MANAGING SALINE AND ALKALI WATERS FOR HIGHER PRODUCTIVITY

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Abstract

Two major approaches to improving and sustaining high agricultural productivity in 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 in substitutional as also in inclusive mode to make possible the productive utilization of poor quality waters without compromising the sustainability of the production resource based at different levels of management units. Some of these issues, as related to the use of marginal quality waters, both at field and irrigation system levels are highlighted.

An overview of the results of field studies encompassing areas with low to moderate monsoonal rainfall (400-600 mm) and underlain by saline/alkali waters, supplemented with deficit canal water supplies, sufficient only to meet 40-50 percent of irrigation requirements shows that there are good possibilities of achieving reasonably high water productivity on sustainable basis by appropriate technological interventions. The important interventions include: in-situ conservation of rainwater in precisely leveled fields; blending saline/alkali and fresh waters to keep the resultant salinity below threshold or their amelioration, if residual sodium carbonate cannot be brought down to acceptable levels by dilution blending or cyclic application and scheduling irrigation with salty waters at less salt sensitive stages. In high watertable areas, provision of sub-surface drainage facilitates the use of higher salinity waters, reducing the overall irrigation requirement. At higher levels of irrigation system, water productivity in saline environment has been found to increase by reallocation of water to higher value crops with limited irrigation requirement, spatial reallocation and transfer of water adopting polices that favour development of water markets and reducing mineralization of fresh water by minimizing application and conveyance losses that find path to saline aquifers.

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

1. 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 wide spread and often is the cause of salinity development in soils, largely because of the misuse of salty waters for crop production. There are two major approaches to improving and sustaining productivity in 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, to not only water, but also to other production inputs. The development of the management options requires the analysis of sensitivity-parameters, which affects interaction between salinity and crop yield (Zeng et al., 2001). Sensitivity of crop-growth stages often determines management options to minimize yield reductions and promotion of salty water use. Most management practices aim at keeping salinity in the crop rootzone, where the action for plant growth takes place, at levels which are 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 alkali waters as compared to saline waters.

Most studies on the effect of salty water use on crop yield refer to individual crops. But in actual practice inter-seasonal 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/alkali water use practices not only for individual crop but also for the cropping system.

Water productivity in the past has been expressed either in terms of irrigation efficiency (the term mostly used by the engineers) or in terms of water use efficiency (mostly used by agriculturists). The first term has 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 bearing relationship with the other in the irrigation system hierarchy. This issue has been pointedly brought out in the introductory paper by Barker and Kijne (2001) and is of great importance in planning saline water use. Most agricultural research has treated saline/alkali water use in the context of rootzone salinity management involving application or withholding of irrigation to maintain an environment favourable to crop production. This approach has enabled development of management practices at field level without much consideration of the implications/practicability at the farm/irrigation system/river basin level. It should however be clearly understood that like water balance, salinity balance has also to be maintained not only at field but irrigation system/basin level (Tyagi, 2001). Manipulation of water diversions of different qualities and origins can be successfully used as a tool for enhancing water productivity on sustainable basis (Srinivaslu et al., 1997). Such manipulations would normally involve reallocation and intra-system /intra-season water transfers which could be facilitated by development of water markets (Strosser, 1997). This process could begin at the level of watercourse, which is the lowest level of large traditional irrigation system in countries like India and Pakistan and spread upward in the system hierarchy.

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

The productivity enhancing measures with use of saline/alkali water at field level such as conjunctive use, watertable management, rainwater conservation in precisely leveled basins and chemical amelioration of alkali waters are discussed. Though not exclusively, but largely the productivity enhancing measures are discussed in the context of rice-wheat system in monsoonal climate with moderate rainfall (400-600 mm) as it prevails in northwest India where occurrence of saline/alkali water is more prevalent (Fig. 1). Water reallocation and transfer, water markets and saline water disposal which have irrigation system/basin level implications, are also briefly presented.

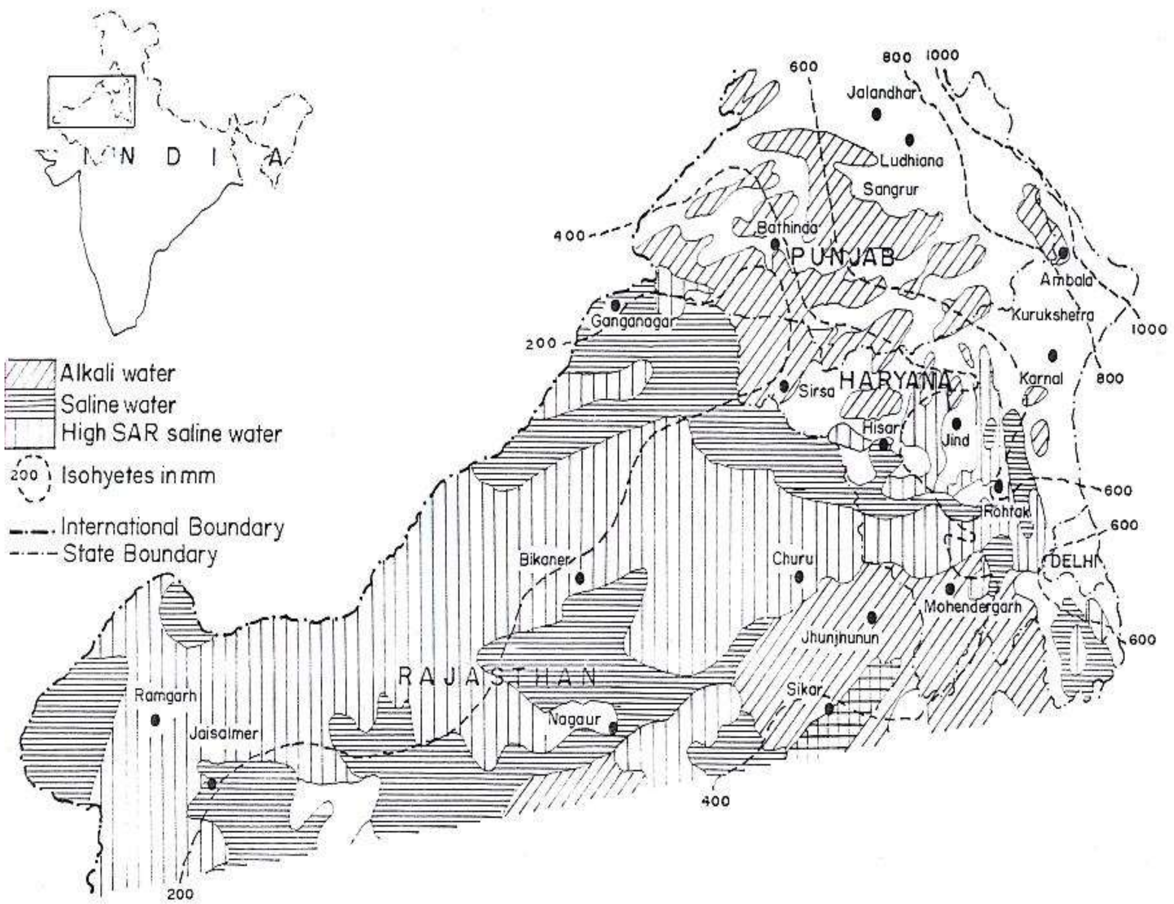


Fig. 1. Distribution of alkali and saline ground waters in north-west India.

