5 Managing Saline and Alkaline Water for Higher Productivity

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Abstract

Two major approaches to improving and sustaining high agricultural productivity in a saline environment involve: (i) modifying the environment to suit the available plants; and (ii) modifying the plants to suit the existing environment. They could be used separately or together to make possible the productive utilization of poor-quality water without compromising the sustainability of the production resource at different management levels. This chapter discusses the issues arising from the use of these approaches as related to the use of marginal-quality water, at both field and irrigation-system levels.

The results are reviewed of field studies encompassing areas with low to moderate monsoonal rainfall (400–600 mm), underlain by saline/alkaline water and supplemented with deficit canal-water supplies, sufficient only to meet 40–50% of irrigation requirements. Analysis of the results indicates that there are good possibilities of achieving reasonably high water productivity on a sustainable basis by appropriate technological interventions. Some important interventions that have been identified include *in situ* conservation of rainwater in precisely levelled fields; blending saline/alkaline and fresh water to keep the resultant salinity below threshold or to achieve its amelioration; and, if residual sodium carbonate cannot be brought down to acceptable levels, dilution-blending or cyclic application and scheduling irrigation with salty water at less salt-sensitive stages. In high-water-table areas, provision of subsurface drainage facilitates the use of higher-salinity water, reducing the overall irrigation requirement. At higher levels of irrigation systems, it was found that water productivity in saline environments can be improved by a number of measures. These include reallocation of water to higher-value crops with a limited irrigation requirement, spatial reallocation and transfer of water-adopting polices that favour development of water markets and reducing mineralizing of fresh water by minimizing application and conveyance losses that find a path to saline aquifers.

In spite of the technological advances that mitigate salinity damage and the likely economic advantages, there is always a need to exercise caution while practising irrigation with salty water for maintaining sustained productivity.

Introduction

Water productivity in agriculture, which is often used as a criterion for decision-making on crop-production and water-management strategies, is severely constrained by salinity of land as well as of water. Salinity of water is more common than that of the land and it is often the cause of salinity development in soils, largely because of the misuse of salty

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water for crop production. There are two major approaches to improving and sustaining productivity in a saline environment: modifying the environment to suit the plant and modifying the plant to suit the environment. Both these approaches have been used, either singly or in combination (Tyagi and Sharma, 2000), but the first approach has been used more extensively because it enables the plants to respond better not only to water but also to other production inputs. The development of the management options requires the analysis of sensitivity parameters that affect interaction between salinity and crop yield (Zeng *et al.*, 2001). The sensitivity of crop growth stages often determines management options to minimize yield reductions and to promote the use of salty water. Most management practices aim at keeping salinity in the crop root zone below the threshold salinity of the given crop at the growth stage in consideration. Though the general threshold limits are fairly well established (Maas, 1990), the threshold salinities for different stages are not well defined. The information gap is more serious for alkaline water than for saline water.

Most studies on the effect of salty water on crop yield refer to individual crops, but, in actual practice, the interseasonal salinity balance that actually influences the crop yields is greatly modified by the cropping sequence. The management practices also vary according to the cropping system followed. Therefore, it is important to consider the saline/alkaline water-use practices not only for individual crops but also for the cropping system.

In the past, water productivity has been expressed either in terms of irrigation efficiency (the term mostly used by engineers) or in terms of water-use efficiency (mostly used by agriculturists). The first term has a hydrological basis and can be extended from field to river-basin scale. In other words, the irrigation efficiency can be defined in a system, with one level having a relationship to the other in the irrigation-system hierarchy. This issue is discussed in other chapters in this volume (e.g. by Seckler *et al.*, Chapter 3, and Molden *et al.*, Chapter 1) and is of great importance in planning saline-water use. Most agricultural research has treated saline/alkaline water use in the context of root-zone salinity management, involving the application or withholding of irrigation to maintain an environment favourable to crop production. This approach has enabled the development of management practices at field level without considering their implications and practicability at the farm/irrigation-system/river-basin levels. It should, however, be clearly understood that, just like the water balance, the salinity balance also has to be maintained at field and irrigation-system/basin levels (Tyagi, 2001). Manipulation of water diversions of different qualities and origins can be successfully used as a tool for enhancing water productivity on a sustainable basis (Srinivasulu *et al.*, 1997). Such manipulations would normally involve reallocation and intrasystem/intraseason water transfers, which could be facilitated by development of water markets (Strosser, 1997). This process could begin at the watercourse level, which is the lowest level of large traditional irrigation systems in countries like India and Pakistan, and spread upward in the system hierarchy.

Lastly, productivity should be understood not only in terms of physical outputs, such as grain or biomass yield, but also in economic terms, such as revenue or profit earned per unit of water diverted, at different levels of the irrigation system. Some time ago, much concern was expressed in the state of Haryana (India) when an overall decline in productivity was reported in certain rice-growing areas (Anon., 1998); but, later on, it was discovered that the decline in productivity was due not to any malfunctioning of the system, but to a shift from high-yielding coarse rice varieties to more remunerative basmati rice, which had a lower yield but fetched a far higher price in the market. Incidentally, a salt-tolerant variety of basmati rice (CSR-30) is now available.

Productivity-enhancing measures are discussed that involve the use of saline/alkaline water at field level, such as conjunctive use, water-table management, rainwater conservation in precisely levelled basins and chemical amelioration of alkaline water. Though not exclusive, this discussion of the productivity-enhancing measures is in the context of the rice–wheat system in a monsoonal climate with moderate rainfall (400–600 mm), as prevails in north-west India, where the occurrence of saline/alkaline water is more prevalent (Fig. 5.1). Water reallocation and transfer, water markets and saline-water disposal, which have irrigation-system/basin-level implications, are also briefly presented.

Salinity/Alkalinity Hazards

The most important criterion for evaluating salinity hazards is the total concentration of salts. The quantity of salts dissolved in water is usually expressed in terms of electrical conductivity (EC), mg l^{-1} (p.p.m.) or meq l^{-1}. The cations Na^+, Ca^{2+} and Mg^{2+} and the anions Cl^-, SO_4^{2-}, HCO_3^- and CO_3^{2-} are the major constituents of saline water. Plant growth is adversely affected by saline water, primarily through excessive salts raising the osmotic pressure of the soil solution, resulting in reduced water availability. In field situations, the first reaction of plants to the application of saline water is reduced germination. This reduced initial growth results in smaller plants (lower leaf-area index). Experimental evidence indicates that the interplay of several factors, such as the evaporative demand, salt content, soil type, rainfall, water-table conditions and type of crop and water-management practices, determines salinity build-up in the soil and crop performance resulting from long-term application of saline water.

