Management Options and Policy Guidelines for Use of Poor Quality Groundwater in Agriculture

D.R. Sharma and P.S. Minhas
Central Soil Salinity Research Institute, Karnal, India

Abstract

The anticipated shortage of fresh water supply to agriculture sector in the 21st century is likely to enhance globally the utilization of relatively poor quality water for irrigation. The poor quality ground waters occur extensively (32-84%) in the arid and semi-arid parts of India and their indiscriminate use poses serious threat to the sustainability of natural resources and environment. Water quality studies over past few decades have enabled development of technological options to cope up with the problems of saline and sodic water use. Possibilities have now emerged to safely use water otherwise designated unfit. These options primarily consist of: i) selection of crops, cropping patterns and crop varieties that produce satisfactory yields under the existing or predicted conditions of salinity and sodicity ii) appropriate irrigation scheduling and conjunctive use options with canal water; rain water management and leaching strategies to maintain a high level of soil moisture, and low level of salts and exchangeable sodium in the rhizosphere, and iii) use of land management practices to increase the uniformity of water distribution, infiltration, and salt leaching besides the optimal use of chemical amendments including time and mode of their application with judicious use of organic materials and chemical fertilizers. Some of the policy guidelines such as establishing water quality monitoring networks, modifications in canal water delivery schedules, groundwater pumping pricing, subsidies on amendments and micro-irrigation systems, promoting conjunctive use and ground water recharging and training need for farmers and extension workers are also highlighted.

Introduction

The availability of fresh water supplies to agriculture sector in future is likely to reduce world over particularly in the Asian countries due to population pressure, improved living standards and inter-sector competition for water. The estimate for India shows this reduction to be 10 to 12% by 2025.

In the back drop of this grim water scenario, the agriculture sector would be left with no other alternative than to use poor quality water sources to meet the irrigation requirements. The ground water surveys in India indicate that poor quality water being utilized in different states range between 32 to 84% of total ground water development. Many more areas with good quality aquifers are endangered with contamination as a consequence of excessive withdrawl of ground water. The ground water of arid region are largely saline and of semi-arid region are sodic in nature.

Indiscriminate use of poor quality water for irrigating agricultural crops deteriorates the productivity of soils through salinity, sodicity and toxic effects. In addition to reduced productivity, the use of poor quality water deteriorates the quality of produce and also limits the choice of cultivable crops. Nevertheless, concerted efforts at different research centers located in different agro climatic zones of the country have yielded valuable concepts and viable technologies for the sustainable irrigation with poor quality water (Minhas, 1996). Possibilities have emerged to safely use water otherwise designated unfit if the characteristics of water, soil and intended crops are known. However, appropriate selection of crops, improved water management and maintenance of soil structure permeability are necessary for sustaining irrigation with these waters. In this paper we have outlined various technological and policy options available for alleviating hazards of salt-affected water and maximizing productivity form their sustained use.

Classification of Irrigation Water

Irrigation waters are mainly classified on the basis of electrical conductivity (EC), sodium adsorption ration (SAR) and residual sodium carbonate (RSC). However, from management point of view, ground water utilized in different agro-ecological regions can be broadly grouped into three classes: good(A), saline(B) and alkali/sodic(C). Depending on the degree of restriction, each of the two poor quality water classes has been further grouped into three homogenous subgroups (Table 1).

Table 1. Classification of poor quality ground water

Water quality	ECiw (dS m^{-1})	SARiw $(mmol^{-1})^{1/2}$	RSC (meq l^{-1})
A. Good	<2	<10	<2.5
B. Saline			
i. Marginally saline	2-4	< 10	<2.5
ii. Saline	> 4	< 10	<2.5
iii. High-SAR saline	> 4	> 10	< 2.5
C. Alkali water			
i. Marginal alkali	<4	<10	2.5-4.0
ii. Alkali	<4	<10	>4.0
iii. Highly alkali	variable	>10	>4.0

Poor Quality Ground Water Resources

In India so far, no systematic attempts have been made to arrive at the estimate of poor quality ground water resources. However, some predictions about use of poor quality water in various states are given in Table 2. The CGWB (1977) approximated that the total area underlain with the saline ground water (EC>4 dS m^{-1}) is 193,438 km^2 with the annual replenishable recharge of 11,765 M m^3 Yr^{-1}, leaving aside minor patches.