2. Salinity/Alkalinity Hazards

The most important criteria 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} (ppm) or mel^{-1}. Mostly cations like Na^+, Ca^{2+} and Mg^{2+} and anions like Cl^-, $SO^{2-}{}_4$, $HCO^-{}_3$ and $CO^{2-}{}_3$ are the major constituents contained in saline waters. Plant growth is adversely affected with saline water, primarily through the effects of excessive salts on osmotic pressures of the soil solution resulting in reduced availability of water. Under the field situations, the first reaction of plants to application of saline water is reduction in germination. A general conclusion can be that the detrimental effect of salinity include, reduced initial growth resulting in smaller plants (lower leaf area index). Experimental evidences indicate that the inter-play of factors like nature and contents of salts, soil type, rainfall, watertable conditions and nature of crop and water management practices followed determine the resultant salinity build up vis a vis crop performance from long term use of saline water.

Some waters, when used for irrigation of crops, have 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 sodium adsorption ratio (SAR), residual sodium carbonate (RSC) and adjusted SAR (Adj SAR). Irrigation with sodic waters contaminated from Na^+ relative to Ca^{2+} and Mg^{2+} and high carbonate (CO^{2-}_3 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 soil solution from exchange sites. Under monsoonal climate alternating irrigation with sodic water and rainwater induces cycles of precipitation and dissolution of salts. Several field observations have shown that though steady state conditions are not reached in monsoonal climate, but quasi-stable salt balance is reached within 4-5 years of sustained sodic irrigation and further rise in pH and ESP is very low (Minhas and Tyagi, 1998).

3. Seasonal Water Balance and Salinization and Desalinization Cycles

In northwest India, the annual weather exhibits three distinct phases: (i) hot and humid season from mid June to September when about 80 percent of the rainfall takes place. This phase covers the growing period of kharif crops namely, cotton, pearlmillet, maize, sorghum, and paddy, (ii) cool and dry season from October to March, which covers the growing period of most rabi crops including wheat, mustard, gram and barley and (iii) hot and dry weather which prevails from April to mid June, which covers part of growing period of wheat, cotton and maize. Seasonal water balance analysis shows that in relative terms winter and summer months being dry are water deficit periods, whereas kharif season from mid June to September has some surplus water (Fig. 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 pre-monsoon 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. The land remains mostly fallow from mid April till mid June 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 monsoon and planting of crops that receive irrigation, the desalinization of the soil profile takes place, and the salinity reaches a minimum value in October (Fig. 3). During November to February, the evaporative demands are low (the value reaches less than 1 mm/day in December-January) and therefore upward flux is low. The low initial salinity in the beginning of 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 summer season starts, the crops are at maturity stage and are able to tolerate higher salinity. The salts accumulated during winter and early summer get leached with monsoon water. This is the reason why the limits for use of saline/sodic waters are higher in this region than recommended elsewhere.

4. Rootzone Salinity Management

Most researches on use of saline/alkali waters have focussed on keeping rootzone salinity under control by various management practices. The important practices includes 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 watertable with saline water prevails, provision of sub-surface drainage and watertable manipulation is often practised to promote use of brackish waters.

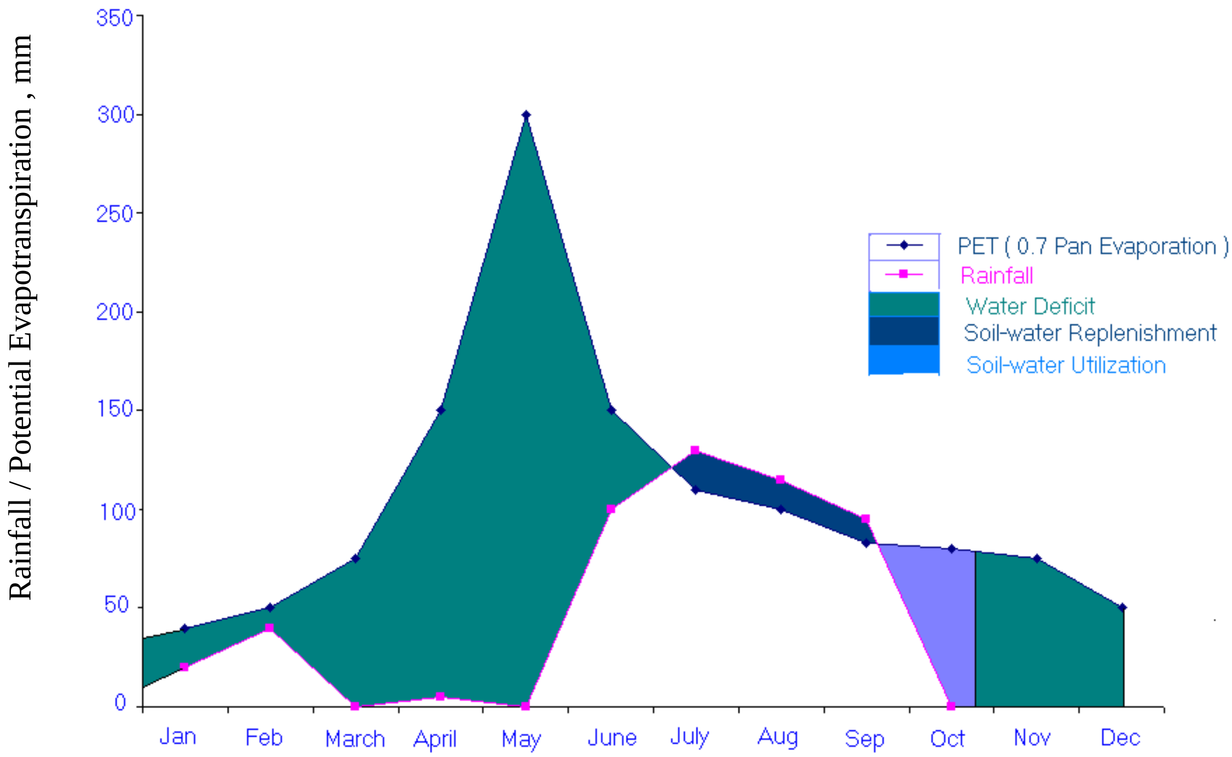


Fig. 2 Annual climatic water balance at Karnal.