Some water, when used for the irrigation of crops, has a tendency to produce alkalinity/sodicity hazards, depending upon the absolute and relative concentrations of specific cations and anions. The alkalinity is generally measured in terms of the sodium adsorption ratio (SAR), residual sodium carbonate (RSC) and adjusted SAR. Irrigation

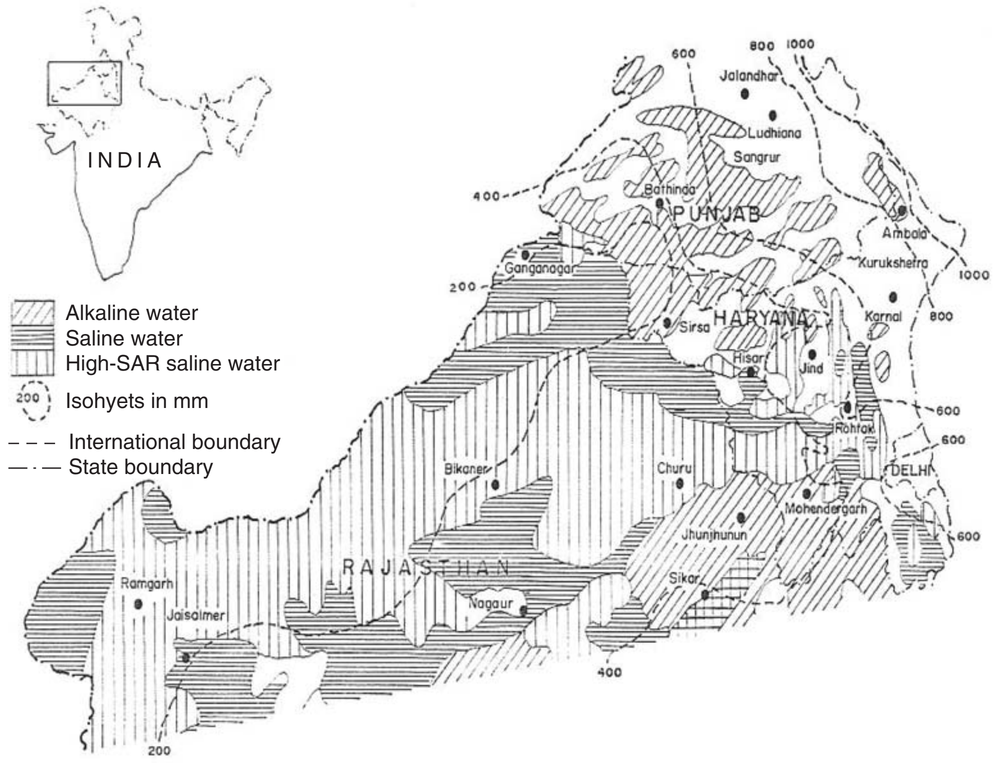

Fig. 5.1. Distribution of alkaline and saline groundwater in north-west India.

with sodic water contaminated with Na^+ relative to Ca^{2+} and Mg^{2+} and high carbonate (CO_3^{2-} and HCO_3^-) leads to an increase in alkalinity and sodium saturation in soils. The increase in exchangeable sodium percentage (ESP) adversely affects soil physical properties, including infiltration and aeration. In the early stages of sodic irrigation, large amounts of divalent cations are released into the soil solution from exchange sites. In a monsoonal climate, alternating irrigation with sodic water and rainwater induces cycles of precipitation and dissolution of salts. Several field observations have shown that, although steady-state conditions are never reached in a monsoonal climate, a quasi-stable salt balance is reached within 4–5 years of sustained sodic irrigation, while a further rise in pH and ESP is very low (Minhas and Tyagi, 1998).

Seasonal Water Balance and Salinization and Desalinization Cycles

In north-west India, the annual weather exhibits three distinct phases, the first of which is the hot and humid season from mid-June to September, when about 80% of the rainfall takes place. This phase covers the growing period of kharif crops, i.e. cotton, pearl millet, maize, sorghum and paddy. The second phase is the the cool and dry season from October to March, which covers the growing period of most rabi crops, including wheat, mustard, gram and barley. The third phase is characterized by hot and dry weather, which prevails from April to mid-June, which covers part of the growing periods of wheat, cotton and maize. A seasonal water-balance analysis shows that, in relative terms, winter and summer months, being dry, are water-deficit periods, whereas the kharif season from mid-June to September has some surplus water (Fig. 5.2). The salinity build-up in the soil is greatly influenced by the weather and the irrigation practice. In waterlogged saline areas, maximum salinity is observed in the pre-monsoonal period in June. This is because, after the first week of April, wheat, which is the dominant irrigated crop, receives no irrigation till its harvest. From mid-April till mid-June, the land remains mostly fallow, when there is no irrigation and there is an upward moisture flux due to high evaporative demand, which results in salinity build-up. With the onset of the monsoon and the planting of crops that receive irrigation, the desalinization of the soil profile takes place, and the salinity reaches a minimum value in

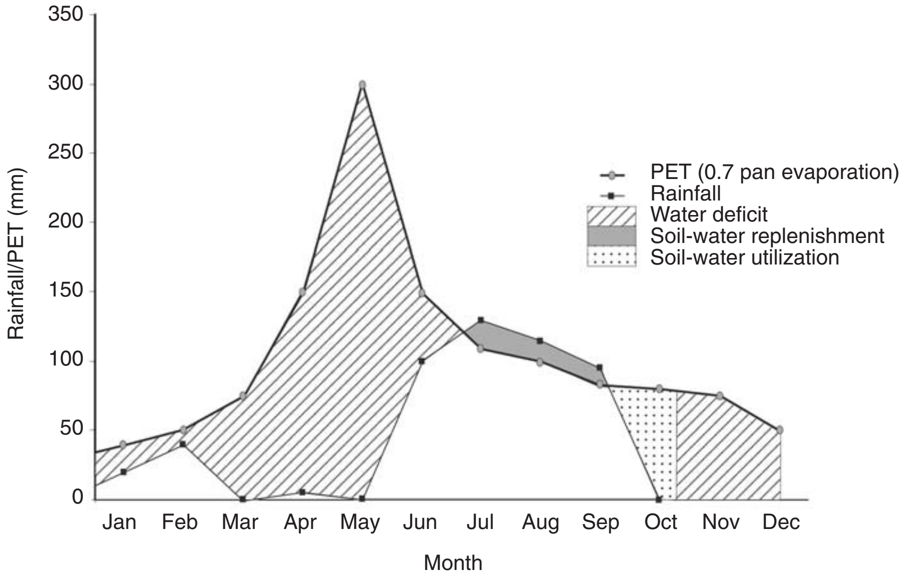

Fig. 5.2. Annual climatic water balance at Karnal. PET, potential evapotranspiration.

October (Fig. 5.3). From November to February, the evaporative demands are low (the value reaches less than 1 mm day^{-1} in December–January) and therefore the upward flux is low. The low initial salinity in the beginning of the rabi season favours saline irrigation, which is further facilitated by low evaporative demands during this season. This limits the rate of salinization in the soil profile due to saline irrigation. By the time the summer season starts, the crops are mature and are able to tolerate higher salinity. The monsoonal water leaches the salts accumulated during the winter and early summer, which is why the limits for the use of saline/sodic water can be higher in this region than recommended elsewhere.

Root-zone Salinity Management

Most research on the use of saline/alkaline water has focused on keeping root-zone salinity under control by various management practices. The important practices include multi-quality water use in different modes, scheduling irrigation with saline water in a manner that avoids its application at sensitive stages, use of chemical amendments, precision levelling and high-frequency irrigation, etc. In situations where high water tables with saline water prevail, subsurface drainage and water-table manipulation are often introduced to promote the use of brackish water.

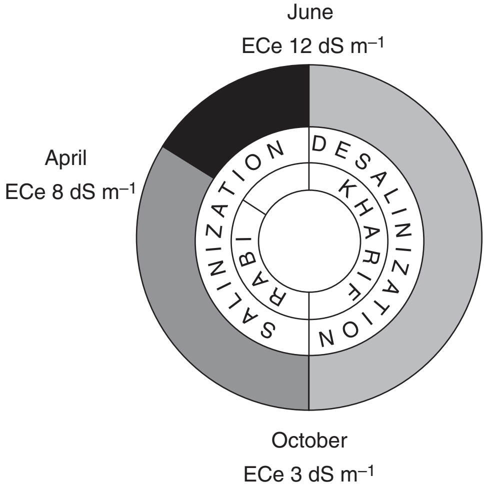

Fig. 5.3. Salinization and desalinization cycle in monsoonal climate. ECe, EC of the soil saturation extract.

