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Nutrient management in salt affected soils for sustainable crop production

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ABSTRACT

Soil salinity and sodicity are the global problems and pose a serious threat to agriculture sustainability. The distribution of salt affected soils exist mostly under arid and semi-arid climates where rainfall is inadequate to leach salts from/out of the root zone. These soils have poor fertility, generally with low availability of nitrogen, calcium, zinc, iron and manganese. Therefore, judicious nutrients management on the principle of INM in these soils is as important as their reclamation. In these soils, crops respond differently to applied nutrients due to their diverse chemical composition impacting precipitation-dissolution reactions and adsorption-desorption kinetics. Nutrient transformation and loss mechanisms of applied nutrients are also affected by the magnitude of soil salinity and sodicity. The paper aims at discussing efficient nutrient management in salt affected soils for sustainable crop production.

Keywords: Nutrient management, salt affected soils, sustainable crop production

The salt affected soils occur in the arid and semi-arid regions where evapo-transpiration greatly exceeds precipitation. The accumulated ions causing salinity or sodicity include sodium, potassium, magnesium, calcium, chloride, carbonate and bicarbonate. Salts generally originate from native soil and irrigation water. The salt affected are also encountered in hurrid regions, in areas subjected to sea water intrusions in deltaic regions and other low lying areas, which occasionally get inundated by the sea water. In India, an area of about 6.74 M ha^{-1} (million hectares) suffers from the problem of salt accumulation, out of which 3.78 M ha^{-1} are sodic while 2.96 M ha^{-1} are saline soils. The states of Gujarat (2.20 M ha^{-1}) and Uttar Pradesh (1.37 M ha^{-1}) in India have the largest area under salt affected soils.

Salts not only decrease the agricultural production of most crops, but also, as a result of their effect on soil physico-chemical properties, adversely affect the associated ecological balance of the area. The plant growth is either decreased or entirely prevented due to excessive build up of salinity and / or alkalinity in the soil resulting in poor crop yield (Choudhary *et al.* 2003). There are two main stresses imposed by salinity/sodicity on plant growth. One is water stress imposed by the increase in osmotic potential as a result of high salt concentration or poor in water relations due to high pH and sodicity of the rhizosphere. Another stress is the toxic effect of high concentration of salts. The presence of sufficient total quantities of essential nutrients in salt affected soil does not guarantee the availability of these nutrients to growing plants for optimum crop growth and yields, because other factors, such as presence of high amounts of salts, low soil moisture content, high soil pH and poor soil physicaland microbiological properties, imbalances in soils and plants may be becoming limiting. In sodic soils, high alkalinity due to presence of high amount of exchangeable sodium and of $C_a\ CO_3$ coupled with poor air-water relations affect the availability of nutrients. The interaction between salinity and mineral nutrition is very complex because it is influenced by plant species and genotypes within species, plant age, composition and level of salinity, concentration of nutrients in the substrate and climatic conditions. Specific ion effect on plant growth in salt affected soils induces mineral nutrient deficiencies (Munns 2002).

Nitrogen

Salt affected soils are poor in total and available nitrogen as these soils contain very low amount of organic carbon due to its rapid decomposition. In the presence of high amounts of salts, nitrogen use efficiency is usually very poor. The process of N transformations is slow due to poor microbial population in consequence

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to high ECe and pH. It has been shown that nitrification is influenced more due to high salinity than ammonification process, resulting in accumulation of NH_3 and nitrites. In these soils there is poor symbiotic N-fixation due to toxic effects of salts on Rhizobia which in turn causes drastic reduction in nodulation. Nitrate uptake by plants is reduced to antagonistic effect of chloride and sulphate and leaching losses of N as NO_3^{-1}. Urea hydrolysis becomes slower with increase in salinity. This was attributed to the possible adverse effect of high pH on the activity of the urease enzyme and/ or the direct toxic effect of carbonates on the N-transforming bacteria. The efficiency of fertilizer N in alkali soils is rather low and is controlled by the factors affecting namely (i) adverse effect of sodicity on the transformations of soil and fertilizer- N and excessive losses of N by ammonia volatilization and denitrification, (ii) nutritional and cationic imbalances within the plants under high soil sodicity resulting in poor crop response to applied fertilizers and (iii) poor plant growth due to partial soil reclamation. Fertilizer- N placed in soil (UPP- urea in paper packet and UB – urea briquette) reduced losses to about 5-6% (Swarup and Yaduvanshi 2004). Bandhyopadhyay *et al.* (2000) observed that denitrification losses of N from saline rice fields were relatively low compared to volatilization losses. Ammonia volatilization losses could be reduced up to some extent by applying urea with FYM or green manuring as compared to urea-N application alone (Yaduvanshi 2001a).