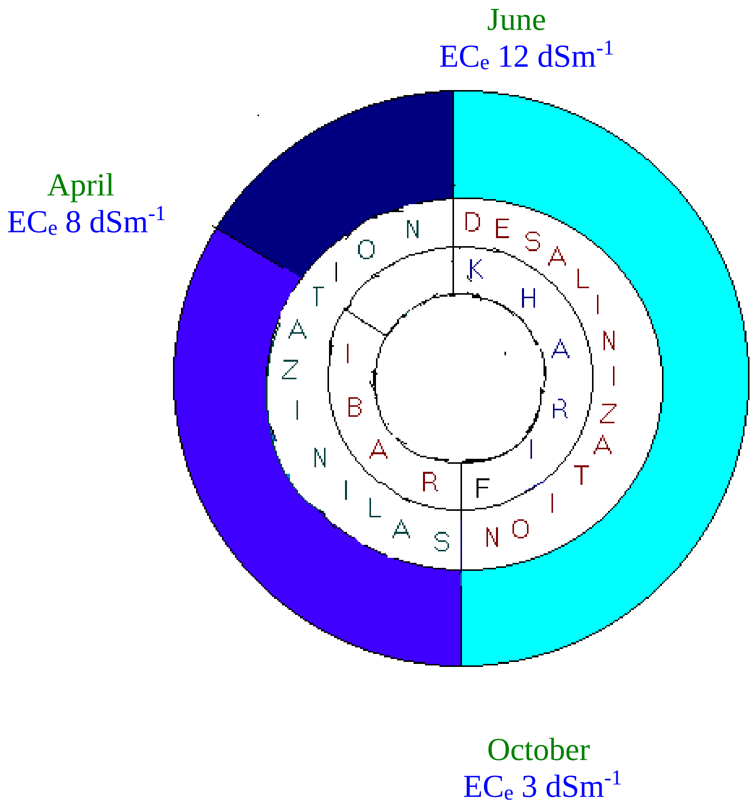
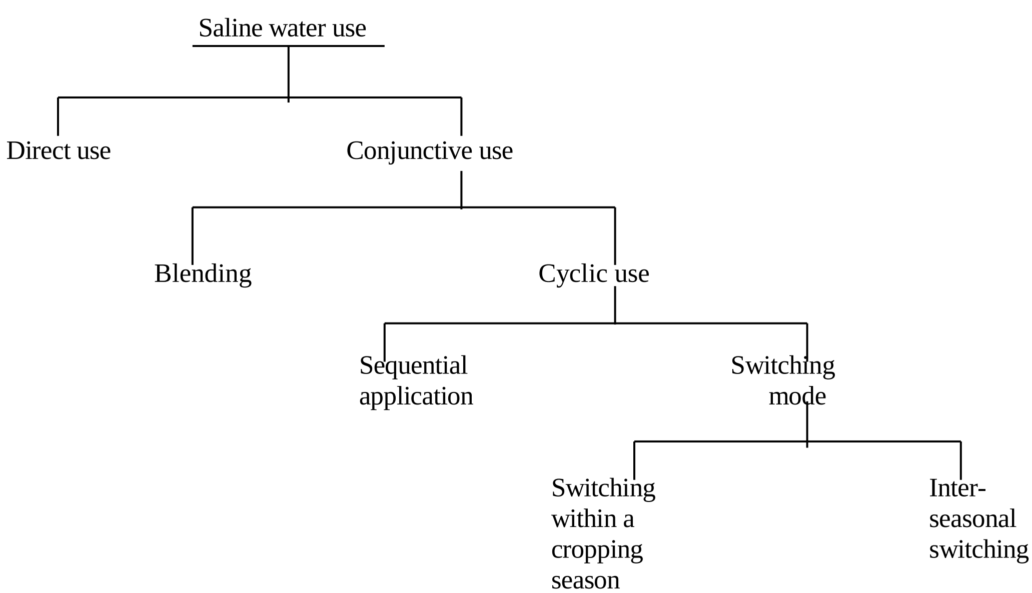


Fig. 3. Salinization and desalinization cycle in monsoonal climate.

4.1 Multi quality irrigation practices

The possible ways of practising multi-quality water use are as shown under. These include direct application of salty water as well as different modes in combination.



4.2 Water application modes and their impact on productivity

Amongst the various application modes direct application of saline waters can be practised where salinity of water is such that a crop can be grown within acceptable yield levels without adversely affecting the soil health. It has been reported by Boumans et al. (1988) that marginal quality waters (EC : 4-6 dS/m) were being directly used in several locations in Haryana. The average yield depressions for crops including cotton, millet, mustard and wheat were less than 20 percent. When higher salinity waters are used directly, pre-sowing irrigation, if required, is given with fresh water. To practice joint use of saline and fresh waters, the available options are blending and 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 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 cyclic mode the use of fresh and saline water is alternated according to a pre-designed schedule. Sometimes one resorts to inter-seasonal switching where fresh and saline waters are applied in different seasons. In a field study Sharma et al. (1995) found that saline drainage effluents could be used in different modes without appreciable yield reduction in wheat crop (Table 1).

Table 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*

EC_{iw} (dS/m)	Blending		Cyclic application		
	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 + 2DW	5.7	95.0
12 (DW)	4.7	78.3	2DW + 2FW	5.4	90.0
			1FW + 3DW	5.1	85.0
			4 DW	4.5	75.0

FW = Fresh water; DW = Drainage water
*The drainage water had EC = 12.5-27 dS/m, SAR 12.3-17.

4.2.1 *Impact of saline water use on soil health*

The salinity build up in the soil profiles where irrigation had been practised for 6 years (Sharma and Rao, 1995) with different quality waters in fields provided with sub-surface drainage is shown in Fig. 4. It is seen that for all waters with salinity in the range of 0.5 to 12 dS/m, soil salinity at the end of monsoon season reduced to less than 4 dS/m.

Several studies have suggested that irrigation water containing salt concentrations exceeding conventional suitability standards can be used successfully on many crops for atleast 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. Effects of irrigation with high salinity drainage effluent as available at Sampla drainage area (Haryana), were monitored for six years on some soil properties. Since the SAR of saline drainage water was more (12.3-17.0) than that of canal water (0.7), hence its use increased soil SAR in all the treatments (Fig. 5).

Leaching of salts by monsoon rains reduced SARe in all the treatments and the remaining SARe values did not cause any alkali hazard to the succeeding crops. Similarly, no significant adverse effects were observed on saturated hydraulic conductivity and water dispersible clay after the monsoon rains. A slight decrease in hydraulic conductivity after monsoon 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. Only slight variation in water dispersible clay after 6 years of irrigation with drainage effluent indicates minimum structural deterioration in soils irrigated with high salinity drainage effluent. Although, no potential adverse effects were observed in these studies at Sampla farm, but it is cautioned that while considering the reuse of drainage effluent, the specific conditions should be carefully evaluated.

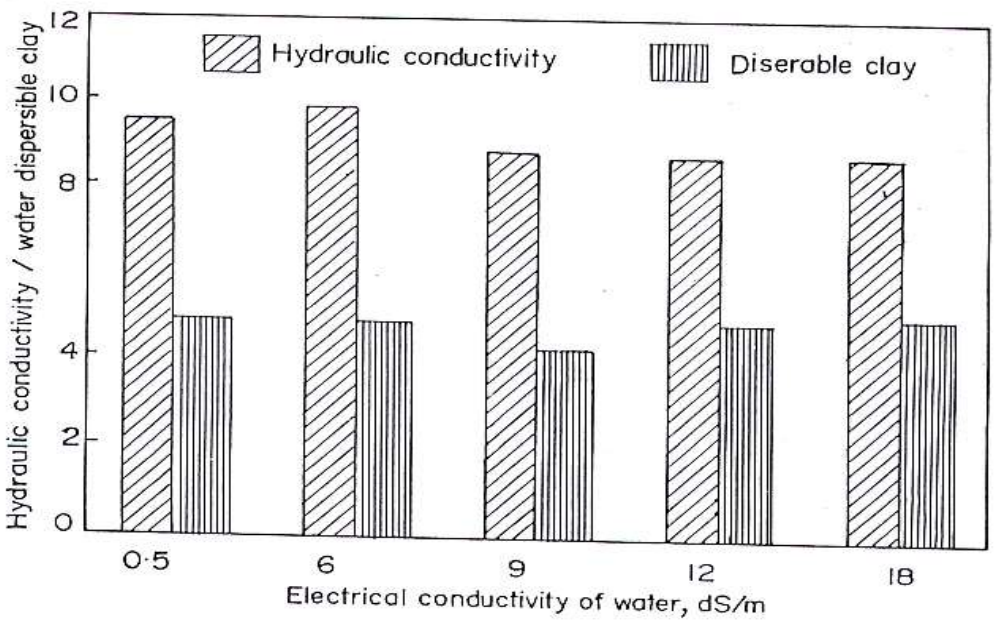


Fig. 4. Increase in soil salinity in different treatments after 6 years.