Multi-quality irrigation practices

Possible ways of practising multi-quality water use are as shown below. These include direct application of salty water, as well as different modes of blending or cyclic use.

Water-application modes and their impact on productivity

Among the various application modes, direct application of saline water can be practised where salinity of the water is such that a crop can be grown within acceptable yield levels without adversely affecting soil health. It was reported by Boumans *et al*. (1988) that marginal-quality water (EC of 4–6 dS m^{-1}) was being used directly in several locations in Haryana. The average yield depressions for crops, including cotton, millet, mustard and wheat, were less than 20%. When higher-salinity water is used directly, a pre-sowing irrigation, if required, is given with fresh water. To practise joint use of saline and freshwater, the available options are blending and the cyclic mode. Blending is promising in areas where fresh water can be made available in adequate quantities on demand. The potential for blending two different supplies depends on the crops to be grown, salinities and quantities of the two water supplies and the economically acceptable yield reductions. Cyclic use is most common and offers several advantages over blending (Rhoades *et al.*, 1992). In sequential application under the cyclic mode, the use of fresh water and saline water is alternated according to a predesigned schedule. Sometimes, there is interseasonal switching, where supplies of fresh water and saline water are applied in different seasons. In a field study, Sharma and Rao (1996) found that saline drainage effluents could be used in different modes without appreciable yield reduction in a wheat crop (Table 5.1).

Table 5.1. Effect of different salinity levels of applied water (blending and cyclic application) over a period of 6 years (1986/87 to 1991/92) on grain yield of wheat.[a]

	Blending		Cyclic application		
EC_{iw} ($dS\ m^{-1}$)	Mean yield ($t\ ha^{-1}$)	Relative yield (%)		Mean yield ($t\ ha^{-1}$)	Relative yield (%)
< 0.6 (FW)	6.0	100	4 FW	6.0	100
6	5.8	96.0	FW + DW	5.8	96.7
9	5.0	80.3	DW: FW	5.6	93.3
12	5.0	80.3	2 FW + 2 DW	5.7	95.0
12 (DW)	4.7	78.3	2 DW + 2 FW	5.4	90.0
			1 FW + 3 DW	5.1	85.0
			4 DW	4.5	75.0

[a] The drainage water had an EC = 12.5–27 $dS\ m^{-1}$ and SAR = 12.3–17.
FW, fresh water; DW, drainage water.

Impact of saline-water use on soil health

The salinity build-up in soil profiles after 6 years of irrigation with different-quality water, in fields provided with subsurface drainage, is shown in Fig. 5.4 (Sharma and Rao, 1996). It can be seen that, for all water with salinity in the range of 0.5–12 $dS\ m^{-1}$, soil salinity at the end of the monsoonal season is reduced to less than 4 $dS\ m^{-1}$.

Several studies have suggested that irrigation water containing salt concentrations exceeding conventional suitability standards can be used successfully on many crops for at least 6–7 years without significant loss in yield. However, uncertainty still exists about the long-term effects of these practices. Long-term effects on soil could include soil dispersion, crusting, reduced water-infiltration capacity and accumulation of toxic elements. The effects on some soil properties (sandy loam soils) of irrigation with high-salinity drainage effluent, as practised in the Sampla drainage area (Haryana), were moni-

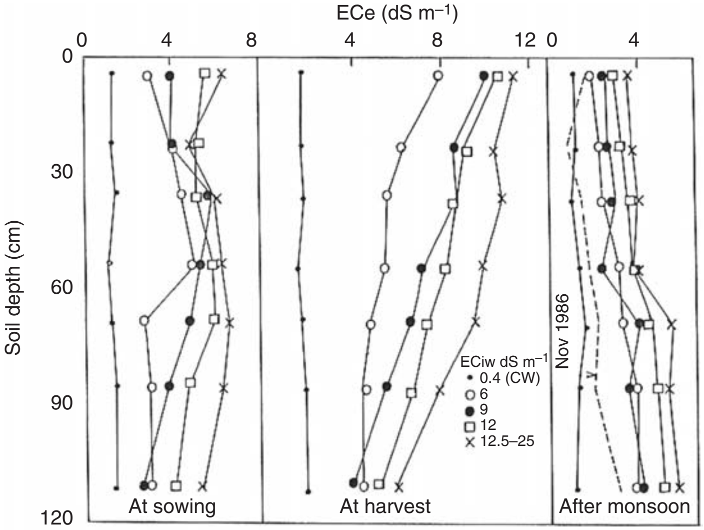

Fig. 5.4. Increase in soil salinity in different treatments after 6 years. ECe, EC of the soil saturation extract; EC_{iw}, electrical conductivity of irrigation water; CW, canal water.

tored for 6 years. Since the SAR of saline drainage water was more (12.3–17.0) than that of canal water (0.7), its use increased soil SAR in all the treatments (Fig. 5.5).

Leaching of salts by monsoonal rains reduced the SAR of the soil saturation extract (SARe) in all the treatments and the remaining SARe values did not constitute any alkaline hazard to the succeeding crops. Similarly, no significant adverse effects were observed on saturated hydraulic conductivity or water-dispersible clay after the monsoonal rains. A slight decrease in hydraulic conductivity after monsoonal leaching will not be a problem during the irrigation season since the negative effect of high SAR of drainage water is offset by the high salinity of the drainage water. The slight variation in water-dispersible clay after 6 years of irrigation with drainage effluent indicates only minimal structural deterioration in soils irrigated with high-salinity drainage effluent. Although no potential adverse effects were observed in these studies at the Sampla farm (Haryana), caution should be exercised when considering the reuse of drainage effluent and the specific conditions should be carefully evaluated.

Use of alkaline water and chemical amelioration

Water having alkalinity/sodicity problems is encountered on a large scale in the rice–wheat-growing areas of Punjab and Haryana in north-west India. Several studies have shown that this water can be used under certain conditions. In a study conducted over a period of 6 years (1981–1987) by Bajwa and Josan (1989), it was found that irrigation with sodic water given after two turns of irrigation with fresh water, to rice as well as to wheat, helped in obtaining yields comparable to those with irrigation with fresh water (Table 5.2). Crop yields even in the case of alternate irrigation with sodic and fresh water were only marginally less than when fresh water alone was used. On average, rice received 18 irrigations, whereas only five turns of irrigation of 6 cm were applied to wheat. In all cases, pre-sowing irrigation was given with fresh water and no amendments to neutralize sodicity were applied. At the end of 6 years, the ESP in plots irrigated entirely with sodic water increased from 3.5 to 46% whereas in alternate irrigation with fresh water and sodic water the ESP

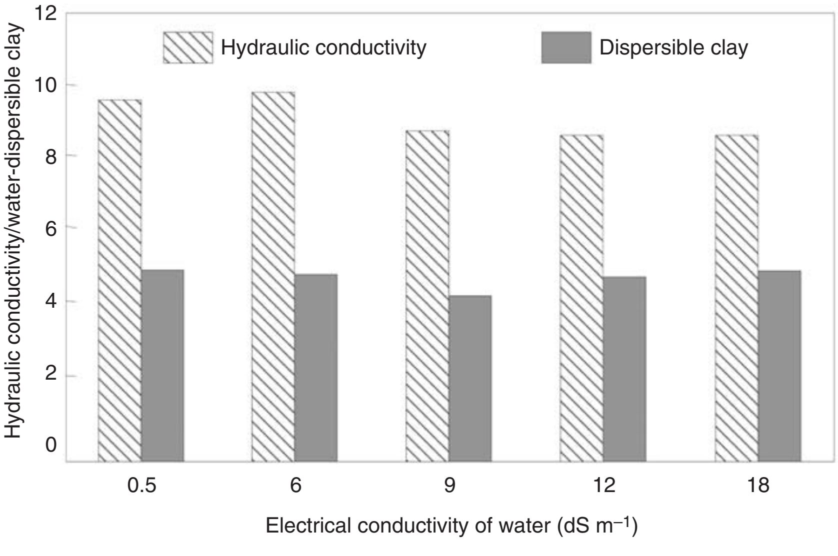

Fig. 5.5. Saturated hydraulic electrical conductivity (mm h^{-1}) of soil saturation extract measured three times during the year, and water-dispersible clay (%) of 0−30 cm layer.