Table 2. Use of Poor quality ground water in various states of India

State	Utilizable ground water resources for irrigation in net terms (M ha-m Yr^{-1})	Net draft (M ha-m yr^{-1})	Level of ground water development (%)	Use of poor quality water (M ha-m Yr^{-1})	Area underlain by saline (EC>4dSm^{-1}) (km^2)
Punjab	1.47	1.67	98	0.68	3058
Haryana	0.86	0.72	76	0.47	11438
Uttar Pradesh	6.31	2.98	42	1.42	1362
Rajsthan	0.95	0.77	73	0.65	141036
Bihar	2.06	0.82	36	NA	NA
West Bengal	1.77	0.63	32	NA	NA
Delhi	0.01	0.01	120	NA	140
Gujarat	1.56	0.85	49	0.26	24300
Karnataka	1.24	0.45	33	0.17	8804
Tamilnadu	2.02	1.40	63	NA	3300
Madhya Pradesh	2.66	0.73	25	0.20	NA
Maharashtra	2.29	0.88	35	NA	NA
Andhra Pradesh	2.70	0.78	26	0.25	NA
Total (India)	32.63	13.50	37		193438

Source: Minhas *et al., 2004*

Management Options for Saline Water Use

Research studies at various centers in different agro-climatic zones of the country have yielded valuable concepts and viable technologies for the sustainable irrigation with poor quality water. It has been established that the success with poor quality water irrigation can only be achieved if factors such as rainfall, climate, water table, and water quality characteristics, soils and crops are integrated with appropriate crop and irrigation management practices. The available management options mainly include irrigation, crop, chemical and other cultural practices but there seems to be no single management measure to control salinity and sodicity of irrigated soil. Instead several management practices interact with each other and should be considered in an integrated manner. In this paper, however, different management options have been described separately as under.

Crop Management

Selection of Crops

For successful utilization of saline water, crops which are semi-tolerant to tolerant such as mustards, wheat and cotton as well as those with low water requirement are recommended. Crops such as rice, sugarcane and berseem, which require liberal water use, should be avoided. In low rainfall areas (<40 cm/annum), mono–cropping is recommended for maintaining salt balances. Salt tolerance limits of cereals, oil seeds, vegetables, and pulses developed in different ecological regions of India are available in Table-3. The choice of crops for a given soil and water salinity condition can be made from this data. Some other specific recommendations related to crop selection and management are as under:

Table 3. Salinity limits of irrigation water for agricultural crops

Crops	Soil texture	Pervious crop	ECiw (dS/m) for yield (%)	
			90	75
		Cereals		
Wheat	Silty clay loam	Sorghum	3.4	7.0
	Sandy loam	Bajra	6.6	10.4
	Loamy sand	Fallow	8.3	11.7
	Sand	Fallow	14.0	16.1
Barley	Sandy loam	Fallow	7.2	11.3
Rice	Silty clay loam	Rice	2.2	3.9
Maize	Clay loam	Wheat	2.2	4.7
Pearl-millet	Sandy loam	Wheat	5.4	9.0
Italian-millet	Sand	Sunflower	2.4	4.6
Sorghum	Sandy loam	Mustard	7.0	11.2
Sorghum fodder	Sandy loam	Berseem	5.2	10.2
		Oilseeds		
Mustard	Sandy loam	Sorghum	6.6	8.8
Safflower	Silty clay loam	Maize	3.3	6.8
Sunflower	Sandy loam	Mustard	3.5	7.2
Groundnut	Sand	Italian-millet	1.8	3.1
Soyabean	Silty clay loam	Mustard	2.0	3.1
		Pulses/Legumes		
Pigeon pea	Sandy loam	Onion	1.3	2.3
Clusterbean	Sandy loam	Variable	3.2	4.5
Cowpea	Loamy sand	Variable	8.2	13.1
Berseem	Sandy loam	Sorghum	2.5	3.2
		Vegetables		
Onion	Sandy loam	Pigeonpea	1.8	2.3
Potato	Sandy loam	Okra	2.1	4.3
Tomato	Sand	Variable	2.4	4.1
Okra	Sandy loam	Potato	2.7	5.6
Chillies	Sand	Variable	1.8	2.9
Brinjal	Sand	Variable	2.3	4.1
Fenugreek	Sandy loam	Potato	3.1	4.8
Bitter gourd	Sand	Variable	2.0	3.4
Bottle gourd	Sand	Variable	3.2	4.5

Growth stages: All crops do not tolerate salinity equally well at different stages of their growth. For example, germination and early seedling establishment are the most critical stages followed by the phase changes from vegetative to reproductive i.e. heading and flowering to fruit setting. Therefore, the use of saline water should be avoided during initial stages of crop growth.

Crop cultivar: In addition to intergenic variations, crop cultivar also vary in their tolerance to salinity. Such cultivars have been identified on their rating for high yield potential, salt tolerance and stability under saline environments and are included in Table 4.