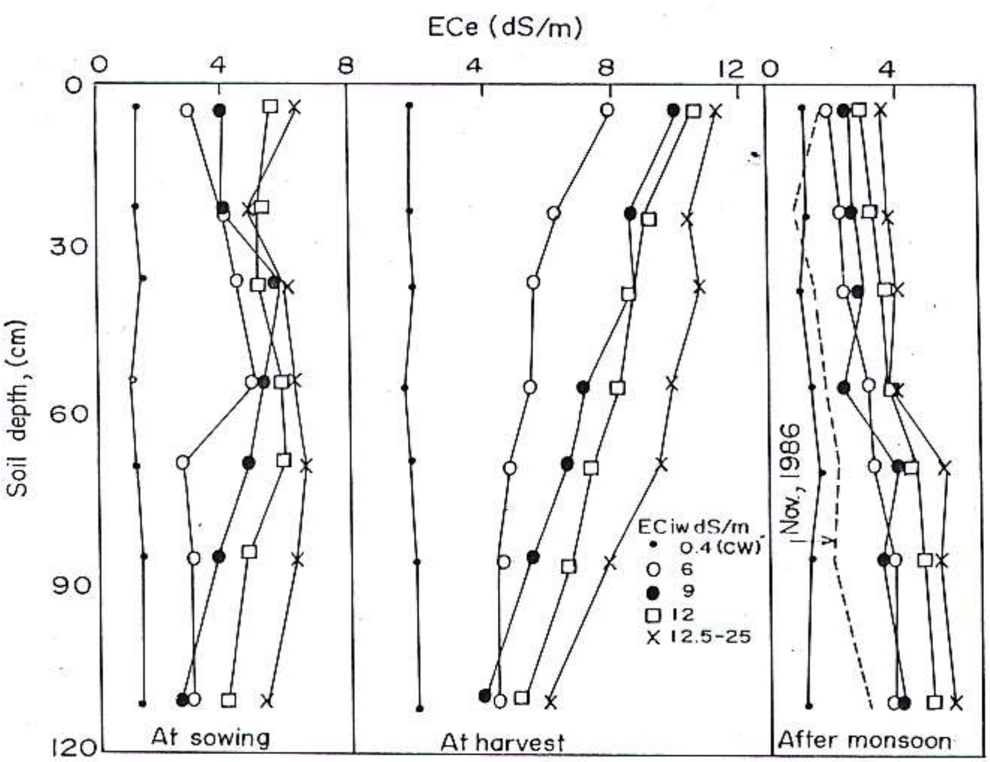


Fig. 5. Saturated hydraulic conductivity (mm/h) and water diserable clay (%) of 0-30 cm layer.

4.2.2 *Use of alkali waters and chemical amelioration*

Waters having alkalinity/sodicity problems are encountered on large scale in rice-wheat growing areas of Punjab and Haryana in northwest India. Several studies have shown that these waters can be used under certain conditions. In a study conducted over a period of 6 years (1981-87) by Bajwa and Josan (1989), it was found that irrigation with sodic water given after 2 irrigations with fresh water to rice as well as to wheat helped in obtaining yield comparable to irrigation with fresh water (Table 2). Crop yield even in case of alternate irrigation with sodic and fresh waters were only marginally less than fresh water alone. On an average rice received 18 irrigations whereas only 5 irrigation of 6 cm were applied to wheat. In all cases, pre-sowing irrigation was given with fresh water and no amendment to neutralize sodicity were applied. At the end of 6 years, ESP in plots irrigated entirely with sodic water increased from 3.5 to 46%, whereas in alternate irrigation with fresh and sodic water irrigation the ESP increased to a level of 18.2 percent only (Fig. 6). The increase in ESP points to the danger involved in use of these waters.

Table 2
Average grain yield of rice and wheat as affected by use of fresh and alkali waters over a period of 6 years (1981-1986)

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

AW(EC 1.25 dS/m, SAR= 13.5, RSC = 10 $meql^{-1}$

It should be understood that when irrigated with poor quality waters, the yields can be maintained at lower level as compared to irrigation with normal waters, if no amendments are applied. The levels at which yields can be sustained depend not only upon the alkalinity of ground waters but also on the water available from rainfall and canals etc. Sharma et al (2001), based on 7 years study (1993-99) evaluated the sustainable yield index (SYI), which indicates the minimum guaranteed yield as percent of the maximum observed yield. The SYI in defined as $Y\text{-}S/Y_{max}$, 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 0.54 to 0.65 in wheat (Table 3) at different doses of gypsum application. The overall build up of pHs (8.5), SARe (20.7) and ECe (2.5 dS/m) in the soil remained below threshold salinity levels of these crops. This may be due to dilution from rainwater alongwith high Ca or Ca+Mg content of the water used. The low level of sodification could also be attributed to large biological production and dissolution of CO_2 under submerged rice culture conditions. It was concluded that maximum yield of about 60 percent in both rice and wheat can be sustained with use of alkali water (RSC=10 me l^{-1}), if 1.25 t ha^{-1} of gypsum were applied annually to rice-wheat in medium rainfall zone (500-600 mm).

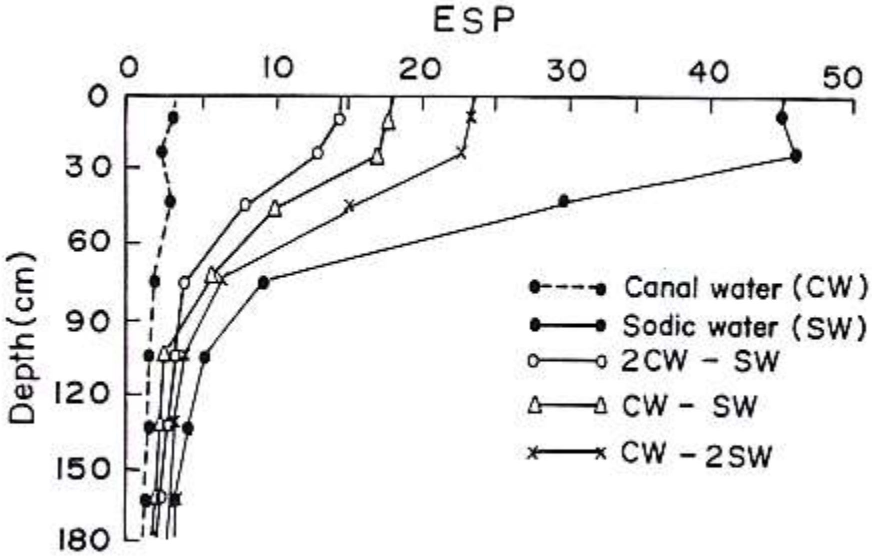


Fig. 6. Build-up of exchangeable sodium percentage (ESP) in 0-30 cm soil layer overtime (6 years) with sodic water application in different combinations.

Table 3
Crop and sustainable yield index (SYI) for rice-wheat cropping irrigated with gypsum amended alkali waters

Treatment (% GR)	Gypsum applied (t ha^{-1})	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	065

Source: Sharma et al. (2001)

4.3 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 subsequent season. In 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 season providing better environment for the succeeding crop. In a six year study conducted at CSSRI (Sharma et al., 2001), three important cropping sequences (rice-wheat, cotton-wheat and sorghum wheat) were compared for productivity with application of alkali waters. The productivity of rice-wheat system in kharif as well as rabi season was higher than sorghum-wheat and cotton-wheat system (Table 4).

Table 4
Equivalent rice and wheat yields (t ha^{-1}) as affected by cropping sequence when irrigated with alkali waters

Cropping sequences	Equivalent rice yield (Kharif)		Equivalent wheat yield (Rabi)		Total equivalent yield(wheat)		Soil pH_2	
	Water quality		Water quality		Water quality		Water quality	
	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(Var. 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 (Var.Jaya)-Mustard	4.0	4.3	4.0	4.4	7.27	7.32	9.1	9.0
Rice(Var. Jaya)-Berseem	3.3	4.1	2.7	3.0	5.41	6.31	9.3	9.1

Source: Sharma, D.K. (2001), Personal Communication.