Appropriate doses of N for salt affected soils

Generally, application of higher dose (25-50%) of nitrogen than that for normal could be one strategy to overcome the adverse effects of salinity. But it has been observed that when salinity is not a limiting factor, applied N fertilizers will increase the yields of crop proportionally more than that when the salinity becomes a limiting factor. Application of 150 kg N ha^{-1} (25% more than normal recommendation) is a common recommendation for both rice and wheat crops grown in alkali soils in Panjab and Haryana. However, in black alkali soils, wheat, paddy, cotton and barley responded only up to 120 kg N ha^{-1}.Nitrogen losses in sodic soils can be substantially reduced by incorporating fertilizer N in to the soil or by applying N in split doses. Regardless of the severity of the effects salinity and sodicity may have an adverse effect on a crop. The application of N to sodic soils usually improves plant growth and yield. As about 30% of fertilizer N applied to wheat grown in alkali soils is lost, general recommendation to wheat in alkali soils in the I G P is to apply 150 kg N ha^{-1} in three equal splits doses (Swarup and Yaduvanshi 2012).

Time of N application

Significant increases in yield of wheat and rice have been obtained with split application of nitrogen. Split application of N for wheat (1/2 at sowing, remaining ½ N in two splits at tillering (21 days) and 42 days after sowing) resulted in maximum yield of the crop. Maximum yields of rice and wheat were obtained when N was applied in three equal splits as basal and at 3 and 6 weeks after transplanting sowing under sodic water condition (Yaduvanshi and Swarup 2005). These benefits were attributed to reduced N losses via volatilization thereby increasing the efficiency of applied N fertilizers. Because of the adverse physical- chemical conditions, the recovery of N could be expected to be still lower in the salt affected soils. Under such situation N use efficiency can be increased by integrated use of organic and inorganic sources of N (Yaduvanshi 2001). Green manuring with *Sesbania* along with urea will minimize nitrogen losses applied through fertilizers In fine textured poorly permeable sodic soils, split application of N may not be required because leaching losses of fertilizer N are negligible. In coarse textured soils, on the other hand, the depth of water infiltration and urea leaching increased with injudicious use of water.

Type of N fertilizers

The nitrate containing fertilizers were appreciable inferior possibly due to more denitrification losses. However, in the case of wheat, the effectiveness of N fertilizers containing NH^{+}_{4} - N and NO_3 – N was almost similar. Application of nitrogen as ammonium sulphate or urea resulted in similar yields in both rice and wheat crops. In saline soils it is better to use NO_3-N fertilizer. While evaluating different N sources Swarup and Yaduvanshi (2004) reported the maximum NH_3 volatilization losses of 17.8 and 37.4% at soil EC of 4 and 8 dSm^{-1}, respectively from field plots receiving ammonium sulphate and the minimum in urea briquettes followed by sulphur-coated urea (Table 1).

Table 1: Nitrogen losses (%) through ammonia volatilization from different fertilizers at two salinity levels

Fertilizer	ECe (dSm^{-1})	
	4	8
Prilled urea	14.6	26.2
Sulphur-coated urea	8.5	16.4
Lac-coated urea	12.0	22.4
Urea briquette	9.6	8.8
Urea in paper packet	5.5	5.3
Ammonium sulphate	17.8	37.4

Source: Swarup and Yaduvanshi (2004)

Increasing N use efficiency through INM

For increasing N use efficiency, a better strategy seems to be to substitute a part of inorganic fertilizer requirements through organic materials. According to Parihar *et al.* (2003), the maximum grain and straw yield of rice was obtained under 100% fertilizer N + 5t FYM ha^{-1} in sodic soils. Chauhan *et al.* (2008) reported that application of 60 kg N ha^{-1} through press mud or farmyard manure in conjunction with 90 kg N ha^{-1} as urea proved most effective in enhancing yield of rice and was at par with 150 kg N ha^{-1} applied as urea. The net income and benefit: cost ratio with recommended dose of N (150 kg N ha^{-1}) and integrated use of N (PM-N_{60} + U-N_{90} kg ha^{-1}) was almost similar (Table 2).

