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NUTRIENT MANAGEMENT STRATEGIES FOR SUSTAINING CROP PRODUCTION WITH SODIC WATER

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ABSTRACT

In arid and semi-arid regions of the world including India, the use of high RSC water for irrigation resulted in reduction of crop yield and deterioration of soil physical and chemical properties. Attempts have been made in the past to minimize the adverse effects of sodic irrigation water through different irrigation, soil, and crop management practices. In gypsum amended soil, rice can tolerate RSC up to 5.0 meqL^{-1} *and wheat upto 10.0 me*L^{-1} *in semi - arid condition under light textured soils. For treating low RSC water irrigation through gypsum bed is most effective and efficient utilization of gypsum while soil application is more appropriate when RSC of water is > 9.0 meq*l^{-1}*. Use of gypsum improved the plant growth and grain yield of crops as compared to application of without amendments. Similarly, application of FYM/SPM also improved the plant growth and yield as compared to inorganic fertilizers alone but its effect on plant growth and yield components was comparatively more or less similar to gypsum application. Application of amendments like gypsum, SPM and FYM improved the soil properties. Placement of N, split application of urea N or coupled with organics/green manuring is viable option to reduce the loss of ammoniacal N through volatilization. Thus, use of gypsum/FYM/SPM along with sodic water is very important for sustainable crop production and to reduce the adverse effect of sodic water.*

Key words: Sodic water, organic manures, inorganic fertilizer, amendment

INTRODUCTION

An important constraint in increasing agricultural production in many arid and semi-arid regions is the inadequate availability of good–quality water for irrigation. Therefore farmers have to use even the poor – quality waters for irrigation of crops. In India 32-84 % of ground waters in different states are of poor quality. These poor quality waters constitute about 47 % in Punjab (Bajwa *et al.* 1974, Sehgal *et al.* 1985), 62 % in Haryana, 84 % in Rajasthan, 38 % in Karnataka, 32 % in Andhra Pradesh, 30 % in Gujarat and 50 % in Agra, Aligarh, Etah, Mainpuri and Mathura districts of UP (Dixit 1974). Due to inadequate quantity and unsatisfactory quality of irrigation water, utilization of lands in these areas for raising cereal, forest and horticultural crops is far less than their potential use. During failures of monsoon such areas come under severe moisture stress and the resultant scarcity of food, fodder, fruits and fuel. The studies conducted at various places have indicated that prolonged use of such water created sodicity/salinity problems and induces severe nutritional disorders/imbalances in the irrigated soils and plants leading to reduced crops yield (Yadav 1989; Bajwa *et al.* 1993). The use of sodic waters increases pH, SAR and ESP in the soils which leaves adverse effects on crop yields (Bower *et al.* 1968; Bingham *et al.* 1979; Shainberg *et al.* 1989; Ayers and Westcot 1985; Bajwa and Josan 1989; Rhoades *et al.* 1992; Minhas and Bajwa 2001; Chaudhary *et al.*, 2004; Sharma and Minhas, 2004). Application of gypsum as soil or water amendment is commonly recommended to off set the deteriorating effects of these types of water. However, organic amendments have also been used to alleviate the adverse effects of soil sodicity on crop growth. Long-term nutrient management strategies developed so far for improving rice-wheat production on sodic lands are potentially applicable to areas primarily met with good quality underground irrigation water (Yaduvanshi 2003; Yaduvanshi *et al.* 2013). Since rice-wheat is the most commonly practiced crop rotation in the Indo-Gangetic plains, improving its productivity particularly in the areas having poor quality groundwater is a major challenge. Development of nutrient management strategies is, therefore, a viable option for sustaining the productivity of this system.

Use of amendments

Sodic water can be used safely and economically after treating with calcium carrying amendments like gypsum. Gypsum is the cheapest source of Ca and available in abundance in our country. Other amendments like phospho-gypsum, pyrites, acids or those forming acids [H_2SO_4, FeS_2, S, $Al_2(SO_4)_3$] can also be used which release Ca^{2+} after reaction with soil $CaCO_3$. However, due to low cost, abundant supply and ease of handling, made it most suitable amendment for sodic water and balancing Na : Ca ratio and ultimately increasing crop growth. Requirement of gypsum depends on RSC level of water, existing levels of soil sodicity, cropping intensity and crop water requirements. Field observations suggests that gypsum application increases or maintains the yield of rice based cropping systems when irrigated with water of RSC > 5 meqL^{-1} under, 500 mm rainfall conditions, whereas in case of fallow-wheat system irrigated with water having RSC 10 meqL^{-1} can be used safely on light texture soils without addition of gypsum. In relatively higher rainfall regions (>600 mm), annual gypsum application equivalent to 50% GR of water was sufficient to sustain at least 4.26 t ha^{-1} of rice and 3.82 t ha^{-1} of wheat yield (Sharma and Minhas 2001). However, after ascertaining about role of gypsum amendment, its amount, mode and time of application can be decided as under.

Methods and Timing of Gypsum Application

It is easier to apply gypsum in soil than through water. Required quantity of powdered gypsum should be broadcasted on previously leveled field and mixed with cultivator or disking in shallow depth of 10 cm. The amount of agricultural grade gypsum (70% purity) for neutralization of each meqL^{-1} of RSC is about 12 kg ha^{-1} per cm depth of irrigation. The best time for application of gypsum is after harvest of *rabi* (winter) crops, preferably in May or June, if some rains are received (Yaduvanshi and Swarup 2005). Otherwise, its application should be postponed till the onset of monsoon. Gypsum can be applied in the standing water also. The soil should be subsequently ploughed upon attaining proper soil moisture condition. Gypsum applied after harvest of *rabi* (winter) crops will also help in considerable improvement of the soil prior to the *Kharif* (summer) season. Pyrite has also been used for amending the deleterious effects of high RSC waters. Pyrite application once before sowing of wheat is better than its split application with all irrigations or mixing with irrigation water (Chauhan *et al.* 1986).