Table 4. Promising cultivars for saline and alkaline environments

Crop	Saline environment	Alkali environment
Wheat	Raj 2325, Raj 2560, Raj 3077, WH 157	KRL 1-4, KRL19, Raj 3077, HI1077, WH 157
Pearl-millet	MH269, 331, 427, HHB-60	MH 269, 280, 427, HHB 392
Mustard	CS416,CS330,-1, Pusa Bold	CS15, CS52, Varuna, DIRA 336, CS 54
Cotton	DHY 286, CPD 404, G 17060, GA,	HY6, Sarvottam, LRA 5166 JK276-10-5, GDH 9
Safflower	HUS 305, A-1, Bhima	Manjira, APRR3, A300
Sorghum	SPV-475, 881, 678, 669, CSH 11	SPV 475, 1010, CSH 1, 11, 14
Barley	Ratna, RL345, RD103, 137, K169	DL4, 106, 120, DHS 12

Cropping sequence: Cropping sequence is another critical step in mitigating saline conditions. The recommended cropping sequence for saline conditions are pearl millet –barley, pearl millet-wheat, pearl millet-mustard, sorghum-wheat or barley-sorghum-mustard, cluster bean – wheat or barley and cotton- wheat or barley. The pearl millet-wheat, pearl millet-barley, pearl millet-mustard, sorghum (fodder)-wheat and sorghum (fodder)-mustard cropping sequences are more remunerative in saline soils. Cotton based cropping sequence are not beneficial since the yield of the winter crops that follow cotton are usually low. In areas with water scarcity, mustard could replace wheat in the cropping sequence since its water requirement is low compared to wheat.

Ionic Composition Effects

Chlorides, being more toxic tend to reduce the tolerance limits of crops to the use of saline water by 1.2 – 1.5 times as compared with sulphate rich water (Manchanda, 1998). Similarly, more salts tend to accumulate in soils when irrigated with water of high SAR and thus tend to reduce the limits of saline water use.

Tree Species

In cases where it is neither feasible nor economical to use saline water for crop production, such water can be used to raise tree species especially on lands those are already degraded. The preferred choice of species should be *Azadirachta indica*, *Acacia nilotica*, *A. tortilis*, *A. farnesiana*, *Cassia siamea*, *Eucaluyptus tereteerms*, *Feronia limonia*, *Prosopis juliflora*, *P. cineraria*, *Pithecellobium dulce*, *Salvadora persica*, *S. oleoides*, *Tamarix*.

Medicinal Plants

Some medicinal plant such as Isabgol (*Plantag oovata*), Aloe and Kalmeg have also been found promising under saline irrigation conditions as an alternative to arable crops.

Water Management

Irrigation and Leaching Management

As each irrigation with saline water results in addition of a certain amount of salts to the soil, salts may gradually accumulate in the root-zone to detrimental levels and cause reduction in crop yields if no leaching takes place. However, proper irrigation and leaching practices can prevent excessive accumulation of salts in the root zone. The following suggestions may be helpful.

- Arid areas would need 15 to 20 percent more water to be applied as irrigation for meeting out the leaching requirements. To maximize the benefit from enhanced quantity of irrigation water, attempts should be simultaneously made to minimize the water applied i.e. saline irrigation should be applied more frequently. Nevertheless, in areas with rainfall more than 400 mm and having monsoon type of climate, no extra leaching is usually required and the conventional irrigation practices may be followed. In the years of sub-normal rainfall, a heavy pre-sowing irrigation with saline water should be applied so that the salts accumulated during the preceding *rabi* season are pushed beyond the root-zone.
- The distribution of water and salts in soils vary with the method of irrigation. A shift towards micro-irrigation systems such as drip and sprinklers, where a better control on salt and water distributions can be achieved, hold promise for enhancing the use efficiency of saline water especially for high value crops (Table 5). Pre-emergence application of saline water through sprinklers, helps to keep soluble salt concentrations low in seedbed during germination and thus better establish the crop. Some of the indigenous alternative to drips on micro scale are the use of pitchers and specially designed earthen pots, however their feasibility on field scale remain untested.
- In the case of saline water logged soils provided with sub-surface drainage, the system can be beneficially employed to induce crop water use from shallow water table through controlled drainage in *rabi* crops and thus reduce the requirement of irrigation water.

Conjunctive Use of Saline and Canal Water

Often water of more than one quality is available at the same location. One such situation commonly arises when farmers have access to limited supplies of canal water along with saline ground water. The existing fresh and saline water supplies could be suitably combined in several ways. First option is to blend the two supplies such that the salinity attained after mixing is within the permissible limits of crop tolerance. The mixing of two water supplies from canal and tubewell also helps in improving the stream size and thus enhances the uniformity of irrigation especially in sandy soils.