Table 2: Effect of integrated nitrogen management on yield and economics of hybrid rice (mean of 2 years)

Treatment	Yield (q ha^{-1})		Net return (Rs ha^{-1})	B:C ratio
	Grain	Straw		
Control	34.55	40.78	6039	0.43
Rec. N	64.76	68.69	21523	1.38
PM- N90+U- N_{60}	56.70	61.94	16854	1.07
PM-N_{75} + U- N_{75}	59.00	63.70	18169	1.16
PM-N_{60} + U- N_{90}	64.37	68.31	21206	1.35
FYM-N_{90} + U- N_{60}	55.65	60.97	14655	0.85
FYM-N_{75} + U- N_{75}	57.45	62.22	15960	0.94
FYM-N_{60} + U- N_{90}	63.68	67.80	19764	1.18
RH-N_{90} + U- N_{60}	50.52	56.16	7263	0.34
RH-N_{75} + U- N_{75}	52.05	56.65	9121	0.44
RH-N_{60} + U- N_{90}	57.90	62.32	13487	0.69
CD (P=0.05)	3.69	4.05		

PM-Press mud, FYM-farmyard manure, RH rice husk, U-Urea

Green manuring or use of FYM improves soil health and the crop yields, especially when applied along with gypsum. In a partially reclaimed alkali soil, a fifty-days-old *Sesbania* green manure crop produced 4.2t ha^{-1} dry matter, accumulated 90 kg N, 11 kg P and 90 kg K resulting a saving equivalent to 60 kg N and 13 kg P ha^{-1} applied through chemical fertilizers in a rice-wheat cropping system (Yaduvanshi 2003). Long term experiment at CSSRI, Karnal has shown that the combination of green manuring with 50 recommended dose (60 kg N, 13 kg P and 21 kg K ha^{-1}) gave a rice yield similar to that obtained from applying 100% recommended dose of NPK (120-26-42 kg ha^{-1}). In addition to supplying plant nutrients, GM also increased organic carbon, available N, P and K in the reclaimed sodic soil (Table 3).

Table3: Effect of green manuring on yield of rice and wheat and soil properties

Treatments	Mean yield (t ha^{-1})		Org. carbon (g kg^{-1})	Available nutrients after wheat harvest (1999)			
	Rice 1994-98	Wheat 1995-99		N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Zn (kg ha^{-1})
Control	2.97	1.34	2.9	101	9.3	187	0.73
100% RDF	5.52	5.01	2.9	178	14.1	253	0.68
100% RDF + GM	6.63	5.37	3.9	195	19.0	285	0.95
50% RDF + GM	5.75	3.81	4.0	171	17.5	261	0.93
Initial soil properties			3.0	171	11.5	220	0.80

Source: Yaduvanshi (2003)

Field experiment conducted on salt affected soil at Faizabad showed that increasing levels of N significantly increased the fodder yield of sorghum (PAL *et al.* 2008). Addition of 2.8t FYM either alone or in combination with Azolobacter improved the yield and maximum fodder yield of sorghum (51.0t ha^{-1}) was obtained under treatment N 80 + Azotobacter + FYM. In a field experiment conducted on a sodic soil of Kanpur, it was noted that combined use of gypsum and green manuring proved significantly superior to control in respect of rice yield (Tripathi *et al.* 2014).

Phosphorus

Next to nitrogen, phosphorus is the most critical nutrient required for efficient crop production in normal soils. Transformation and availability of applied and native P and responses to its application greatly differ in salt affected soils from those in normal soil. In sodic soils, Ca-P is the dominant inorganic P fraction followed by Al-P, Fe-P and saloid bound P. High alkalinity converts native insoluble Ca-P to soluble Na-P and is responsible for higher extractable P in the sodic soils. During early stages of reclamation, soils release sufficient P in soil solution for use of plants. Rice and wheat crops grown on newly reclaimed alkali soils do not respond to the P application. But when P of this surface soil layer gets depleted, rice crop, having shallow root system, starts responding to phosphatic fertilizer. Wheat plants with a relatively deeper root system can also absorb P from the lower layers but do not respond to applied P for 3 to 5 years.