Table 1: Average (1993-03) paddy-wheat and mustard-sorghum yields (Mg ha^{-1}) and soil properties with gypsum applied to soil or passing sodic water through gypsum beds

Treatment	**Paddy**	**Wheat**	**pHs**	**ESP**	**Mustard**	**Sorghum**	**pHs**	**ESP**
Control (T$_1$)	3.08	2.68	9.6	66	2.27	1.18	9.5	61
Gypsum through beds								
3.3 meq L^{-1} (T$_2$)	3.97	3.73	8.0	19	3.06	1.98	8.0	25
5.2 meq L^{-1} (T$_3$)	4.24	3.93	8.0	18	3.18	2.13	8.0	24
Equivalent soil application								
As in T$_2$ (T$_4$)	4.31	3.71	8.2	20	2.86	1.92	8.0	26
As in T3(T$_5$)	4.52	3.89	8.1	20	3.00	2.05	8.1	24
LSD(p=0.05)	0.43	0.46			0.38	0.24		

(AICRP Saline Water 2002)

The best method to reclaim sodic water is passing it through gypsum beds, a specially designed chamber filled with gypsum clods. The gypsum chamber is a brick-cement-concrete chamber. Size of chamber depends on tube well discharge and RSC of water. This chamber is connected to water fall tank of tube well on one side and to water channel on the other side. A net of iron bars covered with wire net (2 mm×2 mm) is fitted at a height of 10 cm from the bottom of the bed. Sodic water flowing from below dissolves gypsum placed in chamber and neutralizes it. RSC of water from tube well discharge of 6.0 l sec^{-1} decreased from 5.5 to 1.9 meqL^{-1} by passing it through a chamber of size 2 .0 ×1.5 ×1.0 m in this method. However, this method is not suitable for reclaiming very high RSC water (> 12 meqL^{-1}) because the size of the chamber required to fill the huge quantity of gypsum needed to neutralize such high RSC becomes too large. It has also been observed that the gypsum bed water quality improvement technique does not dissolve > 8 meqL^{-1} of Ca. The response of crops to the application of equivalent amounts of gypsum, either by passing the water (RSC 9 meqL^{-1}) through gypsum beds where the thickness of bed was maintained at 7 and 15 cm, or the soil application of gypsum (Table 1). Gypsum application through gypsum bed was more responded in comparison to without applied gypsum bed under both the rotations (paddy-wheat, sorghum-mustard) in use of sodic water which was neutralized by 3-5 meqL^{-1} after passing through gypsum beds. Thus, it seems that gypsum bed technique can help in efficient utilization of gypsum.

Nutrient Management

About 3.77 million hectares area is severely affected by sodicity in the Indo-Gangetic plains of India. Nutrient deficiency and toxicity generally occur in these soils. Fertility of these soils with low nutrient reserves is confounded by the low supply of water and oxygen to roots in profiles with dispersive clays. The main problem is of high pH/ESP, high amount of calcium carbonate, very low amount of organic matter and poor physical conditions limiting nutrient availability and plant growth. Sustained alkali water irrigation for 15 years in cotton/pear millet/maize – wheat system grown on sandy loam soils has been found to cause significant reduction in available N, K, Zn and Mn while P and Cu remained unaffected (Sharma *et al.* 2005). In fact irrigation water without RSC resulted in higher available status of these nutrients (Table 2).

Table 2: Status of available nutrients in long-term (15 years) sodic water irrigated soil

Water quality			**Status of available nutrients (kg ha^{-1})**						
EC	**SAR**	**RSC**	**N**	**P**	**K**	**Fe**	**Zn**	**Mn**	**Cu**
2	10	5	127	17.6	143	5.50	1.78	7.51	1.40
2	10	10	128	17.1	138	6.08	2.09	7.22	1.40
2	20	5	129	15.5	144	6.18	2.06	7.62	1.14
2	20	10	125	15.9	142	5.96	2.67	7.55	1.34
4	10	5	120	15.9	143	5.70	1.91	6.91	1.28
4	10	10	122	18.4	152	6.14	1.40	6.56	1.32
4	20	5	127	12.6	153	5.46	2.69	7.91	1.33
4	20	10	124	16.0	155	5.76	2.03	6.25	1.37
2	20	0	118	13.0	132	9.80	2.83	13.60	1.46
Good water			149	17.1	183	6.96	3.55	14.14	1.32
CD (0.05)			11.9	2.1	18.2	1.65	0.93	3.23	NS

However, analyses of soil samples from other field experiments on sodic water irrigation have shown that sodic soils or soils irrigated with sodic water generally become deficient in Ca, N and Zn and low availability of other micronutrients. Also sodic water irrigation increases volatilization losses of applied N; and low Ca^{2+} (< 2 meqL^{-1}) or high HCO_3^- /CO_3^{2-} result in specific toxicity in crops at early crop growth stages. Therefore, crops respond to rates and methods of application of different fertilizers under these conditions. Processes of their transformations and availability under alkali soil conditions are discussed as under.

Calcium: Among the all the nutrients, Ca is most abundant in soil for plant available forms in the soil. It is important for the growth of meristems and functioning of the root tips. Besides being structural component of the cell, Ca plays vital role in regulating many physiological processes that influence both growth and development and also responses to abiotic stresses including salt stress. The alkali soils are deficient in both soluble and exchangeable Ca and excess of soluble and exchangeable Na further aggravate its availability to plants. Though these soils contain $CaCO_3$, ranging from traces to 40 % and more, the availability of Ca from it is insufficient to meet the plant needs because of its low solubility at high pH. Similarly sodic water irrigation causes precipitation of soluble Ca into sparingly soluble $CaCO_3$ and thus decreasing its availability to crop plants. Further, increasing soil ESP with sodic water and its high SAR causes Na antagonism to Ca uptake in crop plants. Thereby in sodic conditions, crop plants are affected in two ways *i.e.* sodicity sensitive plants accumulate toxic levels of Na in high sodicity conditions and in moderately sodic conditions lack of supply of adequate Ca affect its availability (Table 3).