4.4 Shallow watertable management

Providing drainage to assure that 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 field. The upper few centimeters of subsoil water has very little salinity and could be allowed to be used by the plants by manipulating the drainage system operation. Thus plant would meet part of their evapotranspiration needs directly from soil water. The use of ground water by the crops is related to the watertable depth and the salinity of sub soil water (Chaudhary et al., 1974). Minhas et al. (1988) observed that in sandy loam soil with watertable at 1.7 m depth and with groundwater salinity of 8.7 dS/m watertable contributed as much as 50 per cent of the requirement when no irrigation was applied. In another study, shallow watertable at 1.0 m depth with salinity in the range of 3.0 to 5.5 dS/m facilitated the achievement of potential yields even when surface water application was reduced to 50 per cent (Sharma et al., 1995). These fields have been provided with sub-surface drainage. The salinity build up was negligible and the little amount of salt that accumulated was leached in the subsequent monsoon season. The provision of sub-surface drainage also facilitates use of higher salinity waters through surface applications. The yield reduction with progressively increasing salinity of applied water is much less in fields having sub-surface drainage facility as compared to water applied in fields with deeper watertable which had no need of artificial sub-surface drainage. The differences are highly marked at applied water salinities of more than 10 dS/m (Table 5). Relatively higher moisture in the crop root zone in field with sub-surface drainage could be the reason for higher productivity.

Table 5
Relative yield of wheat with saline irrigation under deep watertable and high water table (provided with sub-surface drainage) conditions

Irrigation water salinity (dS/m)	Relative yield (%)	
	Deep watertable	Shallow saline watertable*
0.6	95	100
4.0	90	94
8.0	83	86
12.0	60	78
16	42	74**

* There was provision of subsurface drainage to leach and remove salts.
**Salinity varied between 14-26.5 dS/m, average being 16 dS/m and yield varied between 50-86% with an average of 74%
PSI_{FW} = Pre-sowing irrigation with fresh water
WT = High watertable
Source: Minhas 1993, Sharma et al., 2001.

4.5 Improving economic efficiency of water use

The commonly used definition of water productivity (water use efficiency) 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 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. The economic efficiency can be enhanced by growing crops that may use less water and have low cost of cultivation but fetch higher price in the market. 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 waters. The yield of basmati rice is only 50 percent (about 2 t ha^{-1}) of the coarse rice varieties like Jaya and IR-8, but its irrigation requirements are about 60-65 percent of the coarse varieties. Though it tolerates less sodicity, but the supplemental irrigation given from alkali water is also less and nitrogenous fertilizer use is only 70 percent of the coarse variety.

In a field study which involved sequential application of fresh and alkali waters (FW:AW) the equivalent yield of basmati was 7 t ha^{-1} as compared to only 4.3 t ha^{-1} for Jaya (Table 4). The higher economic returns led to its cultivation in larger area in Haryana though its physical water productivity maybe only half of Jaya or IR-8. In more arid areas where fresh water during rabi season becomes scarce, similar trends are observed with mustard which replaces wheat because it is much more salt tolerant and require only 1-2 post-sowing irrigations as compand to 4-5 irrigations in wheat.

4.6 Special considerations in use of saline/alkali waters

The following are the important points that should be considered in developing saline/alkali water use programmes:

4.6.1 *Pre-sowing irrigation*

Pre-sowing irrigation has significant influence on crop yields that are harvested at the end of season. This is because, seed germination and seedling stage is as the most sensitive stage. Salinity stress at this stage leads to poor crop stand and considerable yield reduction. Response of wheat crop to salinity was observed to vary with ontogeny, initial salinity distribution and modes of salinization (Sharma et al., 1993). The ECe_{50} values (ECe for 50% yield reduction) increased from 9.3 dS/m for periods between sowing to crown rooting to 13.2 dS/m from dough stage to maturity (Fig. 7). The effect of pre-sowing with fresh and saline waters for several crops (Table 6) was studied at CSSRI and it was observed that one of the most sensitive crop like moongbean could sustain irrigation with saline water of 4.7 dS/m, once non-saline water was used at pre-sowing stage. The water use efficiency of moongbean, 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 to only 12 kg ha^{-1} cm^{-1} when irrigated with saline water throughout the growing period. Though less drastic, but similar trend was observed in mustard.

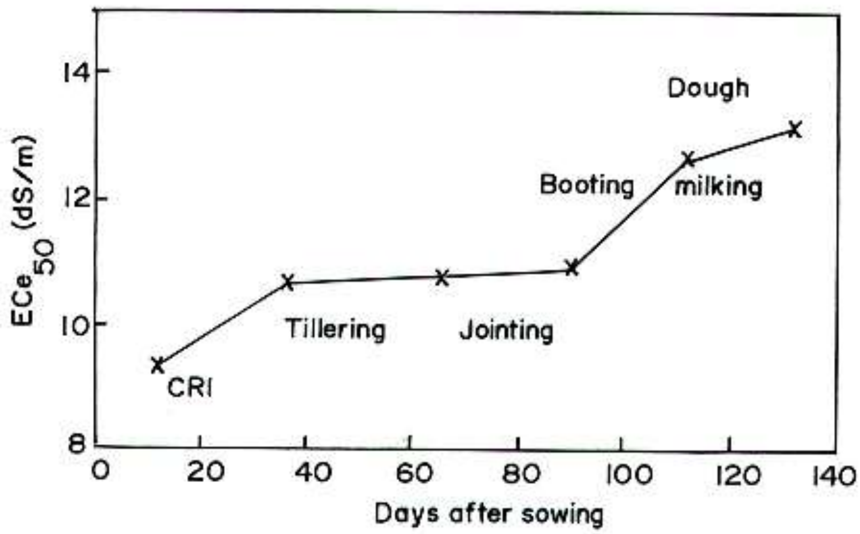


Fig. 7. Salinity tolerance of wheat at various growth stages (ECe_{50} denotes ECe for 50% yield reduction).

4.6.2 *Favourable season*

Crops grown during winter season (wheat, mustard and barley) are more tolerant to use of 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 favourable evapotranspiration regime. The evapotranspiration (ET) is quite low during winter and hence the salinity build-up is slow. ET peaks only after March when the crop is mature, and can tolerate higher salinity.

Table 6
Crop yield and water productivity as influenced by irrigation water salinity and application sequence with different quality waters

Irrigation water salinity (dS/m)	water quality application sequence	Crop yield ($t\ ha^{-1}$)	Water use efficiency $kg\ ha^{-1}\ cm^{-1}$
	Moongbean		
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
Source: Sharma et al. (1993)

4.6.3 *Crop substitution*

Most agricultural crops differ significantly in their tolerance to concentration of soluble salts in the root zone. It is desirable to choose crops/varieties that can produce satisfactory yields under conditions resulting from saline water irrigation. The difference between the tolerance of the least and the most sensitive crops may be 8-10 fold. The wide range of tolerance allows for greater use of marginal waters. The extent the tolerance limits for use of low quality water are raised, it will permit greater use of such waters, thereby reducing the need for leaching and drainage (Tyagi, 1998). Crops which are semi-tolerant to tolerant, as well as those with low water requirement should be grown. For example, mustard is a salt tolerant crop and it requires one or two irrigation after seeding. Experiments at Sampla (Haryana) indicated that highly saline drainage water can be used for post-plant irrigation in mustard without any substantial loss in yield. Thus mustard can be substituted for wheat in part of the area because it tolerates irrigation water salinity of less than 6 dS/m for normal yield.