Table 5. Yield and water use efficiency under different irrigation methods

Crop	Average yield (Mg ha^{-1}) for irrigation method			
	Surface method		Sprinkler method	
	CW*	SW*	CW	SW
Wheat (1976-79)	4.00 (97)**	3.62 (83)	3.69 (107)	3.54 (97)
Barley (1980-82)	3.51 (147)	2.32 (98)	3.48 (159)	2.59 (117)
Cotton (1980-82)	2.30	1.71	2.28	1.34
Pearl millet (1976-78)	2.38	2.07	2.54	1.50
		Drip Method		
		Surface	Subsurface	Furrow
Radish (EC_{water} 6.5 dS m^{-1})		15.7 (17.5)	23.6 (26.2)	9.9 (8.7)
Potato (4 dS m^{-1})		30.5 (93.5)	20.8 (78.5)	19.2 (53.6)
Tomato (10 dS m^{-1})		59.4	43.9	
Tomato (4 dS m^{-1})		42.6	36.9	

*CW- Canal water, SW-Saline water
** Figure in parenthesis denote water use efficiency (Kg/ha-cm).
Source: Aggarwal and Khanna (1983); Singh et al. (1978); AICRP-Agra (2002)

- Application of the two waters separately, if available on demand, can be done either to different fields, seasons or crop growth stages so that the higher salinity water is avoided at sensitive growth stages of the crops. As the germination and seedling establishment stages have been identified as the sensitive stages in most crops, better quality water should be utilized for pre-sowing irrigation and early stages of crop growth. Then a switch over to poor quality water can be made when the crops can tolerate higher salinity. In the seasonal cyclic use, non-saline water is used for salt sensitive crops or in the initial stages of tolerant crops to leach out the accumulated salts from irrigation with salty water to previously grown tolerant crops. Cyclic uses i.e. irrigating with water of different qualities separately offers both operational and performance advantages over mixing.
- For skimming of fresh water floating over seawater in coastal sandy soils, conventional *"Dorouv"* system has been improved with specially designed sub-surface water harvesting system that can irrigate up to 3-5 ha land (Raghu-Babu, 1999).

Nutrient Management

Fertilizers

Application of fertilzers is important for obtaining good yields with saline irrigation.

- Response to applied nitrogen is rather reduced under saline irrigation. Thus, additional doses of nitrogenous fertilisers, though do not materially change salinity tolerance but are recommended to compensate for volatilisation losses.
- Soils irrigated with chloride rich water respond to higher phosphate application, because the chloride ions reduce availability of soil phosphorus to plants. The

requirement of the crop for phosphoric fertilizers is, therefore, enhanced and nearly 50 per cent more phosphorus than the recommended dose under normal conditions should be added, provided the soil tests low in available phospourous.

- For sulphate rich water, no additional application of phosphatic fertilisers is required and the dose recommended under normal conditions may be applied.
- For micro-nutrients such as zinc, the recommended doses based on soil test values should be applied.

Farmyard Manure (FYM)

FYM and other organic manures not only have the nutritive value, they also play an important role in structural improvements. This further influences leaching of salts and reduce their accumulation in the root zone. The other advantage of FYM in saline water irrigated soils are in terms of reducing the volatilisation losses and enhancing the nitrogen-use efficiency. Retention of nutrients in organic forms for longer periods also guards against leaching and other losses. In the context of the advantages of FYM and other organic manure, they should be applied to the maximum possible limit.

Cultural Practices

Owing to reduced germination, often a poor crop stands in fields irrigated with saline water. Thus, to ensure better populations following measures are suggested:

- Reduce inter/intra row spaces and use 20-30% extra seed than under normal conditions.
- Dry seeding and keeping the surface soil moist through sprinkler or post-sowing saline irrigation helps in better establishment of crops.
- Modifications in seedbed e.g. sowing near the bottom of the furrows on both sides of the ridges, applying irrigation in alternate row, and to seed on the north-east side of the ridges, is recommended. For the larger seeded crops, the seeds can be planted in the furrows. The furrow irrigation and bed planting system (FIRB) has been found better than conventional planting in cotton / pearl millet –wheat rotations.
- Adoption of measures for better intake of rainwater (tillage to open up soil) and its conservation in soil via checking unproductive evaporation losses (soil/ straw mulching) is recommended during monsoon season.

Management Options for Use of Alkali Water

Consistent efforts have been made at different research centers in the country to devise ways for the safe utilization of sodic water to raise agricultural crops. With scientific advances, the basic principles of soil-water-plant systems are now fairly well understood and advocate specialized soil, crop and irrigation management practices for preventing the deterioration of soil to levels which limit the crop productivity. Some such management measures for controlling the built up of ESP and maintaining the physical and chemical properties of sodic water irrigated soils are being discussed below.

Land Levelling and Rain Water Conservation

Proper land levelling and provision of 30-40 cm high strong bunds for capturing and retaining rainwater are the essential prerequisites for managing the land irrigated with sodic water. The surface soil should be protected against beating action of raindrops, which can be achieved through ploughing the field in between rains. This practice, besides increasing intake of rainwater helps in controlling the unproductive losses of water through weeds and evaporation. These practices also promote uniform salt leaching and self-reclamation through the dissolution of soil calcium carbonate.