Table 3: Ca and Na contents of some crop plants under different soil sodicity levels

ESP	**Safflower**		**Raya**		**Cowpea**	
	Ca	**Na**	**Ca**	**Na**	**Ca**	**Na**
8.0	1.36	1.01	2.98	0.50	2.35	0.16
16.0	1.28	1.85	2.80	1.00	2.24	0.25
40.0	0.63	2.81	1.84	3.02	1.72	0.66

Calcium deficiency arising with sodic water cause physiological disorders as poor boll opening in cotton and fruit – end - rot in tomato (Yadav and Kaledhonkar, 1998). Absolute Ca contents and its concentrations in relation to Na are good indices of proper growth of crop plants under sodic environments. The addition of acid like H_2SO_4 or acid forming substances like pyrites and elemental S are helpful in solublizing the native $CaCO_3$ and thus meet the Ca needs of plant and soil. Another option can be use of organic manures like farm yard manure (FYM) or pres-mud which under anaerobic conditions during flooding of sodic soils create increased pCO_2 and help in solubilization of native $CaCO_3$ and release Ca and in turn removes Na from exchange complex (Swarup and Yaduvanshi, 2004). Similarly growing of grasses, crops and other plantations also increase solubility of native $CaCO_3$ through biological actions of their roots.

Nitrogen: Sodic soils are very low in organic matter and available N throughout the soil profile. Because of this, most crops suffer from inadequate N supply. Nitrogen transformations are adversely affected by high pH and sodicity. High soil pH coupled with poor physical conditions also adversely affects the transformations and availability of applied nitrogenous fertilizers. Mineralization of organic matter and organic forms of N under reduced infiltration and poor physical conditions is restricted to ammonification stage by lack of aeration or more specifically O_2. A major amount (10-60%) of accumulated NH_3 is liable to volatilization under field moisture range. Ammonia volatilization loss rate follow a first order reaction and its half life range from nearly 62 days at field capacity to only 10 days under irrigation with alkali water causing waterlogged conditions.

Table 4: Ammonia losses from integrated nutrient management system in rice field under reclaimed alkali soil

Treatment	Amount of N lost during application			Total N lost	% N lost
	Basal	1st split	2nd split		
Control	1.23	-	-	1.23	-
N_{120}	8.49	8.21	6.76	23.46	19.55
N_{120} P_{22}	8.28	7.35	6.70	22.33	18.61
$N_{120}P_{22}K_{42}$	8.14	7.24	6.65	21.75	18.13
$N_{120}P_{22}K_{42}$ +GM	5.82	5.20	5.06	16.08	13.40
$N_{120}P_{22}K_{42}$ +FYM	6.73	5.74	5.28	17.75	14.79
$N_{180}P_{39}K_{63}$	12.12	10.60	9.48	32.20	17.89
Mean	8.26	7.39	6.66	-	-
LSD at P=0.05					
Treatments	0.51	0.91	1.19	-	-
Stage of N application 0.32					

It had been reported that ammonium fertilizers were broadcasted directly on the soil without incorporation, NH_3 volatilization losses ranged from 10 to 60 % of the fertilizer - N applied. Losses of ammonia were higher at higher field moisture in un-reclaimed alkali soils. Ammonia volatilization losses could be check up to some extent by applying urea with FYM or green manuring (GM) as compared with urea - N application alone. The losses of NH_3 volatilization from GM combined with urea - N were lower (13.4%) as compared to alone urea - N application (19.5%), the use of GM could be saved 6.0 per cent fertilizer - N (Table 4) , possibly because in the former, nitrifying population could adequately oxidize the ammonia - N slowly mineralized from GM (Yaduvanshi 2001a). Rao and Batra (1983) also reported lower losses from GM (5.6%) as compared to urea - N (30 %) under laboratory incubation studies. Yaduvanshi, (2001a) also reported that ammonia volatilization losses is more at initial urea application (up to 24 hours) and after that sharply declined during the next 48 hours. The basal application of urea at rice transplanting was more losses of ammonia in comparison first and second split application urea –N. The benefits were attributed to reduce N losses through volatilization thereby increasing the absorption of NH_3 - N by plant at the time of first and second split application.

To get the maximum advantage from the applied fertilizer – N, it must be given in right quantity, at the right time and place, from the right source, and in the right combination. Nitrogen application should synchronize with the growth stage at which plants have the maximum requirement for this nutrient. For grain production rice and wheat plant use nitrogen most efficiently when it applied at the maximum tillering stage. Rice plant uses N around the panicle initiation/jointing stage also. Therefore, split application of N for wheat (1/2 at sowing, remaining 1/2 N in two splits at tillering (21 days) and 42 days after sowing. However for rice half at transplanting + 1/4 at tillering + 1/4 at panicle initiation resulted maximum use efficiency of N (Dargan and Gaul, 1974). Maximum yields of rice and wheat were obtained when N was applied in 3 equal splits, as basal and at 3 and 6 weeks after transplanting/sowing under sodic water conditions (Yaduvanshi and Swarup 2005). Proper management of fertilizer N is thus necessary for better N use efficiency. Because of the adverse physical-chemical conditions, the recovery can be expected to be still lower in the salt – affected soils. Under such situation nitrogen use efficiency can be increased by integrated use of organic and inorganic sources of N (Yaduvanshi, 2001$_b$). Under green manuring with Sesbania, N adds through urea, minimize N – losses; and application of N fertilizer at the time of puddling and mix in the soil rather than broadcast on the surface to minimize N –losses.

Table 5: NH_3 losses and rice grain yield with urea application methods and pre-submergence periods

Treatment	**Grain Yield (t ha^{-1})**	**Ammonia volatilization losses (kg ha^{-1})**		
N (kg ha^{-1})		I	II	III Split
N_0	3.61	1.43	0.00	0.00
N_{60}	4.60	6.01	6.42	5.57
N_{120}	4.83	8.31	7.48	6.74
N_{180}	5.13	9.90	9.30	9.09
LSD (P=0.05)	0.22	0.93	0.63	0.75
Method of urea application				
Before puddling	4.73	6.16	5.68	5.24
After puddling	4.38	6.66	5.93	5.43
LSD (P=0.05)	0.24	0.38	0.16	0.12
Pre-submergence period				
0-week	4.44	6.91	6.10	5.62
1-week	4.68	5.88	5.40	5.06
LSD (P=0.05)	0.11	0.53	0.66	0.61

Another factor for low N levels under these conditions is reduced symbiotic fixation of atmospheric nitrogen because of sensitivity of microbes to high sodicity and reduced growth of host leguminous crop plants. Losses of N can be regulated with reduction of pH of alkali soil submergence 1-week prior to crop planting or through substitution of some of rapidly hydrolyzing urea with slow release organic manures. Placement of N fertilizers at 5-6 cm depth in upland crops and about 7-8 cm in paddy fields can restrict up to 90% volatilization losses. Split application of urea can be a viable option to reduce peak NH_4 levels and NH_3 losses thereby improve its use efficiency (Table 5, Swarup, 1998).