4.6.4 *Precision levelling*

Use of saline and alkali waters often requires application of smaller depths at relatively more frequent intervals. In surface water application methods, distribution of water and the application depths are greatly influenced by land levelling quality. It has been mentioned, salinity and non-uniformity in irrigation water have much the same effect on yield water response function and it requires larger volumes of irrigation water to produce the same yields as are equal to those obtained with non-saline water and uniformly applied water (Howell et al., 1990). In surface irrigation, application depth is greatly influenced by land surface uniformity. In a field study (Tyagi, 1984) it was observed that system application depth varied from 40-120 mm as the levelling quality decreased (Fig. 8). Higher application depths were associated with lower application efficiencies the value being as high as 90 percent with L.I. at 0.75 cm as against 45% with L.I. at 6.75 cm. The non-uniformity in levelling was reflected in water use efficiency which was 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. It was concluded that for ensuring desired system application depth (5-6 cm), to achieve optimum productivity and income, the levelling quality has to be such that the average deviation from the desired level is within 3 cm.

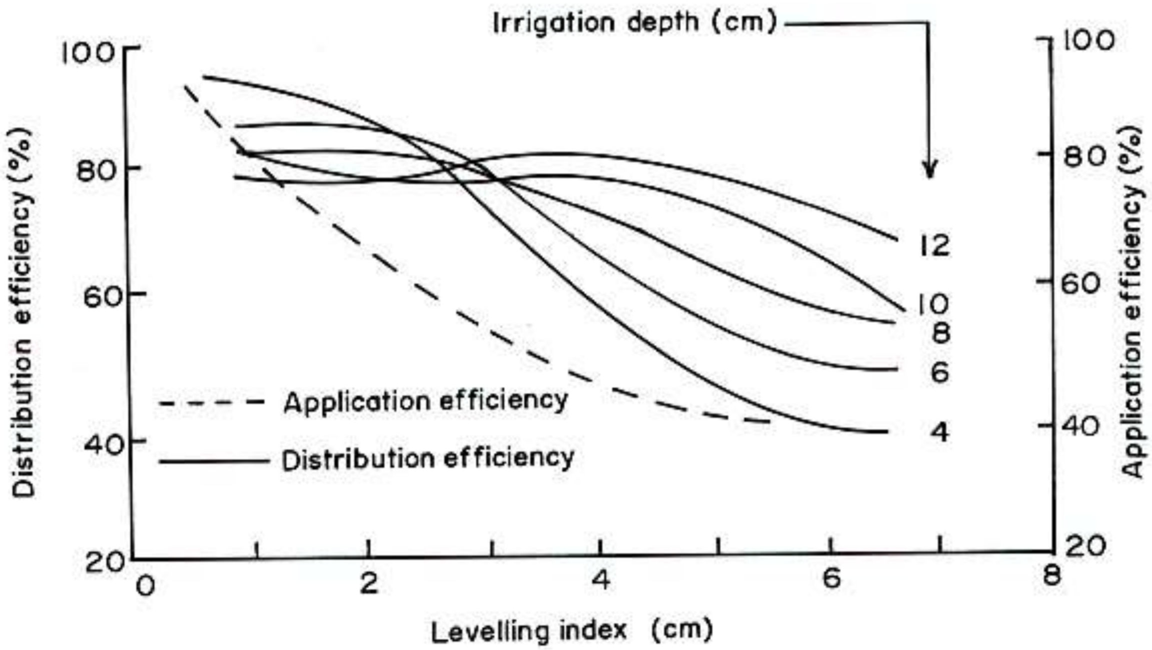


Fig. 8. Relationship between levelling index and distribution efficiency at different irrigation depths.(Tyagi, 1984)

4.6.5 *Rainwater conservation*

Rainwater conservation is the key to use of waters with higher salinity 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 monsoon season. Rice paddies offer the most appropriate conditions for retaining rainwater within the field. It has been shown by Raul et al (2001) that in areas having alkali waters with RSC between 5-10 mel^{-1} in parts of Kalayat and Rajaund administrative blocks in Haryana (India), rice paddies enabled in-situ conservation of 95 percent of monsoon rains and thereby helping in sustaining rice-wheat cropping in 60-70 percent of the area. It may be mentioned that between 30-40% of irrigation requirement of rice and above 50% in wheat, is met by groundwater in these blocks with conserved rain which dilutes saline/alkali water to make it useable. Rainwater conservation and use of gypsum sustains continued use of these alkali waters in the region.

5. Enhancing and Sustaining Water Productivity at Irrigation System Level

Some of the options to improve water productivity in physical and economic terms, include: water transfer and spatial reallocation through change in water allocation policies or market mechanism, diversion of water to more productive/profitable uses and reducing salinization of fresh waters in areas underlain by saline/alkaline aquifers by improving on-farm irrigation system conveyance efficiencies, among others. The sustainability of saline agriculture can be ensured by maintaining salinity balance through evacuation and disposal of salt water to areas outside the basin.

5.1 Loss in productivity due to salinization of fresh waters and its prevention

The 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, there are reductions in crop yields. The reductions vary according to salt tolerance of the crop, cropping pattern, quantity and quality of applied water and the 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. 9. The financial losses with ground water salinity upto 3 dS/m were within Rs. 500 ha^{-1} yr^{-1} but beyond that the losses increased at a very high rate reaching Rs. 8000 ha^{-1} yr^{-1} at groundwater salinity of 10 dS/m which will have effect on profitability of the farming enterprise. It therefore becomes important to reduce irrigation losses in areas underlain by saline aquifiers. Tyagi and Joshi (1996) investigated the techno-economic viability of reducing accretions to groundwater in saline ground water areas through irrigation system improvements and thereby minimizing production losses. The option of reducing salinization of ground water had higher profitability, up to a level 75 percent reduction in ground water accretion by reduction in application, distribution and conveyance losses.

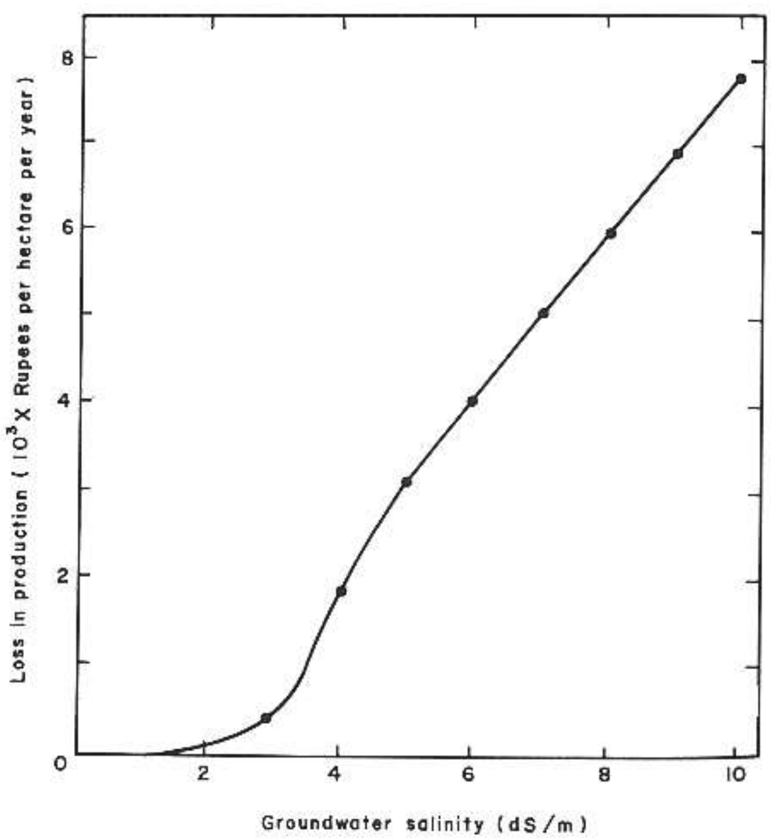


Fig. 9. Agricultural production losses as function of groundwater salinity.