Table 5.2. Average grain yield of rice and wheat as affected by the use of fresh water and alkaline water over a period of 6 years (1981–1986).

Treatment	Crop yield (t ha^{-1})	Irrigation-water productivity (kg ha^{-1} cm^{-1}) Rice	Rice–wheat	Wheat
Fresh water (FW)	6.7	5.4	62	180
Alkaline water (AW)	4.2	3.6	39	120
2 FW–AW	62	6.7	5.2	173
FW–AW	58	6.3	5.3	177
FW–2 AW	53	5.7	4.8	160

AW: EC 1.25 dS m^{-1}; SAR = 13.5; RSC = 10 meq l^{-1}.

increased to a level of only 18.2% (Fig. 5.6). The increase in ESP points to the danger involved in the use of these supplies of water.

It should be understood that, when fields are irrigated with poor-quality water, the yields can only be maintained at a lower level than when irrigated with good-quality water if no amendments are applied. The levels at which yields can be sustained depend not only upon the alkalinity of the groundwater but also on the water available from rainfall and canals, etc. Sharma *et al.* (2001), based on a 7-year study (1993–1999), evaluated the sustainable yield index (SYI), which indicates the minimum guaranteed yield as a percentage of the maximum observed yield. The SYI is defined as $(Y - S)/Y_{max}$, where Y is the average yield, S is the standard deviation and Y_{max} the maximum yield (in the study area it was 6 t ha^{-1} for rice and 5 t ha^{-1} for wheat). The SYI ranged from 0.57 to 0.65 in rice and from 0.54 to 0.65 in wheat (Table 5.3) at different doses of applied gypsum. The overall build-up of pH (8.5), SARe (20.7) and EC of the soil saturation extract (ECe) (2.5 dS m^{-1}) in the soil remained below the threshold salinity levels of these crops. This may be due to dilution by rainwater along with the high Ca or Ca + Mg content of the water used. The low level

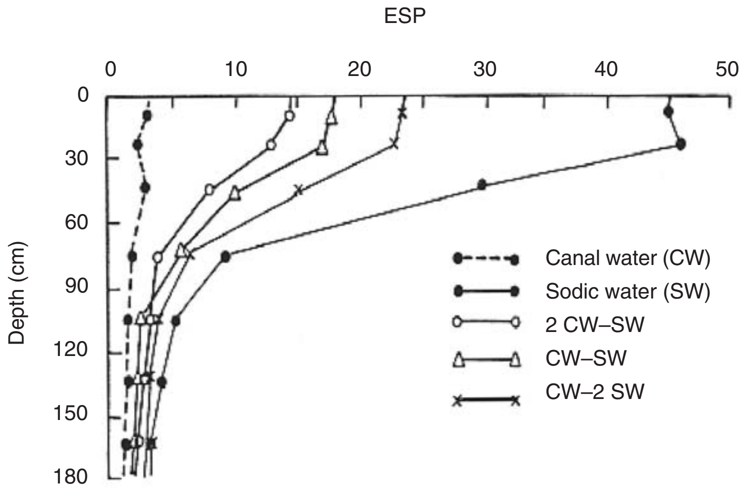

Fig. 5.6. Build-up of exchangeable sodium percentage (ESP) in 0–30 cm soil layer over time (6 years) with sodic water application in different combinations.

Table 5.3. Crop yield and sustainable yield index (SYI) for rice–wheat cropping irrigated with gypsum-amended alkaline water (from Sharma *et al.*, 2001).

Treatment (% GR)	Gypsum applied	Crop yield (t ha^{-1})	SYI		
			Rice	Wheat	Rice–wheat
0	0	4.01	3.55	0.57	0.54
12.5	1.24	4.22	3.75	0.60	0.60
25.0	2.50	4.13	3.68	0.60	0.58
50.0	5.00	4.26	3.82	0.61	0.62
75.0	7.50	4.22	3.83	0.62	0.62
100.0	10.00	4.48	3.94	0.62	0.63
Canal water	Nil	4.46	3.85	0.65	0.65

GR, Gypsum requirement for neutralizing completely sodicity.

of sodification could also be attributed to large biological production and dissolution of CO_2 occurring in submerged rice fields. It was concluded that a maximum yield of about 60% in both rice and wheat can be sustained with the use of alkaline water (RSC = 10 meq l^{-1}) if 1.25 t ha^{-1} of gypsum is applied annually to rice–wheat in the medium-rainfall zone (500–600 mm).

Cropping sequence

The irrigation, drainage and agronomic practices vary from crop to crop. Therefore, the crop grown in the previous season greatly influences the production and productivity of the crop in the subsequent season. In a monsoonal climate, crops that favour higher retention and *in situ* conservation of rainwater, which is salt-free, result in lesser salinity/sodicity development in the soil profile at the end of the season, providing a better environment for the next crop. In a 6-year study conducted at the Central Soil Salinity Research Institute (CSSRI) (Sharma *et al.*, 2001), three important cropping sequences (rice–wheat, cotton–wheat and sorghum–wheat) were compared in terms of their productivity when applied with alkaline water. The productivity of the rice–wheat system in kharif and rabi seasons was higher than the sorghum–wheat and cotton–wheat systems (Table 5.4).

Table 5.4. Equivalent rice and wheat yields (t ha^{-1}) as affected by cropping sequence when irrigated with alkaline water (from Sharma, D.K., 2001, personal communication).

	Equivalent rice yield (kharif)		Equivalent wheat yield (rabi)		Total equivalent yield (wheat)		Soil pH_2	
	Water quality		Water quality		Water quality		Water quality	
Cropping sequences	AW	FW: AW	AW	FW: AW	AW	FW: AW	AW	FW: AW
Sorghum–wheat	2.9	3.5	3.8	4.1	6.22	6.92	9.1	9.0
Rice (basmati)–wheat	4.8	7.0	3.7	4.7	7.62	9.65	9.1	9.0
Cotton–wheat	3.5	4.1	3.5	3.8	6.3	6.66	9.0	9.0
Rice (Jaya)–mustard	4.0	4.3	4.0	4.4	7.27	7.32	9.1	9.0
Rice (Jaya)–berseem (clover)	3.3	4.1	2.7	3.0	5.41	6.31	9.3	9.1

AW, alkaline water; FW, fresh water.