Phosphorus: Next to nitrogen, P is the most critical nutrient required for efficient crop production in normal soils. As such, sodic water irrigation does not alter the availability of P initially. Due to high pH and the presence of soluble carbonates and bicarbonates, sodium phosphates are formed in these soils which are water soluble resultant no response of crops to added phosphorus on sodic soils early years after reclamation. However, other studies indicate that sodic soils are not always high in available phosphorus and significant increase in yields of some crops is obtained with application of P fertilizer. Olsen's extractable P of surface soil decreased due to its movement to lower sub-soil layers, uptake by the crop and increased immobilization with above amendments (Chhabra *et al.*, 1981 and Chhabra, 1985).

Table 6: Effects of NPK fertilizers use on yield of rice and wheat under sodic water conditions

Treatments	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**Mean**
			Rice (Mg ha^{-1})						
T_1 $N_0P_0K_0$	3.42	3.15	2.11	2.20	2.25	2.76	2.71	2.78	2.67
T_2 $N_{120}P_0K_0$	4.84	4.75	3.02	3.23	3.31	4.37	4.04	4.27	3.98
T_3 $N_{120}P_{26}K_0$	5.58	5.76	4.16	4.10	4.16	5.07	4.33	4.79	4.74
T_4 $N_{120}P_{26}K_{42}$	5.46	5.65	4.23	4.24	4.32	5.45	4.38	4.81	4.82
T_5 $N_{120}P_{26}K_{42}$ + Zn	5.45	5.81	4.25	4.84	4.73	5.49	4.53	4.94	5.01
LSD (P=0.05)	0.51	0.56	0.54	0.41	0.34	0.53	0.49	0.44	0.46
			Wheat (Mg ha^{-1})						
Treatments	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	Mean
T_1 $N_0P_0K_0$	1.44	1.65	1.68	1.64	1.67	1.77	1.86	1.69	1.68
T_2 $N_{120}P_0K_0$	2.47	2.85	2.84	2.79	2.65	3.24	3.25	3.17	2.91
T_3 $N_{120}P_{26}K_0$	2.82	3.56	3.28	3.36	3.76	3.84	3.88	3.92	3.55
T_4 $N_{120}P_{26}K_{42}$	2.88	3.55	3.38	3.44	3.91	3.92	4.09	4.00	3.65
T_5 $N_{120}P_{26}K_{42}$ + Zn	2.83	3.65	3.68	3.64	4.22	3.96	4.29	4.09	3.80
LSD (P=0.05)	0.32	0.45	0.33	0.33	0.31	0.27	0.29	0.32	0.32

Long term field studies with gypsum amended alkali soil (pHe 8.6, ESP 32) with sodic water (pH 9.00 and RSC 8.5 meqL^{-1}) used in rice- wheat cropping sequence and NPK fertilizer used for 10 years.

Phosphorus applied at a rate of 26 kg P ha^{-1} to both rice and wheat crop in rotation significantly enhanced the grain yield of rice (Yaduvanshi and Swarup 2005). In plots treated with 120 kg N ha^{-1} alone, the available P decreased to 6.1 kg ha^{-1} over to the initial value of 11.8 kg ha^{-1} in 1994. When the soil available P deceases below 6 kg P ha^{-1} then not only rice and wheat crops stated responding to P application but also needed higher doses of 22 kg P ha^{-1} to sustain yields. Application of fertilizer P significantly affected the per cent P content of both grain and straw of the crops and thus their nutritional value. Wheat responded to apply P when available P came down close to 8.7 kg P ha^{-1} in 0-15 cm soil depth and nearly close to critical level (11.6 kg P ha^{-1}) in the lower depths (15-30 cm). Further studies indicate that crop responses to applied P were limited to only level i.e. 11 kg in the initial years of cropping and that too only to rice crop in a rice-wheat cropping sequence. Application of 26 kg P ha^{-1} significantly affected the rice and wheat yield (Table 6).

Potassium: Application of K fertilizer to either or both the crops had no effect on yields of rice and wheat (Yaduvanshi and Swarup, 2005). Lack of crop responses to applied K in these soils is attributed to high available K status due to presence of K bearing minerals and large contribution of non-exchangeable K (97%) towards total K uptake by plants and reduced the release of K from non-exchangeable reserves in Karnal area. Studies conducted so far suggest that application of K fertilizer to rice-wheat system can be avoided with out having any adverse effect on crop productivity and K fertility status. Results of long term field trials conducted on alkali soils indicate that soil exchangeable K in the treatment receiving fertilizer K, the contribution on non-exchangeable K was lower as compared to without K fertilization (control, 100% N and 100% NP). This reserve was more in plots receiving N and P fertilizers as compared to control. (Yaduvanshi and Swarup, 2006). This may be due to better growth of the plants and thus higher removal of soil K from treatments receiving both NP and N as compared to control. The Contribution of the non-exchangeable K towards total potassium removal was about 94.9 % in the absence of applied K which decreased 69.9 % with use of K. The decreased was about 50.6 % with combined use of K with organic manures (Yaduvanshi, 2001). Similar results have been obtained in partially reclaimed alkali soils also (Swarup and Singh, 1989).