Type of fertilizer

All phosphatic fertilizers containing water soluble P are more effective than those containing wholly or partially water insoluble P. Single superphosphate is a better source of P compared to the other phosphatic fertilizers as it contains some amount of $CaSO_4$. In saline soils availability of P decreases due to precipitation of applied P, higher retention of soluble P, antagonism due to excess of Cl^- and $SO_4{}^{2-}$. Application of phosphatic fertilizers invariably increases crop yields in saline soils by directly providing P and by decreasing desorption of the toxic elements like Cl^-. Thus, while P application can be omitted in initial years following reclamation of alkali soils, P application is a must in saline soils. Increasing levels of P over the recommended dose of 60 kg P_2O_5 ha^{-1} has a better effect on crop yields. Application of P thus seems to mitigate the adverse effect of salinity.

Increasing P use efficiency through INM

Singh and Singh (2007) conducted a field experiment on reclaimed sodic soil using rice-berseem crop sequence. They reported that the application of 10t sesbania along with 100% NPK gave the highest net returns, B:C ratio and produced significantly higher biomass in terms of rice equivalent yield. Among the organic manures, the overall performance of green manure was best followed by FYM and rice-cut straw (Table 4).

Table 4: Production potential and economics of rice-berseem crop sequence as influenced by INM (mean of 2 years)

Treatment	Rice yield (q ha^{-1})		Berseem yield (q ha^{-1})		Net profit (Rs ha^{-1})	B:C Ratio	Rice equivalent yield (q ha^{-1})
	Grain	Straw	Forage	Dry Matter			
Control	21.78	42.50	39.04	7.84	1936.2	1.11	27.45
10t FYM ha^{-1}	25.31	52.00	50.20	10.08	4720.5	1.25	32.61
50% NPK	30.59	60.97	58.59	11.78	8114.9	1.41	39.12
50% NPK + 10t FYM ha^{-1}	33.23	69.21	69.40	13.93	10248.5	1.49	43.30
100% NPK	34.13	71.46	70.81	14.21	9997.3	1.46	44.43
100% NPK + 10t FYM ha^{-1}	38.40	80.81	78.90	15.84	12750.0	1.56	49.87
10t Rice cutstraw ha^{-1}	24.93	57.10	48.31	9.70	5180.3	1.29	31.95
50% NPK + 10t rice cutstraw ha^{-1}	33.04	68.76	68.71	13.79	10443.0	1.51	43.03
100% NPK + 10t rice cutstraw ha^{-1}	37.92	79.63	76.55	15.37	12758.0	1.57	49.05
10t Sesbania ha^{-1}	26.45	57.60	54.58	10.95	5657.9	1.29	34.38
50% NPK + 10t sesbania ha^{-1}	33.06	72.51	70.34	14.12	9960.2	1.47	43.29
100% NPK + 10t sesbania ha^{-1}	38.89	81.90	80.18	16.10	12808.9	1.55	50.55
150% NPK	39.04	82.16	82.42	16.55	12611.6	1.53	51.02
CD (P=0.05)	4.85	5.17	5.63	1.61	-	-	-

A field experiment conducted at Lucknow on reclaimed sodic soil and reported that the yield of rice was significantly higher under 100 NPK + green manure dhaincha followed by 100 NPK + 10t sulphitation press mud cake ha^{-1} in comparison to other treatments. The yield of wheat was significantly higher with the application of 100% NPK with residual effect of green manure followed by sulfitation press mud cake in comparison to other treatments Singh *et al.* (2009). Similary, Kumar *et al.* (2012) reported that the application of N, P and organic sources significantly increased the yield of rice and maximum yield was obtained in 100% NP + GM (6.42 t ha^{-1}) than 100% NP (5.31 t ha^{-1}) and 100% NP + wheat residue (6.02 t ha^{-1}) (Table 5).