Crop Selection

The guiding principle for choosing the right kind of crops and cropping patterns suitable for a particular sodic water is to select only those crops whose sodicity tolerance limits are lower than the expected soil sodicity (ESP) to be developed by the use of that water. Under average conditions of water use, the expected root zone sodicity can be approximated by 1.5 ´ SARiw in fallow- wheat, 2.0 ´ SARiw in millet- wheat and 3.0 ´ SARiw in rice-wheat cropping sequences. Thus, based on the expected ESP to be developed, the suitable crops can be chosen from the list of sodicity tolerant crops given in Table 6 & 7. Since use of sodic water requires repeated application of gypsum, it is advisable to select only tolerant and semi tolerant crops and their varieties having low requirements of water such as barley, wheat, mustard, oats, bajra and sorghum. The choice of promising cultivars can be made from the list given in Table 4. The other guidelines pertinent to selecting crops suitable for sodic water are :

- In low annual rainfall areas (< 400 mm) if the good quality canal water is not available, it is advisable to keep the fields fallow during *kharif* season. During *rabi*, only tolerant and semi-tolerant crops such as barley, wheat and mustard should be grown.
- For areas having rainfall >400 mm per annum, jowar-wheat, guar-wheat, bajra-wheat and cotton-wheat rotations can be practised, provided it is ensured that sowing, particularly of *kharif* crops is done with rain water or good quality canal water. Besides, not more than 2 to 3 irrigations should be applied with sodic water in the *kharif*.
- For areas having annual rainfall >600 mm in the rice-wheat belt of alluvial plains, rice-wheat, rice-mustard, sorghum-mustard, and *dhainacha* (green maure)-wheat rotations can be practiced with gypsum application.
- Alternating sodic water use between moderate water requiring crop rotation and a low water requiring crop helps in checking faster sodicity development by RSC bearing water.
- Sodic water should not be used for growing summer crops in the month of April to June.

Table 6. Relative tolerance of different crops to sodicity of soils

ESP Range*	Crops
10-15	Safflower, peas, lentil, pigeon pea, *urdbean*, banana
16-20	Bengal gram, soybean, papaya, maize, citrus
20-25	Groundnut, cowpeas, onion, pearl-millet, guava, *beal*, grapes
25-30	Linseed, garlic, guar, palma rosa, lemon grass, sorghum, cotton
30-50	Mustard, wheat, sunflower, *ber, karonda, phalsa*, vetiver, sorghum, *berseem, senji*
50-60	Barley, sesbania, paragrass, Rhoades grass
60-71	Rice, sugarbeat, *karnal grass*

*Threshhold ESP

Table 7. ESP tolerance of crops in alkali soils and irrigated with alkali water

Crop	Soil under reclamation			Alkali water irrigation		
	ESP_t^*	Slope	ESP_{75}^{**}	ESP_t	Slope	ESP_{75}
Cotton	—	—	—	14.9	1.3	34.1
Pearl millet	13.6	2.6	23.2	6.1	1.3	25.3
Rice	24.4	0.9	52.1	20.1	1.6	35.7
Wheat	16.1	2.1	28.0	16.2	1.9	29.38

*Threshhold ESP** ESP for 75% yield.

Use of Amendments

Sodic water can be safely and economically used after treating them with calcium bearing amendment such as gypsum. The agricultural grade gypsum can either be added to soil or applied in water through specially designed gypsum beds. Both methods are equally effective in neutralizing the RSC of water and its adverse effects. Acidic amendment like pyrites can also be used for amending the deleterious effect of high RSC water both as soil application and as pyrite bed. The quantity of gypsum applied should be known based on the analysis of water and irrigated soil. It depends on the RSC of water, extent of soil deterioration, and the water requirements of the intended crops and cropping system. However, following guidelines can be of additional help in deciding the need and quantity of amendments required for different sodic water use situations:

Gypsym Application

- Gypsum is generally not needed on well-drained light textured soils in fallow-wheat rotation. In double cropping, however, its application at the rate of 25% - 100% Gypsum Requirment (GR) of water has been reported to boost crop yields (Manchanda, et. al. 1985). Yadav *et al*. (1991) in another study has reported that addition of gypsum at the rate of 50% gypsum requirement of a loamy sand soil was found sufficient to grow even the sensitive *kharif* crops like pearl millet, *moongbean, urdbean*, cowpea and clusterbean in the presence of 600 mm rainfall.

- In relatively high annual rainfall regions (> 600 mm), gypsum application equivalent to 50% of gypsum requirement of water annually was found sufficient to sustain 8-9 Mg /ha of paddy and wheat yields (Sharma and Minhas, 2001) provided the final pHs of surface soil did not exceed 9.0
- Occasional application of gypsum at the rate of 1-2 tons/ha before rainy season is also recommended to offset infiltration problems created by high SAR saline water (SAR>20) particularly on heavy textured soils vulnerable to infiltration reductions.

Method and time of gypsum application in soil: Application of gypsum in the soil is easier than applying it through water. The powdered gypsum may be applied through broadcast in the requisite quantity on a previously leveled field and mixed in shallow depth of 10 cm with a cultivator or disking. The best time for application of gypsum is after the harvest of *rabi* crops, preferably in the month of May or June, if some rain has occurred. Otherwise, its application should be postponed till the first good monsoon showers are received.