Zinc: Continuous use of sodic water leads to development of alkali soils. Though these have been observed to be sufficient (40-100 ppm) in total Zn but low in its available fraction as only 3.3% of total amount has been found as exchangeable, complexes, organically bound and occluded forms, which are considered as available during crop growth period. Reasons for low contents of available fractions of Zn under sodic/alkali conditions are high pH, formation or presence of $CaCO_3$, high soluble P and low organic matter. Availability of Zn in these conditions is regulated by solubility of $Zn\ (OH)_2$ and specifically $ZnCO_3$ with sodic water as reaction products after irrigation. Zn deficiency has been found to be widely prevalent in rice with symptoms appearing as white appearance of young leaves at early stages, delayed crop maturity and reduced yields. Naidu and Rengasamy (1993) reported in Australian sodic sodic soils, most micronutrients are usually poorly available in sodic soils, a fact which is generally attributed to the high soil pH. Generally, the solubility of cationic trace elements decreases as pH increases, while the solubility of the anionic trace elements increases as the pH increases.Application of 25 kg of $ZnSO_4$ ha^{-1} per annum is though for double crop sequence. In arid and semi-arid regions where soils are generally calcareous the availability of all micronutrients in general and Zn in particular decreases when irrigation with high sodicity water is practiced. Another factor which influences iron availability is deterioration in soil physical conditions creating reduced conditions. Minhas and Chhiba (1999) found that water soluble and exchangeable Zn fraction increased while insoluble residual fraction decreased with increase in RSC of irrigation water. This could be due to formation of soluble sodium zincate. Singh (1999) had also recorded that with use of sodic water (RSC 10 and 20 meq L^{-1}), Zn application at 20 kg ha^{-1} improved the grain yield of rice under no gypsum treatment (Table 7) but in presence of gypsum, yield increase was found to be non-significant. Page *et al.* (1990) revealed that micronutrients such as copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) exhibit low levels of solubility in sodic soils, which may result in micronutrient deficiencies. This is particularly important in the case of Zn when rice is grown on sodic soils. Although rice is moderately resistant to soil sodicity, it is sensitive to Zn deficiency, which may appear tillering, and rusty-brown spots on matured leaves. Studies conducted in India (Singh *et al.* 1987) have shown that the application of zinc sulphate at 40–50 kg ha^{-1} along with gypsum is a useful practice to ensure good crop yields in sodic and alkali during early growth stages causing stunted growth, poor soils (Table 7).

Table 7: Effect of Zn fertilizer with and without gypsum application on yield of rice under different levels of RSC water

RSC (meq L^{-1})	**Zn levels (kg ha^{-1})**			
	0	**10**	**20**	**Mean**
Without gypsum				
0	5.9	6.2	6.0	6.0
5	5.6	5.8	6.0	5.8
10	5.1	5.3	5.6	5.3
20	4.2	4.4	4.6	4.4
Mean	5.2	5.4	5.5	
CD (0.05)	RSC levels 0.30, Zn levels 0.26, RSC x Zn - NS			
With gypsum				
0	5.9	6.2	6.0	6.0
5	6.0	6.0	6.1	6.0
10	5.8	5.9	5.7	5.8
20	5.2	5.6	5.6	5.4
Mean	5.7	5.9	5.9	
CD (0.05)	RSC levels – 0.23, Zn levels – NS, RSC x Zn - NS			

Iron: Availability of iron is reduced with sodic water irrigations because of following reasons, i) decreased solubility with increase in soil pH and ii) Presence of CO_3^{2-} and HCO_3^- in irrigation water induce iron chlorosis in different crops leading to reduced growth and poor metabolism. Reports indicate that application of $FeSO_4$, a soluble salt could not overcome iron deficiency under alkali conditions (Swarup 1980). There exists negative relationship between pH and Fe-Mn availability. Soluble Fe salts when applied to alkali soils are rendered unavailable because of rapid oxidation and precipitation, and their recovery by soil-test methods is very low (Swarup, 1981). Since iron solubility is decreased as soil pH and $CaCO_3$ increase with depend upon amount of organic matter. Therefore, iron exhibit low levels of solubility in sodic soils, which may result in micronutrient deficiencies. Correction of iron deficiency using soluble salts as $FeSO_4$ is generally not found useful unless it is accompanied by changes in the oxidation status of the soil brought about by prolonged submerged and addition of easily decomposable organic matter (Katyal and Sharma, 1980). Application of Fe (3 per cent solution of $FeSO_4$) gives a limited relief to the suffering crop and must be used to supplement the improvement in reduction status of the soil. Results available on Fe concentration in plants growing under salt stress are as inconsistent as those on Zn concentration. The concentration of Fe in the shoots of pea (Dahiya and Singh 1976) and in lowland rice (Verma and Neue1984) increased, but its concentration decreased in the shoots of barley and corn under salinity (Hassan *et al.* 1970a, b). In sodic soil, an increase in the availability of Fe during submergence condition, benefitted rice because lowland rice favour reducing form of Fe in sodic soil. However, considerable variations existed among the genotypes for their Fe concentration in their shoot (Qadar, 2002). In soil, significant decrease in DTPA extractable iron in soils irrigated with sodic water for 9 years were recorded by Bajwa *et al.* (1993). Application of Fe should be practiced with use of amendments based on soil test reports.

Manganese: The alkali soils are rich in total Mn but are generally poor in water-soluble plus exchangeable and reducible forms of Mn (Swarup, 1989). The solubility and availability of Mn is also governed by pH and oxidation-reduction status of the soils achieved after irrigation with sodic water as similar to Fe. Pasricha and Ponnamperuma (1976) found that the effect of $NaHCO_3$ and NaCl on the kinetics of water - soluble Mn^{2+} were similar to those of Fe^{2+}. As a result, Mn deficiency is increasingly being observed in wheat grown in rice-wheat cropping system on coarse – textured alkali soils. Due to oxidation of Mn, it is very difficult to correct Mn deficiency by soil application of $MnSO_4$ and repeated spray of $MnSO_4$ is needed to make up the deficiency of this element in upland crops. Adoption of rice-wheat system for more than two decades on gypsum-amended alkali soils resulted in decline of the DTPA- extractable Mn to a level of 2.7 mg kg^{-1}, where wheat responded to manganese sulphate application at a rate of 50 to 100 kg ha^{-1} (Soni *et al.*, 1996). Substantial leaching losses of Mn occur following gypsum application in alkali soils (Sharma and Yadav, 1986). In a study with rice genotypes for their tolerance to sodicity and Zn deficiency stresses, an increase in Mn concentration was found under sodic conditions (Qadar, 2002). This is because during submergence Mn solubility's after conversion to reduced state and leaches to deeper depths particularly in coarse textured soils. It oxidizes readily under upland conditions, hence its soil application is not effective, but repeated foliar application of $MnSO_4$ is most effective in overcoming its deficiency in crops.