Shallow water-table management

Providing drainage to ensure that the salt concentration does not exceed the level that can be tolerated by crop roots is a requirement for continued productivity. Provision of drainage and leaching over a period of time leads to improvement in the quality of subsoil water in drained fields. The upper few centimetres of subsoil water have very little salinity, and plants could be allowed to use it by manipulating the operation of the drainage system. Thus the plants would meet part of their evapotranspiration needs directly from soil water. The use of groundwater by the crops is related to the water-table depth and the salinity of subsoil water (Chaudhary *et al.*, 1974). Minhas *et al.* (1988) observed that in sandy loam soil with the water table at 1.7 m depth and with groundwater salinity at 8.7 dS m^{-1}, the water table contributed as much as 50% of the requirement when only irrigation was applied.

In another study, a shallow water table at 1.0 m depth with salinity in the range of 3.0 to 5.5 dS m^{-1} gave rise to yield levels equal to the potential yield with good-quality irrigation water, even when the application of surface water was reduced to 50% (Sharma *et al.*, 2001). These fields had been provided with subsurface drainage. The salinity build-up was negligible and the small amount of salt that accumulated was leached in the subsequent monsoonal season. The provision of subsurface drainage also allows the use of higher-salinity water through surface applications (Minhas, 1993; Sharma *et al.*, 2001). The yield reduction with progressively increasing salinity of applied water was much less in fields having a subsurface drainage system than in fields with a deeper water table, which had no need of artificial subsurface drainage. The differences are highly marked at applied water salinities of more than 10 dS m^{-1} (Table 5.5). Relatively higher moisture in the crop root zone in fields with subsurface drainage could be the reason for the higher productivity.

Table 5.5. Relative yield of wheat with saline irrigation under conditions of a deep water table and a high water table but provided with subsurface drainage (from Minhas, 1993; Sharma *et al.*, 1991).

Irrigation-water salinity (dS m^{-1})	Relative yield (%)	
	Deep water table	Shallow saline water table[a]
0.6	95	100
4.0	90	94
8.0	83	86
12.0	60	78
16	42	74[b]

[a]There was provision for subsurface drainage to leach and remove salts.

[b]Salinity varied between 14 and 26.5 dS m^{-1}, the average being 16 dS m^{-1} and the yield varied between 50 and 86%, with an average of 74%.

Improving Economic Efficiency of Water Use

The commonly used definition of water productivity does not take into account the net benefits that accrue from crop production. It should, however, be understood that farmers are interested in increasing water productivity only to the level at which it maximizes their net benefits. The cost of cultivation and the prevailing market price often decide the crop variety that the farmers cultivate, irrespective of the physical water productivity. Growing crops that use less water and have low cost of cultivation but fetch a higher price in the market can enhance economic efficiency. A case in point is the increase in area of basmati rice in several districts of Haryana (Kaithal, Kurukshetra Panipat) in places with marginal-quality water. The yield of basmati rice is only 50% (about 2 t ha^{-1}) of the coarse rice varieties, such as Jaya and IR-8, but its irrigation requirements are about 60–65% of the coarse varieties. Although basmati rice has lower tolerance for sodicity, the supplemental irrigation with alkaline water is also less and its nitrogenous fertilizer demand is only 70% of the coarse variety.

In a field study that involved sequential application of fresh water and alkaline water (FW:AW), the equivalent yield of basmati was 7 t ha^{-1} as compared with only 4.3 t ha^{-1} for Jaya (Table 5.4). The higher economic returns led to its cultivation in a larger area in Haryana, though its physical water productivity may be only half of Jaya or IR-8. In more arid areas, where fresh water during the rabi season is scarce, similar trends are observed with mustard, which replaces wheat because of its much higher salt tolerance and requirement of only one or two post-sowing turns of irrigation compared with four or five turns of irrigation for wheat.

Special Considerations for the Use of Saline/Alkaline Water

The following are the important points that should be considered in developing saline/alkaline water-use programmes.

Pre-sowing irrigation

Pre-sowing irrigation has a significant influence on crop yields harvested at the end of the season. This is because seed germination and seedling stage are the most sensitive stages. Early salinity stress leads to poor crop stand and considerable yield reduction. The response of wheat to salinity was observed to vary with its growth stage, initial salinity distribution in the soil profile and the modes of saline-water application (irrigation with blended or sequential application) (Sharma *et al.*, 1993). The ECe_{50} (ECe for 50% yield reduction) values increased from 9.3 dS m^{-1} for periods from sowing to crown rooting to 13.2 dS m^{-1} from dough stage to maturity (Fig. 5.7). The effect of pre-sowing irrigation with fresh water and saline water was studied at CSSRI for several crops (Table 5.6). It was observed that one of the most sensitive crops (e.g. mung bean) could sustain irrigation with saline water of 4.7 dS m^{-1} if non-saline water was used at the pre-sowing stage. The water productivity of mung bean, when irrigated with fresh water at pre-sowing and subsequently with saline water (EC_w 4.7), was 41 kg ha^{-1} cm^{-1}, compared with only 12 kg ha^{-1} cm^{-1} when irrigated with saline water throughout the growing period. Though less drastic, a similar trend was observed in mustard. (Note: the values of water productivity are based on water extracted from the soil profile during the growth periods.)

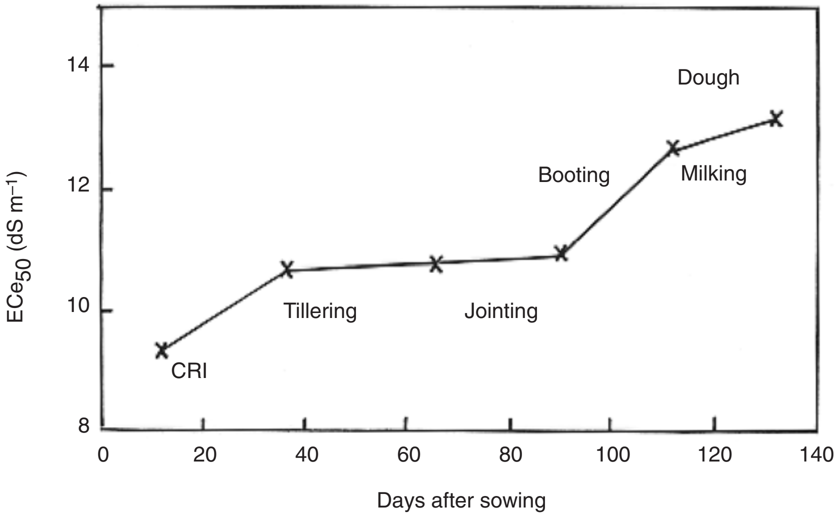

Fig. 5.7. Salinity tolerance of wheat at various growth stages (ECe_{50} denotes ECe for 50% yield reduction). CRI, crown root initation stage.

Table 5.6. Crop yield and water productivity as influenced by irrigation-water salinity and application sequence with different-quality water (from Sharma *et al.*, 1993).

Irrigation-water salinity (dS m^{-1})	Water-quality application sequence	Crop yield (t ha^{-1})	Water productivity (kg ha^{-1} cm^{-1})
Mung bean			
0.3	Entire season	2.52	56
4.7	Entire season	0.27	12
4.7	After PI_{FW}	1.56	41
Mustard			
0.3	Entire season	2.32	63
12.3	Entire season	1.05	58
12.3	After PI_{FW}	1.80	64

PI_{FW}, pre-sowing irrigation with fresh water.