Table 5: Effect of different INM treatment S on yield of rice

Treatment	Yield (t ha^{-1})	
	Grain	Straw
T_1 Control	2.26	1.62
T_2 75% NP	4.29	2.43
T_3 100% NP	5.31	3.05
T_4 75% NP + 10t FYM ha^{-1}	5.52	2.92
T_5 75% NP + 10t SPM ha^{-1}	5.46	2.95
T_6 75% NP + GM (in situ)	5.65	2.92
T_7 75% NP + 2.5t WR ha^{-1}	5.24	2.80
T_8 100% NP + 10t FYM ha^{-1}	6.21	3.65
T_9 100% NP + 10t SPM ha^{-1}	6.39	3.71
T_{10} 100% NP + GM (in situ)	6.42	3.72
T_{11} 100% NP + 2.5t WR ha^{-1}	6.02	3.46
CD (P=0.05)	0.26	0.28

Potassium

In sodic soils, high contents of sodium and deficiency of Ca result in decreased uptake of potassium by plants. The responses of crops to applied K have not been observed in the Indo-Gangetic alluvial soils possibly due to the presence of illite clay minerals, which are capable of releasing sufficient potassium to meet the crop needs. Results of long term field trials conducted on alkali soils indicate that in the treatment receiving K fertilizer, contribution from non-exchangeable K was lower as compared to without K fertilization (control, 100% N and 100% NP) (Yaduvanshi and Swarup 2005). This contribution was more in plots receiving N and P fertilizers compared to the control. The contribution of non-exchangeable K towords total potassium removal was about 94.9% in the absence of applied K which decreased 69.9% with applied K (Yaduvansh 2001). The decrease was about 50.6% with combined use of fertilizer K along with organic manures. Yaduvanshi and Swarup (2006) further reported that the contribution of non-exchangeable K was more in plots receiving N and P as compared to control.Singh and Sharma (2001) observed that nitrogen use efficiency of 120 and 150 kg N ha^{-1} increased markedly with application of 50 kg K_2O ha^{-1}.

Saline soils often contain medium to high amounts of available K. But during reclamation losses of K due to leaching may take place leading to its low availability. Plants grown under high soil salinity conditions show K deficiency symptoms due to antagonistic effect of Na on K absorption. Therefore, plants may respond to polassiam application.

Application of K fertilizer in saline soils benefits crop yields by (i) directly supplying K, (ii) improving tolerance of plants to Na level,. (iii) improving water use efficiency and (iv) improving N use efficiency (Swarup and Yaduvanshi, 2012). For correcting Na-induced K deficiency in plants grown on sodic soil with medium to high amounts of exchangeable K, instead of applying K fertilizers, it is suggested that a proper amount of amendment should be added to correct Ca: Na balance so as to improve the K content of plants.

Calcium and Magnesium

The uptake of calcium in salt affected soils is decreased due to ion interaction, precipitation and increase in ionic strength. With increase in pH, the solubility of calcium carbonate decreases and, therefore, availability of Ca from this source becomes insufficient to meet the plant needs. Apart from this sodium has antagonistic effect on calcium absorption by the plants. Use of organic manures like FYM or press mud cake which under aerobic conditions during flooding of sodic soils create increased p CO_2 and reduced redox potential (Eh) of sodic soils, help in solubilization of native Ca CO_3 and release calcium and this released Ca in turn removes Na from the exchange complex (Swarup and Yaduvanshi 2004). Cultural practices like growing of crops also increases solubility of soil Ca CO_3 and inturn calcium availability to plants. The observed ameliorative effect of rice cultivation in alkali soils has been reported to be mainly due to mobilization of Ca from $CaCO_3$ by the biological process in plant roots. Under sodic conditions, crop plants are affected in two ways, (1) sodicity sensitive plants accumulate toxic levels of sodium in high sodic conditions, and (2) in moderately sodic conditions lack of supply of adequate calcium affects its availability (Table 6).

Table 6: Calcium and Na contents (%) of some crop plants at varying soil sodiccity

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

Source: Swarup and Yaduvanshi (2004)

Absolute calcium contents and its concentration in relation to sodium under sodic environment are good indication of proper plant growth. In 15 years long term study Choudhary *et al.* (2011) confirmed that organic materials alone can be used to solubilize calcium from inherent and precipitated $CaCO_3$ in calcareous soils for achieving sustainable yields in sodic water irrigated rice-wheat cropping system. Salt tolerance of crop has been reported to increase with the addition of calcium in the salt affected soils. The extent to which supplemental calcium is effective in alleviating the adverse effects of sodium salinity depends on the crop, the Ca concentration, and on the sodium source.