5.2 Conjunctive use

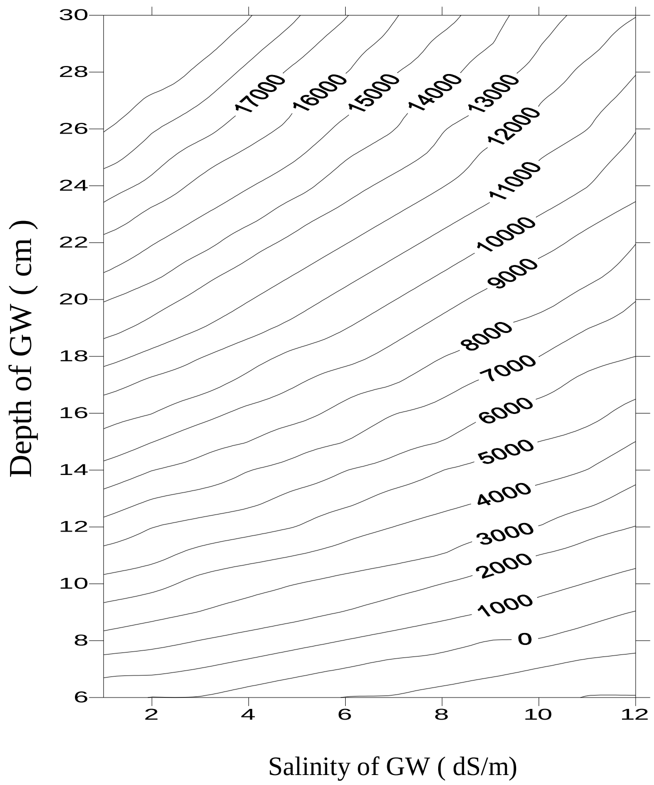
Both fresh and saline waters are limited but the availability of saline groundwater is more dependable. The profitability of farming enterprize reduces as the salinity of groundwater increases. At given level of canal water and saline groundwater, the irrigation would be practised till the incremental benefits balance incremental cost.

The profitability analysis for wheat crop with use of saline groundwater and given level of canal water in Kaithal district for the watercourse was performed to see how for the application of saline water would remain economically viable (Anonymous, 2001). Two levels of canal water supply (10 and 15 cm/ha) were considered. It was interesting to note that the profit decreased from Rs. 12000/ha to Rs. 7000/ha when canal water supply was decreased from 15 cm to 10 cm with use of 15 cm of ground water having electrical conductivity of 6 dS/m (Fig. 10). Since the overall availability of ground water at system level is also limited, the chances of minimizing productivity losses by applying higher quantity of ground water does not appear to have feasibility. The only option is to reduce irrigation intensity (irrigated area/cropped area) and by arriving at an optimal mix of irrigated and rainfed areas.

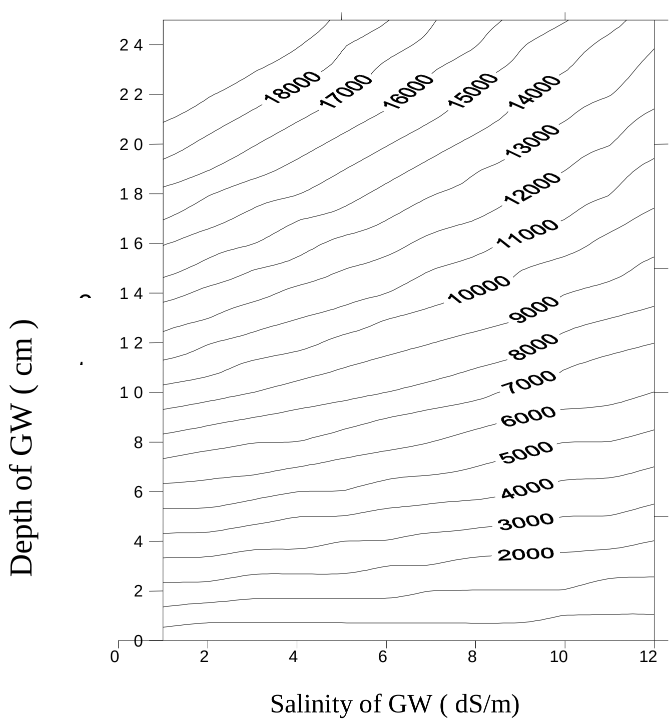
5.3 Productivity increase through promotion of ground water market at water course level

The large differences in supply between the head and tail reaches is a common problem. This problem gets further accentuated when there is a high overall deficit in canal supplies 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 season. The tail end water inadequacies are further complicated by the progressive decrease in ground water quality from head to tail reaches. A typical case that has been investigated pertains to Kaithal circle of Bhakra canal in Haryana, where canal water availability progressively decreased from 25 cm ha^{-1} in head reach to 8 cm ha^{-1} in the tail reach, while the ground water salinity increased from 2.5 dS/m to 6.8 dS/m (Fig. 11).

The watertable in the head reach is also substantially higher than the tail reach. This situation favours development of groundwater through shallow tubewells in head reach and its transfer to tail reach. Such small-scale water markets are already in existence in Haryana and their existence in Chistian Sub-Division in Punjab (Pakistan) has been investigated by Strosser (1997). Strosser mentioned that the impact for tubewell water market on farm gross income was significant at 40% of the actual gross income, aggregated for eight sample watercourses. He, however, also mentioned that water markets could lead to decreased aquifer recharge and increase the soil salinity. The potential increase in relative yield with such ground water transfer from head to tail reach of water course in Batta Minor (Bhakra system) was analysed using SWAP model (Chandra, 2001). The results indicated that the relative yield would increase from 0.70 to 0.85 in entire watercourse, if 50 percent of marginal quality groundwater from head reach was transferred and used in tail reach without disturbing canal water allocation. The relative yield would go up to 0.89, if instead of blending, it was used in cyclic modes (Fig. 12).



(a) 10 cm Canal Water



(b) 15 cm Canal Water

Fig. 10. Profitability of conjunctive use of groundwater (GW) of varying salinity and canal water at two levels of supply.

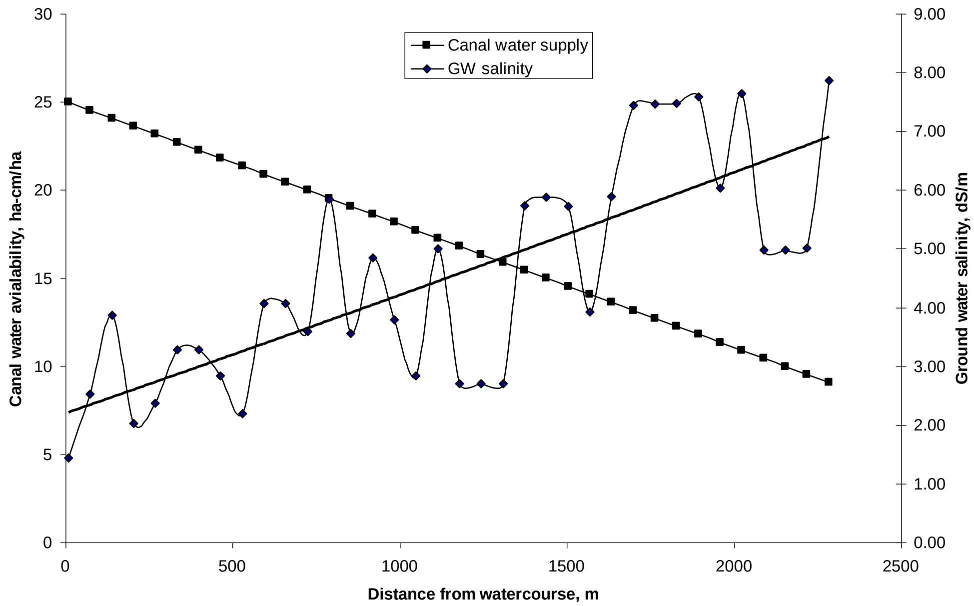


Fig. 11. Variation in canal water availability and ground water salinity from head to tail reach of watercourse No. 25963 L (Batta minor).