Favourable season

Crops grown during the winter season (wheat, mustard and barley) are more tolerant to saline water than those grown during summer (pearl millet, sorghum and groundnut). Also, the soil profile is almost free of salts after the monsoon leaching and has a capacity to receive salts without exceeding critical limits. Added to this is the more favourable evapotranspiration regime of the winter season. Evapotranspiration peaks again after March, when the crop is mature and can tolerate higher salinity.

Crop substitution

Most agricultural crops differ significantly in their tolerance of a concentration of soluble salts in the root zone. It is desirable to choose crops/varieties that can produce satisfactory yields under the conditions resulting from irrigation with saline water. The difference between the tolerance of the least and the most sensitive crops may be eight- to tenfold. This wide range of tolerance allows for considerable use of marginal water supply. The extent by which the tolerance limits for the use of low-quality water are raised governs the greater use of such water, thereby reducing the need for leaching and drainage (Tyagi, 1998). Semi-tolerant to tolerant crops and those with low water requirements should be grown. For example, mustard is salt-tolerant and it requires only one or two turns of irrigation after seeding. Experiments at Sampla (Haryana) indicated that highly saline drainage water can be used for post-planting irrigations of mustard without any substantial loss in yield. Thus mustard can be substituted for wheat in part of the area because it tolerates salinity of up to 6 dS m^{-1} for normal yields.

Precision levelling

The use of saline and alkaline water supplies often requires the application of smaller depths at relatively more frequent intervals. In surface-water application methods, the distribution of water and the application depths are greatly influenced by the quality of land levelling. Salinity and non-uniformity in irrigation water have much the same effect on the yield–water response function and both require larger volumes of irrigation water to produce the same yields as can be obtained with non-saline water and uniformly applied water (Howell *et al.*, 1990). In surface irrigation, the uniformity of the soil surface affects the required application depths. In a field study (Tyagi, 1984), it was observed that the system application depth ranged from 40 to 120 mm as the levelling quality decreased

(Fig. 5.8). Higher application depths were associated with lower application efficiencies: with a levelling index (LI) of 0.75 cm, the application efficiency was as high as 90% compared with 45% at an LI of 6.75 cm. The non-uniformity in levelling was reflected in a water-productivity value of 93.1 kg ha^{-1} cm^{-1} at LI = 0.75 cm to 59.1 kg ha^{-1} cm^{-1} at LI = 6.75 cm. The study indicated that to ensure a desired system application depth of 5–6 cm, required to achieve optimum productivity and income, the levelling quality had to be such that the average deviation from the desired depth was less than 3 cm.

Rainwater conservation

Rainwater conservation is the key to the use of poor-quality water as it not only meets part of the irrigation requirements but also facilitates leaching of salt. The quantity of rain that can be conserved within the field depends upon the crop grown during the monsoonal season. Rice paddies offer the most appropriate conditions for retaining rainwater within the field. Raul *et al.* (2001) showed that, in parts of Kalayat and Rajaund administrative blocks in Haryana (India) having alkaline water with an RSC between 5 and 10 meq l^{-1}, rice paddies enabled *in situ* conservation of 95% of monsoonal rains, thereby helping to sustain rice–wheat cropping on 60–70% of the area. In these blocks, between 30 and 40% of the irrigation requirement of rice and over 50% for wheat is met by groundwater mixed with conserved rain, which dilutes the saline/alkaline groundwater to make it usable. Rainwater conservation and the use of gypsum sustain the continued use of these alkaline water supplies in the region.

Enhancing and Sustaining Water Productivity at Irrigation-system Level

One of the options to improve water productivity in physical and economic terms is the transfer of water and spatial reallocation through a change in the water-allocation policies or through a water market. Other options include diversion of water to more productive and profitable uses and reducing salinization of fresh water in areas underlain by saline/alkaline aquifers by improving the on-farm irrigation conveyance efficiency. The sustainability of saline agriculture can be ensured by maintaining the salinity balance within the river basin through evacuation and disposal of salt water to areas outside the basin.

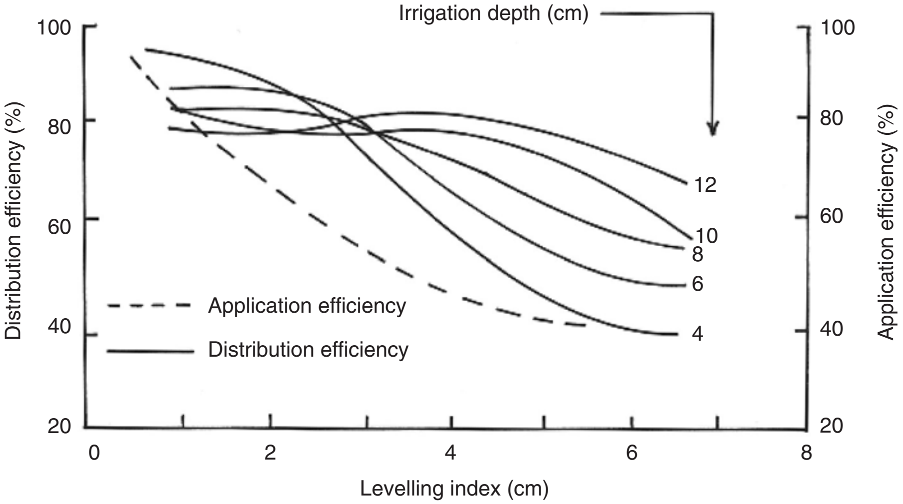

Fig. 5.8. Relationship between levelling index and distribution efficiency at different irrigation depths (from Tyagi, 1984).

Loss in productivity due to salinization of fresh water and its prevention

Fresh water that is lost through seepage and percolation in areas underlain by saline aquifers also becomes saline. Though this water can be reused for irrigation, crop yields will be less. How much less depends on the salt tolerance of the crop, cropping pattern, quantity and quality of applied water and climatic conditions. Obviously, the losses in production and productivity are area-specific. An attempt to estimate the production losses with increasing salinity of groundwater used for irrigation was made for Sirsa and Hisar districts in Haryana and is shown in Fig. 5.9. The financial losses with groundwater salinity of up to 3 dS m^{-1} were within Rs 500 ha^{-1} $year^{-1}$. At higher salinity levels, the losses increased at a very high rate, reaching Rs 8000 ha^{-1} $year^{-1}$ at a groundwater salinity of 10 dS m^{-1}, which has a profound effect on the profitability of the farming enterprise. In areas underlain by saline aquifers, percolation and seepage losses should therefore be reduced as much as possible. Tyagi and Joshi (1996) investigated the techno-economic viability of reducing accretions to groundwater in saline groundwater areas through irrigation-system improvements. Reducing salinization of groundwater by cutting down on up to 75% of the application, distribution and conveyance losses had a high profitability.

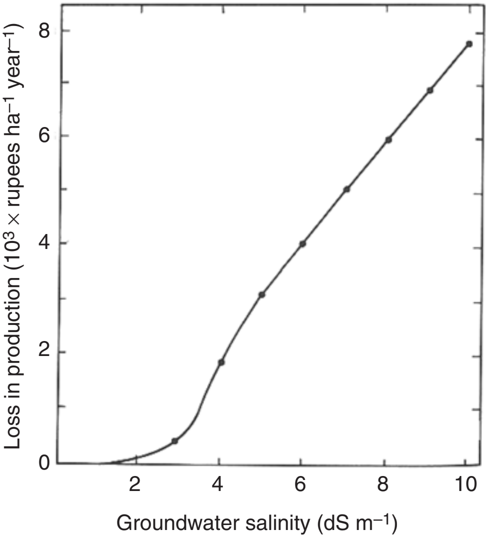

Fig. 5.9. Agricultural production losses as a function of groundwater salinity.