Gypsum can be applied in the standing water also. The soil should be subsequently ploughed upon attaining proper soil moisture condition. Gypsum applied after the harvest of a r*abi* crop will also help in considerable improvement of the soil prior to the on set of *kharif* season. Pyrites has also been used for amending the deleterious effects of high RSC water. Pyrite application once before the sowing of wheat has proved better than its split application at each irrigation or mixing it with irrigation water (Chauhan et al., 1986).

Gypsum bed: An alternative approach to reclaim sodic water is to pass it through a specially designed chamber filled with gypsum clods. Using this approach, water can be reclaimed before it enters the field. The gypsum chamber consists of a brick-cement-concrete chamber, the size of which depends on tubewell discharge and RSC of water. The chamber is connected to a water fall box on one side and to water channel on the other side. A net of iron bars covered with wire net (2 mm x 2 mm) is fitted at a height of 10 cm from the bottom of the bed. With a little modification, the farmers can also convert their tube well waterfall chamber in to gypsum chamber. Sodic water flowing from below dissolves gypsum placed in chamber and gets reclaimed. By this method, the RSC of water was reported to be reduced from 5. 5 to 1.9 me/l by passing it through a chamber of size 2.0 x 1.5 x 1.0 m with tube well discharge of 6l/sec in studies conducted at HAU, Hisar.

Gypsum bed method is however, not suitable for reclaiming a very high RSC water (> 12 me/l) because in that case the size of the chamber becomes too large and the quantity of gypsum required to fill the chamber is too high. It has also been observed that the gypsum bed water quality improvement technique may not dissolve > 8 me/l of calcium. The response of crops to the application of equivalent amounts of gypsum, either by passing the water (RSC 9 meq/l) through gypsum beds where the thickness of bed was maintained at 7 and 15 cm, or the soil application of gypsum is presented in Table 8. Though crops under both rotations (paddy-wheat, sorghum-mustard) responded to the application of gypsum in either of the methods, overall response of crops was slightly more in case of sodic water which was ameliorated (3-5 meq/l) after passing through gypsum beds. Thus, it can be argued that gypsum bed technique can help in efficient utilization of gypsum.

Table 8. Average yields (Mg/ha) under paddy-wheat, mustard-sorghum (1993-2003) rotations and soil properties* as affected by equivalent doses of gypsum applied either to soil or passing sodic water through gypsum beds

Treatment	Paddy	Wheat	pH	ESP	Mustard	Sorghum	pH	ESP
Control (T_1)	3.08	2.68	9.6	66	2.27	1.18	9.5	61
Gypsum through beds								
3.3 meq/l (T_2)	3.97	3.73	8.0	19	3.06	1.98	8.0	25
5.2 meq/l (T_3)	4.24	3.93	8.0	18	3.18	2.13	8.0	24
Equivalent soil application								
As in T_2 (T_4)	4.31	3.71	8.2	20	2.86	1.92	8.0	26
As in T3(T_5)	4.52	3.89	8.1	20	3.00	2.05	8.1	24
LSD(p=0.05)	0.43	0.46			0.38	0.24		

* At the harvest of *rabi* (2002-03) crops. (AICRP Saline Water, 2002)

Irrigation Management

Conventional irrigation practices such as basin irrigation could be adopted to manage alkali water. Emphasis should be to minimize the irrigation with alkali water as deterioration of soil directly depends on the quantities of irrigation water. The 'alkali hazard' is reduced considerably, if the water is used alternatively or mixed with canal water. Besides reducing the gypsum requirement of soil, conjunctive use of alkali and canal water also helps in bringing more area under protective irrigation and also in controlling rise in ground water table and associated problems. Canal water should preferably be applied during initial stages including pre-sowing irrigation to boost establishment of crops. Studies have sown that when sodic water was used in cyclic mode equal to with canal water, yield of both the paddy and wheat crops were maintained with canal water except in the CW-2SW mode (Table 9).

Table 9. Effect of cyclic use of sodic and canal water on soil properties and crop yields

Water quality/mode	adj. SAR*	pH	ESP	Average yield (Mg/ha)	
				Rice	Wheat
Canal water (CW)	0.3	8.2	4	6.78	5.43
Sodic water (SW)	22.0	9.7	46	4.17	3.08
2 CW-1SW	8.9	8.8	13	6.67	5.22
1 CW-1SW	12.8	9.2	18	6.30	5.72
1 CW-2SW	18.5	9.3	22	5.72	4.85

	ECw dS/m	Ca	Ca+Mg	RSC	SAR	adj SAR
		…….(meq/l)……..				
CW	0.25	1.6	2.1	nil	0.3	0.4
SW	1.35	0.4	0.9	10.1	13.5	26.7

