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Managing saline and alkali water for higher agricultural productivity

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Abstract
Two major approaches to improving and sustaining high agricultural productivity in saline/alkali environment involves (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 water 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 water 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 water, 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 water at less salt sensitive stages. In high water table areas, provision of sub-surface drainage facilitates the use of higher salinity water, 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 policies 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 practicing irrigation with salty water for maintaining sustained productivity.

Keywords: Managing saline, alkali water, higher agricultural 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 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) [21]. 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) [23]. 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 root zone, 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) [8], the threshold salinities for different stages are not well defined. The information gap is more serious for alkali waters as compared to saline waters.
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) [1]. 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.

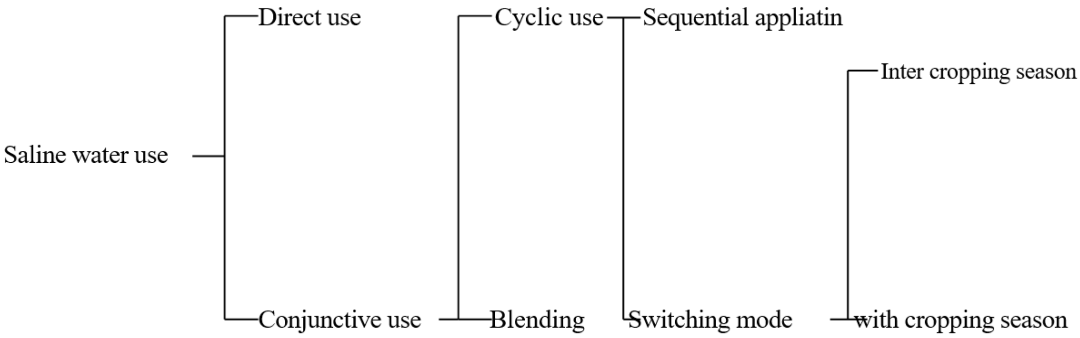
Lastly, the productivity enhancing measures with use of saline/alkali water at field level such as conjunctive use, water table management, rainwater conservation in precisely leveled basins and chemical amelioration of alkali waters are discussed. Though not exclusively, but largely the productivity 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. Water reallocation and transfer, water markets and saline water disposal which have irrigation system/basin level implications, are also briefly presented.

2. Root zone Salinity Management

Most researches on use of saline/alkali waters have focussed on keeping root zone 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 leveling and high frequency irrigation etc. In situations where high water table with saline water prevails, provision of sub-surface drainage and water table manipulation is often practiced to promote use of brackish waters.

2.1 Multi quality irrigation practices

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



2.2 Water application modes and their impact on productivity

Amongst the various application modes direct application of saline waters can be practiced 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) [4] that marginal quality waters (EC : 4-6 dS/m) were being directly used in several locations in Haryana. 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) [12]. In sequential application under cyclic mode the use of fresh and saline water is alternated according to a pre-designed schedule.

2.2.1 Impact of saline water use on soil health

The salinity build up in the soil profiles where irrigation had been practiced for 6 years (Sharma and Rao, 1995) [13] with different quality waters in fields provided with sub-surface drainage is shown in Fig. 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. 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. 2).

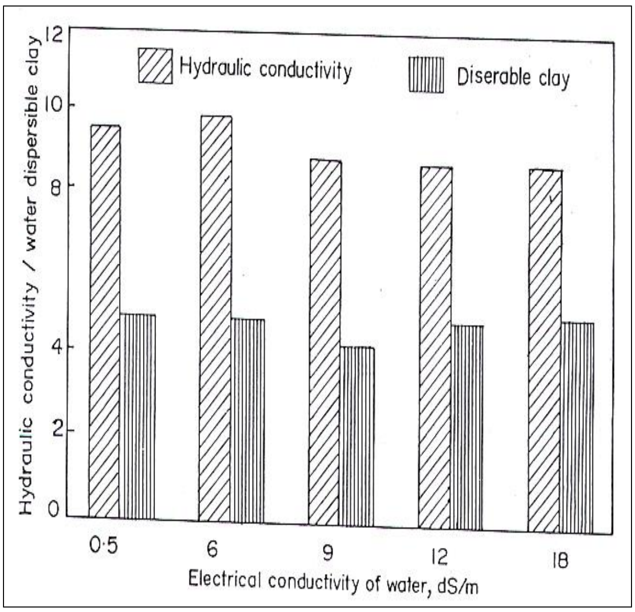


Fig 1

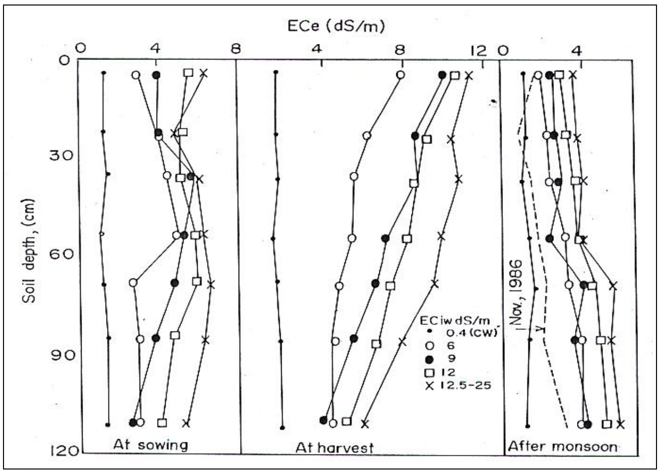


Fig 2

2.2.2 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) [3], 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. Crop yield even in case of alternate irrigation with sodic and fresh waters were only marginally less than fresh water alone. On 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 was 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. The increase in ESP points to the danger involved in use of these waters.

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) [15], 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 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).

2.3 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) [15], 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.

2.4 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 water table depth and the salinity of sub soil water (Chaudhary *et al.*, 1974) [6]. Minhas *et al.* (1988) [9] observed that in sandy loam soil with water table at 1.7 m depth and with groundwater salinity of 8.7 dS/m water table contributed as much as 50 per cent of the requirement when no irrigation was applied.

2.5 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 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.

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-1). 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 compared to 4-5 irrigations in wheat.

Table 1: 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, *et al.*, 2001) [15], Personal Communication.

2.6 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:

2.6.1 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) [14].

2.6.2 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) (Sharma *et al.,* 1993) [14]. 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 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.

2.6.3 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) [20].

2.6.4 Precision leveling

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 leveling quality (Howell *et al.,* 1990) [7]. In a field study (Tyagi, 1984) [18] it was observed that system application depth varied from 40-120 mm as the levelling quality decreased. 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.

2.6.5 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. Rice paddies offer the most appropriate conditions for retaining rainwater within the field. It has been shown by Raul *et al.* (2001) [11] 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.

3. 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.

3.1 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. Tyagi and Joshi (1996) [19] 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.

3.2 Conjunctive use

Both fresh and saline waters are limited but the availability of saline groundwater is more dependable. The profitability of farming enterprise 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) [2].

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

The large differences in supply between the head and tail reaches are 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.

The water table in the head reach is also substantially higher than the tail reach. This situation favours development of groundwater through shallow tube wells 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) [16]. Strosser mentioned that the impact for tube well 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 analyzed using SWAP model (Chandra, 2001) [5].

3.4 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) [17] 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.

4. Actual Saline Water Use Practice

There is several water use practices are in vogue. The survey conducted in Hisar district (Haryana) also indicated that saline water pumped by shallow tube wells 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 tube well 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) [21].

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 tube well with saline water is rotated every season/year to avoid development of salinity in particular piece of land. In case of tube wells 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 tube well 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.

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