Conjunctive use

Supplies of both fresh water and saline water are limited but the availability of saline groundwater is more dependable. For a given level of canal water and salinity of the groundwater, the farming enterprise will remain profitable until the incremental benefits balance the incremental costs.

A profitability analysis was carried out for wheat irrigated with saline groundwater at a given level of canal-water supply for a watercourse command area in the Kaithal district to see how far the application of saline water would remain economically viable (Anon., 2001). Two levels of canal-water supply (10 and 15 cm ha^{-1}) were considered. It was found that the profit decreased from Rs 12,000 ha^{-1} to Rs 7000 ha^{-1} when the canal-water supply was decreased from 15 cm to 10 cm with a groundwater (EC = 6 dS m^{-1}) use of 15 cm (Fig. 5.10). Since the overall availability of groundwater at system level is also limited, the chance of minimizing productivity losses by applying more groundwater does not appear to be feasible. The only option is to reduce irrigation intensity (irrigated area/cropped area) and to arrive at an optimal mix of irrigated and rain-fed areas.

Productivity increase through the promotion of a groundwater market at watercourse level

The large difference in supply between the head and the tail reaches is a common problem. This problem gets compounded when there is a high overall deficit in canal supplies needed to meet the demand of the culturable command area (CCA) of the canal system. Typical examples are the western Yamuna and Bhakra canal system, where the canal-water supplies are adequate to meet only 30–50% of irrigation demands per crop

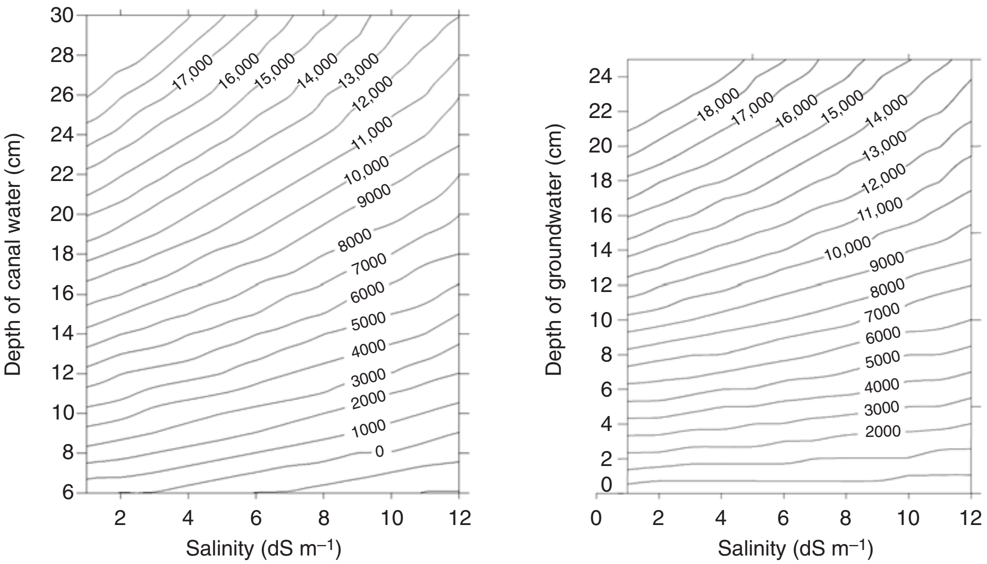

Fig. 5.10. Profitability of conjunctive use of groundwater of varying salinity and canal water at two levels of supply.

season. The water inadequacies at the tail end are further complicated by the progressive decrease in groundwater quality from head to tail reaches. A typical case that has been investigated pertains to the Kaithal circle of Bhakra canal in Haryana. Here the availability of canal water progressively decreased from 25 cm ha^{-1} in the head reach to 8 cm ha^{-1} in the tail reach, with groundwater salinity increasing from 2.5 dS m^{-1} to 6.8 dS m^{-1} (Fig. 5.11).

The water table in the head reach is also substantially higher than in the tail reach. This situation favours the development of

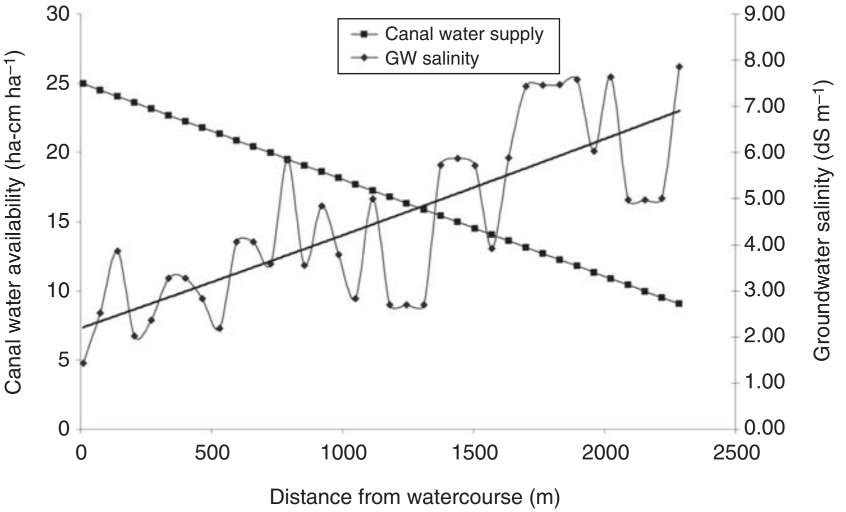

Fig. 5.11. Variation in availability of canal water and salinity of groundwater (GW) from head to tail reach of watercourse no. 25963 L (Batta Minor).

groundwater through shallow tube wells in the head reach and its transfer to the tail reach. Such small-scale water markets are already in existence in Haryana and their existence in the Chistian Subdivision in Punjab (Pakistan) has been investigated by Strosser (1997), who mentioned that the impact of a tube-well water market on farm gross income was significant at 40% of the actual gross income, aggregated for eight sample watercourses. However, he also mentioned that water markets could lead to decreased aquifer recharge and an increase in the soil salinity. The potential increase in relative yield with such groundwater transfer from the head to the tail reach of a watercourse in Batta Minor (Bhakra system) was analysed using the SWAP model (Chandra, 2001). The results indicated that the relative yield would increase from 0.70 to 0.85 in the entire watercourse if 50% of marginal-quality groundwater from the head reach was transferred and used in the tail reach without disturbing canal-water allocation. The relative yield would go up to 0.89 if, instead of blending, the groundwater was used in a cyclic mode (Fig. 5.12).

The state of Haryana has experimented with the transfer of groundwater from freshwater areas with higher rainfall and greater availability of canal water to areas that are less favourably endowed with water. This relieved waterlogging and stabilized the canal water supply in the lower reaches. This practice on a limited scale has been adopted in marginal groundwater areas in the Hisar district by installing shallow tube wells along the branch and distributary canals. Since the projects were state-funded and were not market-oriented, technical and hydrological constraints that operate at higher spatial levels would need to be understood and resolved before promoting saline-water development and use at system level. Particular attention will have to be paid to reduced canal water flow and increased salinity of mixed water as one moves from the head reach of the minors/distributaries/branch canals to their lower reaches.