* After accounting for 828 and 434 cm of irrigation and rainwater, respectively.
* Source : Bajwa and Josan (1989)

Nutrient Management

Fertilizer Application

Since sodic water cause a rise in soil pH that leads to greater nitrogen losses through volatilization and denitrification, extra nitrogen may have to be added to meet the requirement of the crops. Similarly, the availability of zinc and iron is also low due to their precipitation as hydroxides and carbonates. Some beneficial tips as regards fertilizer use are:

- Application of 25% extra nitrogen is needed as compared to the normal conditions.
- Zinc sulphate @ 25 kg per ha should be added, particularly for the r*abi* crops.
- Phosphorus, potassium and other limiting nutrients may also be applied on the basis of soil test values.
- Some sodic water may be rich in nutrients such as nitrogen, potassium and sulphur. Water should be analysed and the fertiliser dose of concerned nutrient reduced accordingly.

Addition of Organic Materials

It is generally accepted that addition of organic materials improve sodic soils through mobilization of inherent Ca^{2+} from $CaCO_3$ (Calcium Carbonate)and other minerals by organic acids and increased pCO_2 in soils. The solublized Ca^{2+} in soil replaces Na^+ from the exchange complex. Reclamation of barren alkali soils by addition of organic materials has been widely reported. However for soils undergoing sodication, some disagreement exist in literature regarding the short–term effects of organic matter on the dispersion of sodic soil particles (Gupta et.al, 1984). Nevertheless, majority of the available reports still suggest the overall beneficial and positive role of FYM towards improving soil properties and crop yields. The response of organic sources also varies with the nature of organic matter added. Sekhon and Bajwa (1993) reported the effectiveness of different materials as: paddy straw > green manure> FYM. Moreover, with the mobilization of Ca^{2+} during decomposition of organic materials, the quantity of gypsum required for controlling the harmful effects of sodic water irrigation can be considerably decreased. Thus, occasional application of organic materials should help in sustaining yields of crops irrigated by sodic water.

Water Quality Guidelines

Based on the experiences of using saline and sodic water in the field and results from different experiments available on the subject, some guidelines have been prepared for water quality. These guidelines have been prepared at CSSRI, Karnal in consultation with the scientists from HAU, Hisar and PAU, Ludhiana which might be helpful for utilizing water more efficiently. These guidelines emphasize the long- term influence of water quality on crop production, soil conditions and farm management. These guidelines assume that all the rainwater received in the field is being conserved to impart leaching and desalinizing the upper root zone. The guidelines for Saline water RSC<2.5 meq/litre is listed in Table 10(a) and for alkali water (>2.5 meq/litre)is give in Table 10(b).

Table 10(a). Guidelines for using poor irrigation water

A. Saline water (RSC < 2.5 meq/l)

Soil texture (% clay)	Crop tolerance	Upper limits of ECiw (dS/m) in rainfall regions (mm)		
		350	350-550	550-750
Fine(> 30)	S	1.0	1.0	1.5
	ST	1.5	2.0	3.0
	T	2.0	3.0	4.5
Moderately fine(20-30)	S	1.5	2.0	2.5
	ST	2.0	3.0	4.5
	T	4.0	6.0	8.0
Moderately coarse(10-20)	S	2.0	2.5	3.0
	ST	4.0	6.0	8.0
	T	6.0	8.0	10.0
Coarse(< 10)	S	- -	3.0	3.0
	ST	6.0	7.5	9.0
	T	8.0	10.0	12.5

Note: S: sensitive, ST: semi-tolerant and T: tolerant crops.

These guidelines identify special consideration for saline water such as:

- Use gypsum when saline water (having SAR > 20 and/or Mg/Ca ratio > 3 & rich in silica) induces water stagnation during rainy season and crops grown are sensitive to it.
- Fallowing during rainy season is helpful when SAR > 20 and water of higher salinity are used in low rainfall areas.
- Additional phosphatic fertilization is beneficial, especially when C1/SO4 ratio in water is > 2.0.
- Canal water preferably is used at early growth stages including pre-sowing irrigation for conjunctive use with saline water.
- Putting 20% extra seed rate and a quick post-sowing irrigation (within 2-3 days) will help better germination.
- When ECiw < ECe (0-45 cm soil at harvest of rabi crops), saline water irrigation just before the onset of monsoon will lower soil salinity and will raise the antecedent soil moisture for greater salt removal by rains.
- Use of organic materials in saline environment improves crop yields.
- Accumulation of B, F, NO3, Fe, Si, Se and heavy metals beyond critical limits proves toxic. Expert advice prior to the use of such water may be obtained.
- For soils having (i) shallow water table (within 1.5 m in *kharif*) and (ii) hard sub-soil layers, the next lower ECiw/alternate mode of irrigation (canal/saline) is applicable.