Gypsum, phosphogypsum and other amendments act as direct sources of calcium for plant growth. Thus, the application of amendments, apart from improving the soil physico-chemical properties through replacement of excess sodium, is also necessary to supply calcium for plant growth. The growing of grasses, crops and other plantations also increase solubility of native $CaCO_3$ through biological actions of the roots.

Limited information is available on magnesium-salinity interactions. A high concentration of substrate Ca^{++} often results in increased leaf-Ca along with a marked reduction in leaf-Mg. Calcium is strongly competitive with Mg^{2+} and the bonding sites on the root plasma membrane appear to have less affinity for the highly hydrated Mg^{2+} ions than for Ca^{2+}. It has been known that solution with a Mg^{2+} / Ca^{2+} ratio greater than one, such as those that result by diluting sea water, reduce the growth of maize.

Sulphur

The studies on the influence of salinity on sulphur nutrition of the plants are quite meagre. The study on the effects of both chloride and sulphate salinity on pea indicated that chloride-salinity reduced the sulphur content in the straw. Sulphur accumulation in the roots, however, was enhanced by chloride – salinity. Tripathi and Kumar (2013) reported significant response of rice to sulphur application in salt affected soil up to 40 kg S ha^{-1}. The percentage yield response due to sulphur addition ranged from 9.3 to 18.8 and 9.7 to 19.3 in grain and straw, respectively. Yaduvanshi *et al.* (2015) applied 45 kg S ha^{-1} through single superphosphate as a source of S with recommended dose of NP fertilizers to minimize the adverse effect of sodic water.

Micronutrients

Availability of micro-nutrients in these soils is mainly controlled by pH, organic matter content, crop species, salinity / alkalinity level and presence of calcium carbonate.

Iron

Iron deficiency is most common in upland crops particularly grown on calcareous/alkaline soils of the arid regions. Iron deficiency is also observed in alkali soils on rice nurseries particularly grown on raised beds. Iron deficiency in crops is one of the most difficult micronutrient deficiencies to correct in the field. Iron is sensitive to oxidation-reduction status of a soil. Iron solubility is controlled by pH, $CaCO_3$, oxidation status of the soil and amount of organic matter. Therefore, soil application of $FeSO_4$ is often ineffective unless it is accompanied by changes in the oxidation state of the soil brought about by prolonged submergence and addition of easily decomposable organic matter (green manuring). Simple techniques like increasing gap between puddling of the field and transplanting of rice mitigate iron deficiency. Pretreatment of nursery beds by incorporation of green manure, FYM or compost helps in creating reduced conditions and mobilizing soil iron to meet the plant needs. Hence, it is always advisable to apply excess water to rice nurseries when they show iron deficiency symptoms. In sodic soil an increase in the availability of Fe during submergence condition benefitted rice because low land rice favour reducing form of Fe. However, considerable variations existed among the genotypes for their Fe concentration in their shoots. Ferrous sulphate, Fe-EDTA, Fe-EDDHA, pyrites, biotite, organic manures poultry and piggery manure and sewage sludge have been used as sources of Fe to correct its deficiency in crops. Out of these, ferrous sulphate, Fe-EDTA and FYM are most commonly used. The rates of soil application of Fe are very high (50-150 kg $FeSO_4$ ha^{-1}) as compared to foliar application and as such soil application is uneconomical.

Singh (2006) reported that upland rice grown on reclaimed sodic soil responded significantly upto 50 kg $FeSO_4$ ha^{-1} as judged by increased grain and straw yield and Fe uptake by rice. Soil application of iron was inferior as compared to its foliar application.

Similarly high cost of organic carriers (Fe-chelates) discourages farmers to use them. Application of chelated forms of iron like Fe-EDTA, Fe-DTPA iron citrate and iron tart rate have also been found beneficial in alleviating the iron deficiency of fruit plants grown on sodic soil.