Table 8: Effect of gypsum with and without different organic manures on yield of rice and wheat and soil properties

Treatment	Yield (t ha^{-1})		Soil pH	OC (%)	Avail. Nutrients (Kg ha^{-1})		
	Rice (94-03)	Wheat (94-04)			N	P	K
$N_0P_0K_0$	2.60	1.76	8.50	0.32	104	10.2	215
N_{120} P_{26} K_{42} (100 % RD)	4.9	3.69	8.52	0.35	140	22.6	285
N_{120} P_{26} K_{42} + FYM	5.29	4.16	8.38	0.43	164	22.9	299
N_{120} P_{26} K_{42} + gypsum	5.23	4.10	8.18	0.37	145	19.0	297
N_{120} P_{26} K_{42} + Pressmud (PM)	5.31	4.46	8.29	0.42	160	24.2	298
N_{120} P_{26} K_{42} + FYM + gypsum	5.35	4.22	8.28	0.42	156	24.5	300
N_{120} P_{26} K_{42} + PM+ gypsum	5.41	4.52	8.28	0.40	160	24.0	297
CD at 5 %	0.42	0.34	0.08	0.60	8.9	2.1	20.5

Use of inorganic fertilizers with organic manures

At lower input levels, even a small increase in the amount of chemical fertilizers alone has a dramatic effect on the crop yields. However, as the amount of the applied fertilizer is progressively increased, the proportional response of crop diminishes and eventually at higher doses and may not be economical. In intensive cropping system, heavy use of chemical fertilizers alone have created economic, environmental and ecological problems and are adversely affecting the sustainable agricultural. The crop yield is higher when both chemical and organic sources are used as compared to either chemical or organic sources individually. This is attributed to the proper nutrient supply as well as creation of better soil physical and biological conditions when the two are combined together. Fertilizers supply available forms of nutrients readily to the plants on application in contrast to the organic manures, which make the nutrient slowly available on their decomposition over a long period of time. While the chemical fertilizers are mostly pure salts, supplying one or two nutrients. However, organic manures applied in proper amounts can meet the micronutrient requirements also. The efficiency of fertilizer nutrient also increases when used in combination with organic manures. Recent studies on integrated nutrient management have shown that rice and wheat yields increased significantly with integrated use of gypsum or FYM or SPM and 100% of recommended levels of inorganic NPK fertilizers in comparison to single inorganic fertilizers alone. There was substantial improvement in organic carbon and available nitrogen, phosphorus, potassium and zinc in soil over the initial status. The results of this study clearly show the beneficial effects of FYM and SPM for rice and wheat yield under sodic water irrigation (Table 8). It will become more crucial in the future because of increasing cost of chemical amendments. Use of organic amendments like SPM and FYM with inorganic fertilizers was more effective in improving and maintaining fertility of sodic soil under sodic water irrigation (Yaduvanshi and Swarup, 2005; Swarup and Yaduvanshi, 2004). In sugarcane, both the amendments (gypsum and FYM), either alone or together decreased the adverse effect of high RSC and improved yield contributing parameters like cane number, cane height and cane thickness (Choudhary *et al.* 2004). Sharma and Minhas, 1998 reported that yields of both wheat and cotton did not decline during the initial 4 years of irrigation with sodic waters in comparison to good water but the wheat yields reduced significantly at higher levels of RSC and SAR in sodic water during 5th year especially when EC_w was 4 dSm^{-1}. The use of gypsum, pyrites and FYM in conjunction with irrigation water having EC 4 dSm^{-1} and SAR 10 resulted in significantly higher yield of rice and wheat (Dubey and Mondal 1994).

Large quantities of combine harvested rice and wheat straw are being produced in states of Punjab, Haryana and Uttar Pradesh. The residues are being burnt, presently, to clear the fields for timely sowing of crops and convenient disposal of waste. One tone of rice residues contains approximately 6.1 kg N, 0.8 kg P and 11.4 kg K, while one tone of wheat residues contains 5.1 kg N, 1.2 kg P and 10.5 kg K. Rice-wheat cropping system occupies about 10 million hectares area in India. Incorporation of wheat residue 50 days prior to rice transplanting either alone or with green manuring or with SPM with recommended dose of NP improved rice yield as compared to recommended dose of N and P fertilizer alone (Yaduvanshi and Sharma 2007a and b) (Table 9). As crop residues are rich source of organic mater, nutrients and energy, they must be returned to the soil. Besides the loss of organic matter and plant nutrients, burning of crop residues also cause atmospheric pollution in form of toxins and green house gases. The results from tillage practices have shown that no-tillage (NT) practice increases organic carbon and infiltration rate of sodic water irrigated soil in comparison to conventional tillage conditions. No-tillage practice also reduces soil pH and SAR. The NT either alone or with residual effect of gypsum or SPM or FYM has been found as an effective option to sustain higher yields of wheat under use of sodic water irrigation in a rice-wheat system; besides saving of 7.22 cm of irrigation water and three disking and planking operations (Yaduvanshi and Sharma 2008).

Table 9: Effect of crop residue management on yield (mean of 3 years) and soil properties of alkali soil under poor quality water

Treatments	**Grain yield (t ha^{-1})**		**pH**	**OC (%)**	**Available Nutrients (Kg ha^{-1})**		
	Rice	**Wheat**			**N**	**P**	**K**
N_0 P_0	1.05	0.87	9.05	0.28	142	26.8	201
N_{90} $P_{19.5}$ (75 % NP)	2.69	2.31	8.98	0.26	143	25.4	198
N_{120} P_{26} (100 % NP)	3.49	2.94	8.97	0.27	144	27.9	193
100 % NP + wheat residue Burning	3.72	2.99	8.78	0.32	158	29.3	220
100 % NP + Incorporated wheat residue	4.34	3.19	8.65	0.33	157	29.4	223
100 % NP+ Incorporated wheat residue + GM	4.45	3.35	8.70	0.33	157	29.0	220
100 % NP+Incorporated wheat residue+ SPM	4.41	3.34	8.79	0.34	156	29.2	219
CD (0.05)	0.58	0.45	0.101	0.011	5.65	1.69	9.40

The paper has focused on one of the major reasons for the aggravation of the adverse effects of sodicity on plant growth and yield because of inadequate supply of inorganic nutrients, namely, nitrogen, phosphorus, potassium, calcium and zinc. To get the maximum benefit from applied nutrients, they must be given in the right quantity, at the appropriate time and place, from a proper source and in the right combination to eliminated adverse effect of sodic water up to some extent. The above discussion has resulted in the identification of several gaps in addition to the need for systematic studies dealing with physiological aspects and interaction s when multiple nutrient deficiencies occur under sodic soils/water conditions. Some of the issues need to be focused on are: 1) generating resource inventories on salt affected soils, and poor quality waters for appropriate land use planning, 2) improving the nutrient use efficiency, which is low in salt affected soils, 3) minimizing the dependence of inorganic fertilizer, as the raw materials for their production are not infinite, 4) sustaining the crops productivity in post-reclamation phase in relation to soils and water quality vis-à-vis organic matter dynamics and carbon sequestration and 5) identifying varieties having higher nutrient use efficiency as well as tolerance to salt with the long term objective of multiple stress tolerance. Although the mechanisms of salt tolerance in plants have received much attention over the past several years, the differences in salt tolerance among genotypes still remain less understood. Success of improving the salt tolerance of genotypes requires effective and reliable screening traits for nutrient use efficiency in screening genotypes programme. Since no single process can account for variation of plant response to salinity/sodicity, combined physiological traits could be reliable and feasible as screening criteria for salt tolerance.