Table 10 (b). Guidelines for irrigation water

B. Alkali water (sodic) with RSC > 2.5 meq/l and ECiw < 4.0 dS/m

Soil texture (% caly)	Upper limits of		Remarks
	SAR √(m mole/l)	RSC, meq/l	
Fine (>30)	10	2.5-3.5	1. Limits pertain to *kharif* fallow – *rabi* crop rotation when annual rainfall is 350 –550 mm.
Moderately fine (20-30)	10	3.5-5.0	2. When the water have Na < 75%, Ca+Mg >25% or rainfall is > 550mm, the upper limit of the RSC range becomes safe.
Moderately coarse (10-20)	15	5.0-7.5	3. For double cropping, RSC neutralization with gypsum is essential based on quantity of water used during the *rabi* season. Grow low water requiring crops during *kharif*. Avoid growing rice.
Coarse (<10)	20	7.5-10.0	

Textural criteria should be applicable for all soil layers down to at least 1.5 m depth. In areas where ground water table reaches within 1.5 m at any time of the year or a hard subsoil layer is present in the root zone, the limits of the next finer textural class should be used. Fluorine is at times a problem and limits should be worked out.

Policy Guidelines

In order to implement various technological options for enhancing the use of saline sodic water under real world field situations, the management strategies must be backed by strong policies on water management. In this section some of the policy guidelines are outlined:

Water Quality Monitoring Network

At present no systematic data collecting network is available in most developing countries. Data are gathered in random fashion and there is no mechanism for their proper storage. Water quality management must form an integral part of overall water management objectives at the basin or canal command level. Thus, systematic database must be generated on water quality through network of stations in the basin or irrigation commands by strengthening the existing central and state level agencies.

Modifications in Surface Water Delivery Schedules

Consistent with the irrigation system water supplying capacity, release from reservoir based schemes should be modified to deliver more water during pre-sowing irrigation. This is essentially a case of intra-seasonal modification in water delivery scheduling. Policy interventions are required to ensure canal water supplies at sowing time of crops in saline irrigated areas.This would encourage farmers to bring more area under cultivation leading to enhanced productivity.

Ground Water Pumping Pricing

The present scenarios of providing substantial public subsidies in terms of free electricity is not only costing the exchequer but also leading to huge withdrawl of ground water in areas underlain with better quality water. Thus, a careful assessment of costs, public information, and education on costs of water services and consequences of subsidies are important for rational pricing strategies. Pricing of electricity has to be differential. Areas endowed with better quality water may be charged higher electricity tariff so that 'water save' concept could be given practical shape whereas area disadvantaged with poor quality water may be provided with additional subsidies for the promotion of judicious use of electricity. Moreover, the electricity networks in the saline areas should be made more intensive as the number of tube wells required are more in poor aquifers as compared with the good aquifer.

Subsidies on Amendments

The farmers in areas underlain with alkali water further have to incur additional recurring costs on the amendments such as gypsum for sustaining crop productivity. Though the state governments provide for the subsidies on gypsum for alkali soil reclamation these are not rendered in alkali water areas. This matter needs to be addressed as more farmers are shifting to paddy-wheat cultivation in such areas, and demand for amendments are increasing.

Promoting Conjunctive Use

Technically sound and economically viable technologies are available for conjunctive use of surface and poor quality ground water that not only promote the latter's use but also can help maintain overall salt and water balances in the basins. However, so far due to regional/state level conflicts, the better quality surface water resources are not being made available for regions already suffering from the twin problems of scarcity as well as saline ground water resources. Such issues should be tackled on priority to give thrust to agricultural production in the affected areas.

Further Subsidies on Micro-irrigation Systems/Dorouv Technology

Development of micro-irrigation systems including the use of drips, which of course are more capital intensive is considered to be the major innovation to enhance the use of low quality water. Though subsidies are given for promoting these techniques, further incentives are required for installation of such water saving irrigation systems. Farmers nedd to be trained also in marketing opportunities for selling their produce. A case in point is grapes which was introduced on large scale in Hissar and Sirsa districts of Haryana without any proper processing and market mechanisms in place. As a consequence, farmers suffered heavy losses and abandoned the crop. On the other hand in Bijapur where organised marketing and processing facilities are functional, the farmers are using saline water with drip irrigation systems.

Participatory Planning

In order for policy guidelines to be effective, participatory planning, by including the farmers is critical. Especially the planning process should be restructured for improving the services and promoting user's participation at the lower levels of the irrigation systems. For example, includ ing group of farmers at the tail end of the irrigation system, who make use of poor quality water and are usually left out of the planning exercises.

Training Needs

Existing staff skills need to be upgraded and new expertise introduced for water quality monitoring and management. The other alternative is to acquire new capabilities through recruitment of specialists in water quality management to address the newly emerging challenges.

Recharge Measures

Cost effective artificial recharge measures have to be adopted on the basis of water balance studies in the sub-basins. Surface water bodies and canal systems have to be fully utilised for achieving recharge through potential zones especilly during spill season.

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