Balance between saline-water use and disposal

One of the important objectives in groundwater development is to maintain salinity below critical levels for the crops to be grown in the region. Continued recirculation of saline water without any disposal of salts would make the aquifers more saline and ultimately unusable. Therefore, not all saline water can or should be used. How much of it can be used depends upon the supplies of fresh water (canal), rainfall, original salinity of the

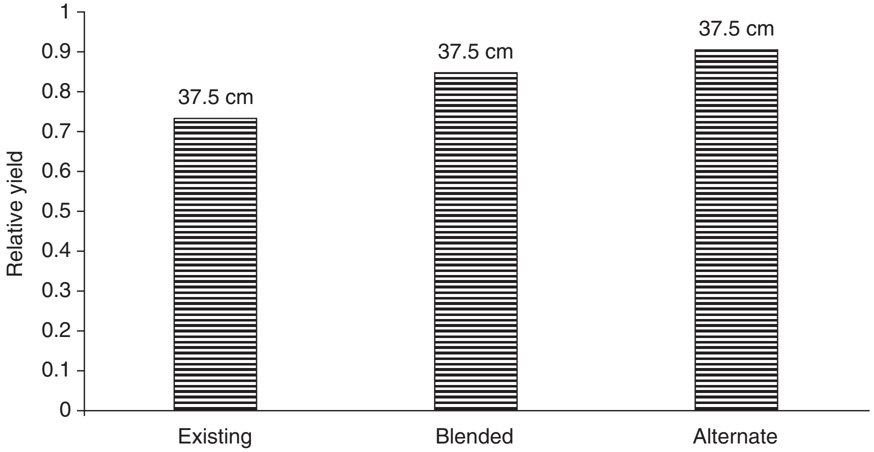

Fig. 5.12. Improvement in water productivity at watercourse (25963L) level by groundwater transfer from head to rail reach.

effluents, soil characteristics, crops and drainage conditions. Srinivasulu *et al.* (1997) have estimated that water equivalent to a minimum of 15% of the annual groundwater recharge with an average EC of 6 dS m^{-1} will have to be disposed of to maintain the salinity balance in groundwater underlying Sirsa and Hisar districts of Haryana. Such a disposal rate would ensure sustainability. Similar estimates will have to be made for other areas.

Extent and Actual Saline Water-use Practices

Irrigation with saline water, developed through shallow tube wells and open wells, is quite extensive. These tube wells were developed primarily for irrigation but have also been providing drainage relief. Studies based on a farm survey conducted in 1983/84 and reported by Boumans *et al.* (1988) estimated that in marginal and saline water zones about 120,000 ha-m were being pumped through more than 68,900 shallow tube wells in 1982/83. It was inferred that the rise in water table was slowed down largely due to these wells. Recent estimates show that 316,000 ha were being irrigated with saline water in the state of Haryana (Manchanda, 1996), of which 75,000 ha were in the region where waterlogging and salinity are either an existing or a potential threat.

Water-use practices

Several water-use practices are in vogue. The survey in the Hisar district (Haryana), mentioned above, also found that saline water pumped by shallow tube wells is, in most cases, used directly without any mixing. Mixing is normally done only if the salinity exceeds 6 dS m^{-1} and, in such cases, the water from the tube well is pumped into a watercourse carrying canal water. Farmers also resort to pumping of groundwater into the canal or watercourse if they perceive that the watercourse discharge is too small to cover the planned irrigation area in the allotted time. Cyclic use of canal and saline water is more common. This is largely because canal water is available for only a few hours after each rotation period of 2–4 weeks' duration and because the opportunity to irrigate with mixed or blended water is small. This constraint could be relaxed if on-farm reservoirs were constructed (Tyagi and Sharma, 2000).

Some farmers do not follow the practice of intraseasonal conjunctive use but reserve a parcel of land for irrigation by saline water only. In that case, they grow salt-tolerant crops, such as mustard, which is not given any pre-sowing irrigation but is sown in residual moisture after the rainy season and is given one or two supplementary turns of irrigation. Since the canal-water charges are levied on an area basis and not on the basis of the number of irrigation turns received from canal water, the farmers save on canal irrigation charges (though the charges are very low) by adopting this practice. The area receiving irrigation exclusively from tube wells with saline water is rotated every season/year to avoid salinization of a particular piece of land. If the tube wells yield water with high RSC, gypsum, which is readily available from the Land Reclamation Corporation outlets, is applied to neutralize the sodicity. Gypsum is either applied to the soil or put into the channel in gunny bags on which water from the tube well falls and slowly dissolves the gypsum. In such cases, gypsum is not powdered but is in the form of big clods. A more scientific way of applying gypsum is through gypsum-dissolving beds, which are specifically constructed for this purpose. Whether applied to the soil or applied with the irrigation water, the basis for computation of the gypsum requirements remains the same. There is, however, a difference in the time of application. In the case of soil-applied gypsum, the entire quantity of gypsum required, estimated on the basis of the amount and quality of the RSC-rich water, is applied all at once. If the sodicity of the soil is already high, the gypsum required to neutralize the RSC of the applied water may have to be applied at the beginning of the season; otherwise, it could be applied before the next crop is planted. In the case of water-applied gypsum, neutralization takes place before its application and there is, therefore, no build-up of sodicity in the soil.

Availability of gypsum is ensured through an organized arrangement with the government.

Epilogue

Saline/alkaline water has been successfully used to augment irrigation supplies and help to raise water productivity in semi-arid regions. This success can be attributed largely to available canal water supplies, which make it possible to plan and practice irrigation with marginal-quality water when it is least harmful and also in diluting the salt concentration in the root zone, keeping it below threshold limits. Monsoonal rainfall, which plays a crucial role in the desalinization cycle, is another factor that regulates the seasonal salt balance in the root zone to permit saline-water use even with traditional irrigation methods. More saline water is used during winter, when it is more productive and least harmful. Similar successes with saline/alkaline water, use have not been achieved in more arid areas, which do not have the benefit of canal irrigation. In those areas, interseasonal fallowing and rain-fed farming with very limited use of saline water applied to salt-tolerant crops continue to be the norm.

In irrigated areas provided with an extensive canal network but with an inadequate water supply, saline groundwater development through shallow tube wells is primarily for irrigation but it also keeps the water table in check. However, continued recirculation and reuse of the marginal-quality water without any disposal of saline water outside the system brings the danger of slowly salinizing both soil and aquifers. In the long run, the practitioners of this technology of using saline/alkaline water, which was initially shown to be successful at the field scale, will have to consider regional salt balances. Simulation studies based on limited data indicate a gradual rise in salinity of both soil and aquifers when the use of saline/alkaline water is extended to larger areas and continued for a long time.

Considering the present situation in respect of saline/alkaline water use, it looks attractive to focus on research that would help develop strategies for the use of this water in areas with only a small and inadequate amount of seasonal rainfall. Harnessing synergetic effects of improved salt-tolerant crop varieties and of improved hydraulic technologies offers a possible approach to enhancing productivity in such areas.

Unlike the crop–water–salinity relationship of saline water, the production functions for alkaline water are not well established. Also, the impact of the use of this water on groundwater aquifers is not well known. Field research and monitoring that would help bridge these gaps in our current understanding deserve our attention.

There are numerous models that help in generating scenarios for the possible consequences of saline-water use on a regional scale. However, models for scenario building at irrigation-system/river-basin scale, where groundwater alkalinity is a problem, are missing. Added to this is the problem of the vast amounts of data that are required but are seldom available for the areas where they are most needed. Therefore, studies aimed at the generation of data to be used in the regional salt- and water-balance model are needed if the sustainability of the technology that improves water productivity at field scale is to be ensured at a higher level of the irrigation system/river basin.

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