REFERENCES

Ayers, R.S. and Westcot, D.W. (1985) Water Quality for Agriculture. Irrigation and Drainage. Paper Review **1**. Rome: FAO.

Bajwa, M.S., Singh, N.T. and Randhawa, N.S. (1974) Chemical composition of underground waters Punjab. *J. Res. PAU ,Ludhiana* **12**: 117-122.

Bajwa, M.S. and Josan, A.S. (1989) Effect of gypsum and sodic irrigation water on soil and crop yields in a rice-wheat rotation. *Agriculture Water Management* **16**: 53-61.

Bajwa, M.S., Josan, A.S. and Chaudhary, O.P. (1993) Effect of frequency of sodic and saline-sodic irrigation and gypsum on the build up of sodium in soil and crop yields. *Irrigation Science* **13**: 21–26.

Bingham, F.T., Mather, R.J. and Sposito, G. (1979) Effects of irrigation water composition on exchangeable sodium status of a field soil. *Soil Science* **127**: 248-252.

Bower, C.A., Ogata, G. and Tucker, J.M. (1968) Sodium hazard of irrigation waters as influenced by leaching fraction and by precipitation or solution of calcium carbonate. *Soil Science* **106**: 29-34.

Chaudhary, O.P., Josan, A.S., Bajwa, M.S. and Kapur, M.L. (2004) Effect of sustained sodic and saline-sodic irrigation and application of gypsum and FYM on yield and quality of sugarcane. *Field Crop Research* **87**: 103-116.

Chauhan, R.P.S., Chauhan, C.P.S. and Singh, V.P. (1986) Use of pyrites in minimizing the adverse effects of sodic waters. *Indian Journal of Agricultural Sciences* **56**: 717-721.

Chhabra, R., Abrol, I. P. and Singh, M. V. (1981) Dynamics of phosphorus during reclamation of sodic soils. *Soil Science* **132**: 319-324.

Chhabra, R.(1985) Crop responses to phosphorus and potassium fertilization of a sodic soil. *Agronomy Journal.* **77**: 699-702.

Dargan, K.S. and Gaul, B. L.(1974) Optimum nitrogen levels for dwarf varieties of paddy in semi-reclaimed alkali soils. *Fertilizer News.* **19**: 24-25.

Dahiya, S.S., and Singh, M. (1976) Effect of salinity alkalinity and iron application on the availability of iron, manganese, phosphorus and sodium in pea (*Pisum sativum* L.) crop. *Plant Soil* **44**: 697-702.

Dixit, S.P. (1974) Quality of irrigation water from different sources in western Uttar Pradesh. Proceedings of All India Symposium on Soil Salinity, pp.107-11,UP Instt. Agric. Sci., Kanpur.

Dubey, S.K. and Mondal, R.C. (1994) Effect of amendments and saline irrigation water on soil properties and yields of rice and wheat in a highly sodic soil. *Journal of Agriculture Science (Cambridge)* **122**: 351-357.

Hassan, N.A.K., Jackson, W.A., Drew, J.V., Knudsen, D. and Olson, R.A. (1970a) Influence of soil salinity on production of dry matter and uptake and distribution of nutrients in barley and corn. 1. barley (*Hordeum vulgare*). *Agronomy Journal* **62**: 43-45.

Hassan, N.A.K., Jackson, W.A., Drew, J.V., Knudsen, D. and Olson, R.A. (1970b) Influence of soil salinity on production of dry matter and uptake and distribution of nutrients in barley and corn. II. Corn (Zea mays L.). *Agronomy Journal* **62**: 46-48.

Katyal, J.C. and Sharma, B.D. (1980) A new technique of plant analysis to resolve iron chlorosis. *Plant Soil* **55**: 105-119.

Minhas, N. and Chhiba, I.M. (1999) Zinc transformations in rice soil irrigated with sodic water. *Indian Journal Agricultural of Sciences* **69**: 251-254.

Minhas, P.S. and Bajwa, M.S. (2001) Use and management of poor quality water in rice – wheat production system. *Journal Crop Production* **4**: 273-306.

Naidu, R., and Rengasamy, P. (1993) Ion interactions and constraints to plant nutrition in Australian sodic soils. *Australian Journal of Soil Research* 31:801–19.

Page, A.L., Chang, A.C., and Adriano, D.C. (1990) Deficiencies and toxicities of trace elements. In: Tanji KK, editor. Agricultural Salinity Assessment and Management; Manuals and Reports on Engineering Practices No. 71. American Society of Civil Engineers, New York; 1990. p. 138–60.

Pasricha, N.S. and Ponnamperuma, F.N. (1976) Influence of salt and alkali on ionic equilibria in submerged soils. *Soil Science Society of America Proceeding* **40**: 374-376.

Qadar, A. (2002) Selecting rice genotypes tolerant to zinc deficiency and sodicity stresses. 1. Differences in zinc, iron, manganese copper, phosphorus concentrations and phosphorus/zinc ratio in their leaves. *Journal Plant Nutrition* **25**: 457-473.

Rao, D.L.N. and Batra, L. (1983) Ammonia volatilization from applied nitrogen in alkali soils. *Plant Soil* **20**: 219-228.

Rhoades, J.D., Kandiah, A. and Mishali, A.M. (1992) The use of saline waters for crop production. Food and Agriculture Organization Irrigation and Drainage Paper No. 48, Food and Agriculture Organization, Rome, Italy. pp 133.