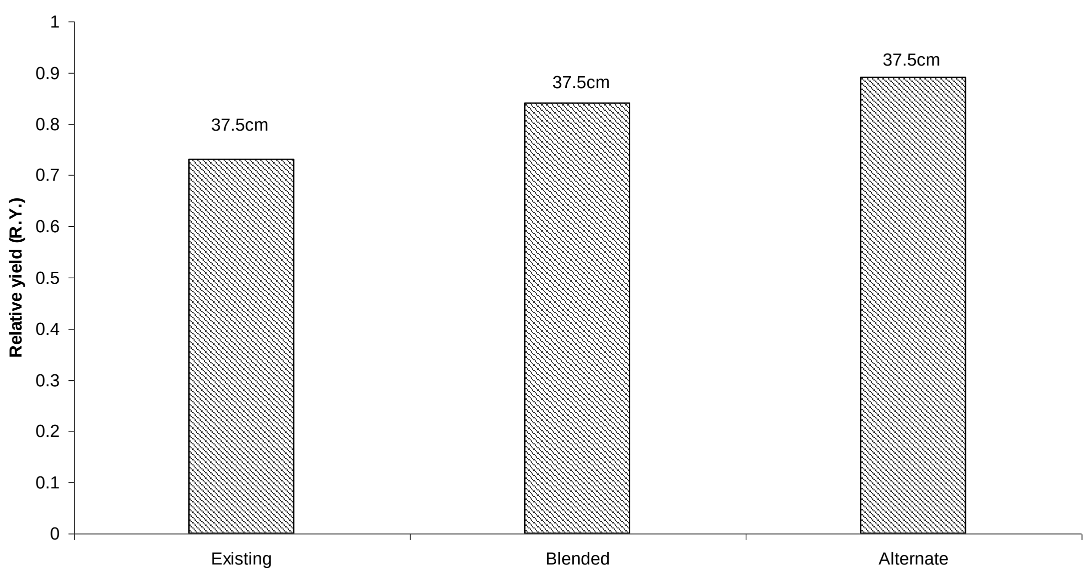


Fig. 12. Improvement in water productivity at watercourse (25963L) level by ground water transfer from head to tail reach.

The state of Haryana has experienced with transfer of ground water from fresh water areas with higher rainfall and grater availability of canal water to areas which are less favourably placed with regard to water supply. This relieved the waterlogging and stabilized the canal water supply in lower reaches. This practice on a limited scale has been adopted in marginal ground water areas in Hisar district by installing shallow tubewells 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 for promoting saline water development and use at system level. Particular attention will have to be paid to reduced canal water flow and increasing salinity of mixed water as one moves from head reach of the minors/distributaries/branch canals to their lower reaches.

5.4 Balance between saline water use and disposal

One of the important objective 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 effluents, soil and the crops and drainage conditions. Srinivasulu et al. (1997) have estimated that water equivalent to a minimum of 15 percent of the annual groundwater recharge with average E.C. of 6 dS/m will have to be disposed off for maintaining salinity balance in groundwater in Sirsa and Hisar districts of Haryana. This will ensure sustainability. Similar estimates will have to be made for other areas.

6. Extent and Actual Saline Water Use Practices

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

6.1 Water use practices

There are several water use practices are in vogue. The survey conducted in Hisar district (Haryana) also indicated that saline water pumped by shallow tubewells in most cases is used directly without any mixing. Mixing is normally done only if the salinity exceeds 6 dS/m and in such cases the water from the tubewell is pumped into the watercourse carrying canal water. The farmers also resort to pumping of ground water into the canal watercourse, if they perceive that the watercourse discharge was too small to cover the planned irrigation area in the allotted time. Cyclic use of canal and saline waters is more common. This is largely due to the fact that canal water is available for only a few hours after each rotation period of 2-4 weeks duration and the opportunity to practise irrigation with mixed or blended water is very limited. This constraint could be relaxed, if on-farm reservoirs are constructed (Tyagi and Sharma, 2000).

Some farmers do not follow the practice of intra-season conjunctive use, but reserve parcel of the land to be irrigated entirely by saline water. In that case, they grow salt tolerant crops like mustard, which is not given any pre-sowing irrigation but is sown in residual moisture after rainy season and is given one or two supplementary irrigation. Since, the canal water charges are levied on area basis and not on the basis of number of irrigations received from canal water, the farmers save on canal irrigation charges (through the charges are rather very low) by adopting this practice. The area receiving irrigation exclusively from tubewell with saline water is rotated every season/year to avoid development of salinity in particular piece of land. In case of tubewells having problem of residual sodium carbonate (RSC), gypsum which is readily available from Land Reclamation Corporation outlets is applied to neutralize sodicity. Gypsum is either applied to soil or is put in the channel in gunny bags on which water from tubewell falls and dissolves the gypsum. In such cases gypsum is not powdered but is kept 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 soil or applied with irrigation water, the basis for computation of gypsum requirements remains the same. There is, however a difference in time of application. In case of soil applied gypsum, the entire quantity of gypsum requirement which is estimated on the basis of the quality and quantity of applied RSC waters at a time. In case the sodicity of the soil is already high, the gypsum to neutralize RSC of applied water may have to be applied in the beginning of the season, otherwise it could be applied before the next crop. In case of water-applied gypsum the neutralization takes place before its application and therefore there is no buildup of sodicity in the soil. Availability of gypsum is ensured through organized arrangement by the government.

Prologue

The saline/alkali waters have been successfully used to augment irrigation supplies and helped 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 waters when it is least harmful and also in diluting the salt concentration in the rootzone keeping it below threshold limits. Monsoon rainfall, which plays crucial role in the desalinization cycle is another factor that regulates seasonal salt balance in the rootzone to facilitate saline water use even with traditional methods of irrigation. Saline water use is more during winter when it is more productive and least harmful. Similar success with saline/alkali water use has not been achieved in more arid areas which do not have the facility of canal irrigation. In those areas inter seasonal fallowing, rainfed farming with very limited use of saline water in salt tolerant crops continues to be the norm.

In irrigated areas provided with extensive canal network with inadequate water supply, saline groundwater developed through shallow tubewells is primarily an irrigation activity though it also keeps the watertable in check. But continued recirculation and reuse of the marginal quality waters without any disposal of saline water outside the system has the danger of slowly salinizing both soil and aquifers when the practice becomes more extensive. The practioners of technology of saline/ alkali water use, which has been shown to be initially successful at the field scale, will have to consider regional salt balance in the long run. The scenario building exercises based on limited data indicate gradual rise in salinity of both soil and aquifers.

In view of the situation that prevails with respect to saline/alkali water use, it looks attractive to focus on research that would help develop strategies for use of these waters in areas not having much fresh water endowments except small seasonal rainfall. Harnessing synergetic effects of improved salt tolerant crop varieties and improved hydraulic technologies offers a possible approach to enhance productivity in such areas.

Unlike the crop-water-salinity relationship of saline waters, the production functions for alkali waters are not well established. Same is the case with their impact on ground water aquifers. Field research that would help in establishing crop-water-alkalinity functions and the salt transport through crop rootzone and vadose zone also needs attention.

There are numerous models that help in generating scenarios for the possible consequences of saline water use on regional scale. Alkalinity is also an equally serious problem with ground waters. Models that facilitate scenario building on irrigation system/river basin scale, where groundwater alkalinity is a problem, are missing. Added to this difficulty is the problem of vast amount of data that is needed, but is seldom available for the areas where it is most needed. Therefore studies aimed at generation of data to be used in regional salt and water balance model need emphasis if sustainability of the technology that improves water productivity at field scale is to be ensured at higher level of the irrigation system/river basin.

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