Manganese

The availability of Mn in soil is controlled by pH and oxidation-reduction state of the soil. Due to auto-oxidation of Mn, it is very difficult to correct Mn deficiency by soil application of $MnSO_4$. Foliar application of Mn is, therefore, effective and economically better than soil application. Repeated (3-4 times) 1% $MnSO_4$ solution sprays are needed to correct Mn deficiency in upland crops. Deep ploughing so as to mix subsoil with the surface layers generally helps in redistribution of soil Mn and increases its availability to the plants. Deficiency of Mn is seldom a problem for wet land rice while it can become a serious limiting factor for the upland crops of rice and other upland crop, grown after rice. Manganese deficiency is being increasingly observed in the wheat crop following rice in rice-wheat cropping system particularly on coarse textured soils. However, due to low permeability in un-reclaimed/partially reclaimed sodic soils, Mn deficiency can be expected to be of lower magnitude due to less leaching losses than normal soils.

Foliar application of 0.5% $MnSO_4$ (3 foliar sprays) proved superior to soil application of 50 kg $MnSO_4$ ha^{-1}.Three sprays of 0.5% and two sprays of 1 and 2% $MnSO_4$ solution were equally effective on wheat for similar response. Concentration of Mn-EDTA in sprays could be reduced to one-fourth of $MnSO_4$ H_2O. Manganese sulphate, MnO_2, Mn frits, Mn-EDTA as well as some multi-micronutrients mixtures have been evaluated for their efficiency to correct Mn deficiency in crops. Among these sources of Mn, MnO_2 is the least effective. Soil application of Mn-EDTA often accentuates the Mn deficiencies on alkaline calcareous soils rather than correcting them. The magnitude of response to Mn application decreased successively as the rating of the tolerance increased and there were no significant responses in the most tolerant categories.

Copper

There is a meagre information on the effect of soil salinity on copper uptake by crop plants. Influence of salinity on copper is variable. The deficiency of copper is sporadic and the response to copper fertilization is observed only at a few locations. Nevertheless, in salt affected soils, the deficiency of copper is not common and so are the studies related to its management.

Zinc

Sodic soils contain medium to high amounts of total zinc (40 to 100 mg kg^{-1} soil). The availability of zinc to the plants grown in these soils is adversely affected by high pH, presence of $CaCO_3$, high soluble P and low organic matter. Most often sodic soils contains less than 0.6 mg DTPA-extractable Zn kg^{-1} and show acute Zn deficiency. A highly significant negative correlation was observed between extractable Zn and pH and $CaCO_3$ content of the soils. In sodic soils, the solubility and extractability of added Zn decreased with time but increased with increase in ESP. Higher extractability of zinc at high ESP is attributed to the formation of soluble sodium zincate. Besides, being poor in available zinc, the use efficiency and recovery of applied zinc is further adversely affected due to 85-90% of applied Zn getting fixed.

Availability of Zn in salt affected soils

The availability of native and applied zinc in sodic soils slightly improved due to reduction in pH on flooding. This results primarily due to release of Zn from solid phase due to significant decrease in pH, which chiefly governs the availability of Zn in sodic soil during growth of rice (Swarup and Yaduvanshi 2004). Solubility of Zinc in sodic soils is controlled by Zn $(OH)_2$ and $ZnCO_3$, which are the immediate reaction products. During initial periods (upto 21 days) the Zn concentration in soil solution is regulated by both Zn $(OH)_2$-Zn^{2+} (aq) and ZnCO3-Zn^{2+} (aq) systems and thereafter by $ZnCO_3$-Zn^{2+} (aq) system alone because of the buffering effect of soil carbonate equilibria. Among different zinc carriers, water soluble zinc sulphate is the most efficient in alleviating zinc deficiency in sodic soils. At equivalent zinc rates multi-micronutrient mixture including zinc has been found to be agronomically and economically inferior to zinc sulphate.

Methods of Zn application

Soil application of zinc is superior to foliar application. Swarup and Yaduvanshi (2004) in a comparative study on the methods of zinc application, reported that soil application of Zinc along with FYM was superior to the application of $ZnSO_4$ alone, root dipping, zinc sprays and zincated urea. Sodic soils are highly conducive for zinc fixation. These require relatively much higher dose of Zn than normal soils to ensure adequate supply of Zn to a particular crop. Singh *et al.* (2008) reported that 40 kg $ZnSO_4$ ha^{-1} applied to the first rice crop may be sufficient for the two years for rice-wheat cropping system grown on a reclaimed sodic soil. Soil applied Zn was superior to its foliar application.

