsidy on gypsum was withdrawn, credit facilities in kind, as in case of other agricultural inputs, should be given and its recovery be made in easy installments when the land becomes productive. Land revenue may be exempted from the lands under reclamation/rehabilitation (with or without gypsum or with plantation) till lands become fully productive to their potential.

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