Sehgal, J.L., Bajwa, M.S. and Khurana, P.K. (1985) Soils of Punjab and their management. In Soils of India. *FAI, New Delhi*. pp. 316-42.

Shainberg, I., Sumner, M.E., Miller, W.P., Farina, M.P.W., Pavan, M.A. and Fey, M.V. (1989) Use of gypsum on crops. A Review. *Advances in Soil Science* **9**: 1-112.

Sharma, B. M. and Yadav, J. S. P. (1986) Leaching losses of iron and manganese during reclamation of alkali soil. *Soil Science* **142**: 149-52.

Sharma, D.R. and Minhas, P.S. (2001) Response of Rice-Wheat to Alkali Water Irrigation and Gypsum Application. *Journal of the Indian Society of Soil Science* **49:**324-327.

Sharma, D. R., Kumar, C., Kaledhonkar, M. J. and Minhas, P.S. (2005) Effect of sustained alkali water irrigation on soil properties, growth and yield of maize-wheat system. *Central Soil Salinity Research Institute, Karnal,* India.

Sharma, D. R. and Minhas, P.S. (1998) Effect of irrigation with sodic waters of varying EC, RSC and SAR/ adj. SAR on soil properties and yield of cotton – wheat. *Journal of the Indian Society of Soil Science* **46**: 116-119.

Sharma, D. R. and Minhas, P.S. (2004) Soil properties and yields of upland crops as influenced by long-term use of water having variable residual alkalinity, salinity and sodicity. *Journal of the Indian Society of Soil Science* **152:** 100-104.

Singh, Joginder. (1999) Interactive effects of zinc, gypsum and sodic irrigation water on transformations and availability of micro-nutrients to rand wheat. Ph. D. thesis submitted to PAU, Ludhiana.

Singh, M.V., Chhawra, R and Abrol, I.P. (1987) Interaction between application of gypsum and zinc sulphate on yield and chemical composition of the rice grown on an alkali soils. *Journal of Agriculture Science (Cambridge)* **108**: 275-279.

Soni, M. L, Swarup, A. and Singh, M. (1996) Influence of rates and methods of manganese application on yield and nutrition of wheat in a reclaimed sodic soil. *Journal of Agricultural. Science., (Cambridge)* **127**: 433-439.

Swarup, A and Singh, K.N. (1989). Effect of 12 – years rice wheat cropping and fertilizer use on soil properties and crop yields in a sodic soil. *Field Crops Research* **21**: 277-287.

Swarup, A. (1980) Effect of submergence and farm yard manure application on yield and nutrition of rice under sodic conditions. *Journal of the Indian Society of Soil Science* **28**: 532-534.

Swarup. A. (1981) Effect of iron and manganese application on the availability of micronutrients to rice in sodic soil. *Plant and Soil*. **60**: 481-5.

Swarup. A. (1989) Transformation and availability of iron and manganese in submerged sodic soil in relation to yield and nutrition of rice. Fertilizer News **34 (7)**: 21-31.

Swarup, A., (1998) Nutrient management for crop production in alkali conditions. In: Salinity Management in Agriculture (eds. S.K. Gupta, S. K. Sharma and N. K. Tyagi) CSSRI, Karnal. Pp. 99-107.

Swarup, A. and Yaduvanshi, N.P.S. (2004) Response of rice and wheat to organic and inorganic fertilizers and soil amendment under sodic water irrigated conditions. *IRRI News Letter* **29**: 49-51.

Verma, T. S. and Neue, U. (1984) Effect of soil salinity level and zinc application on growth, yield and nutrient composition of rice. *Plant and Soil* **82**: 3-14.

Yadav, J.S.P. (1989) Irrigation Induced Soil Salinity and Sodicity. Proceeding of World Food Day Symposium on Environmental Problems Affecting Agriculture in the Asia and Pacific Region held at *FAO, Bangkok, Thailand*. pp. 47-62.

Yadav, R. K. and Kaledhonkar, M. J. (1998) Effect of toposequential differences and ground water quality on performance of cotton and Egyptian clover. Central Soil Salinity Research Institute, Annual Report. pp. 28-29.

Yaduvanshi, N. P. S. (2001a) Ammonia volatilization losses from integrated nutrient management in rice field of alkali soil. *Journal of the Indian Society of Soil Science* **49**: 276-280.

Yaduvanshi, N.P.S. (2001b) Effect of five years of rice-wheat cropping and NPK fertilizer use with and without organic and green manures on soil properties and crop yields in a reclamation sodic soil. *Journal of the Indian Society of Soil Science* **49**: 714-719.

Yaduvanshi, N.P.S. (2003) Substitution of inorganic fertilizers by organic manures and the effect on soil fertility in a rice-wheat rotation on reclaimed sodic soil in India. *Journal of Agriculture Science (Cambridge)* **140**: 161-169.

Yaduvanshi, N. P. S. and Swarup, A. (2005) Effect of continuous use of sodic irrigation water with and without gypsum, farm yard manure, pressmud and fertilizer on soil properties and yields of rice and wheat in a long term experiment. *Nutrient Cyclic in Agroecosystems.* **73**: 111-118.

Yaduvanshi, N. P. S. and Swarup, A. (2006) Effect of lonf term fertilization and manuring on potassium balance and non-exchangeable K release in a reclaimed sodic soil. *Journal of Indian Society of Soil Science* 54: 203-207.

Yaduvanshi, N.P.S. and Sharma, D.R. (2007a) Use of wheat residue and manures to enhance nutrient vailability and rice-wheat yields in sodic sunder sodic water irrigation. *Journal of the Indian Society of Soil Science* **55**: 330-334.

Yaduvanshi, N.P.S. and Sharma, D.R. (2007b) Incorporate wheat residue with green manure for sustaining rice-wheat production in sodic water. *Indian Farming* **57**: 15-17.

Yaduvanshi, N.P.S. and Sharma, D.R. (2008) Tillage and residual organic manures/chemical amendment effects on soil organic matter and yield of wheat under sodic water irrigation. *Soil and Tillage Research* **98**: 11-16.

Yaduvanshi, N.P.S., Sharma, D.R. and Swarup, A. (2013) Impact of integrated nutrient management on soil properties and yield of rice and wheat in a long term experiment on a reclaimed sodic soil. *Journal of the Indian Society Soil of Science* **61**: 188-194.