Doses of Zn application

According to Singh and Tripathi (2008), grain and straw yields of rice cultivars grown on sodic soil increased significantly with application of 50 kg $ZnSO_4$ ha^{-1}. Singh *et al.* (2008) conducted an experiment on reclaimed sodic soil using potato cultivars. Application of 40 kg $ZnSO_4$ ha^{-1} significantly increased the tuber production. Tripathi and Kumar (2013) reported that application of 40 kg zinc sulphate ha^{-1} in sodic soil enhanced significantly grain and straw yield of rice along with zinc uptake. Tripathi and Singh (2019) reported that release of available P increased upto 15 days after incubation and then declined at 30 to 90 DA1 in all three alkali soils. The release of available Zn decreased during initial 45 DA1 and it increased thereafter from 60 to 90 DA1. Gypsum application at 25 to 50% of GR and 75 to 100% GR can be helpful in increasing the availability of native P and Zn, respectively in alkali soils of eastern part of Uttar Pradesh.

Frequency of Zn application

Options on Zinc application include (i) soil application (broad cast or band placement), (ii) foliar application as sprays, (iii) dusting seeds with Zn powder or soaking them in Zn solutions, (iv) swabbing foliage or pressing wounds with Zn paste or solution, (v) dipping roots of transplanted crops in solution or suspension of Zn salts, and (vi) pushing galvanized nails or pieces of metallic Zn into tree trunks. Out of these, soil application and foliar spray are the most extensively used. Soil application of Zn is prophylactic and foliar sprays are a therapeutic treatment. Soil application of Zn to annual crops is a preferred method over less efficient foliar sprays. Biweekly foliar spays with 0.5% $ZnSO_4$ + 0.25% lime suspension are recommended using 500 L water ha^{-1} on crops exhibiting Zn deficiently symptoms. Spraying is continued until the disappearance of the deficiency symptoms. Zinc sprays are almost exclusively used to alleviate Zn deficiency in trees and the Zn sources are more effective if the sprays are made before the spring flush of the growth.

Increasing Zn use efficiency through INM

Addition of organic matter improves crop productivity in sodic soil through increased N supply, mobilization of Fe and Mn and improved root respiration as well as soil physical properties. Sesbariia green manure along with 100% NPK recorded maximum grain yield of transplanted paddy and the treatment was equivalent to 150% NPK. Soil organic carbon and available Zn and Mn content increased more with addition of organic matter than with soil inorganic application on a sodic sandy loam soil at CSSRI Karnal (Swarup and Yaduvanshi 2000). Chauhan and Kumar (2003) obtained maximum yield and zinc uptake by rice crop with FYM N_{60} + urea N_{60} + 25 kg zinc sulphate ha^{-1} on an alkali soil (Table 7)

Table 7: Effect of integrated nutrient supply with and without zinc on yield and uptake of zinc by rice in alkali soil

Treatment	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Zn uptake (g ha^{-1})
Absolute control	2.43	3.33	89.0
NPK + $ZnSO_4$	4.17	5.83	271.0
FYM N_{30} + UN_{90} + Zn SO_4	4.20	5.93	283.3
FYM N_{60} + UN_{60} + Zn SO_4	4.26	6.02	292.0
FYM N_{90} + UN_{30} + Zn SO_4	4.14	5.80	287.8
FYM N_{30} + UN_{90}	3.73	5.63	185.1
FYM N_{60} + UN_{60}	4.07	5.81	188.9
FYM N_{90} + UN_{30}	3.87	5.78	194.6
CD (P=0.05)	0.33	0.35	25.2

Field experiment conducted on sodic soil at Kanpur revealed that the application of 40 Kg $ZnSO_4$ ha^{-1} in rice enhanced significantly the grain and straw yield, yield attributes and zinc uptake (Tripathi and Kumar 2013).

Boron

Boron is not likely to be deficient in sodic soils. Spectacular response of cereals, pulses, oil seeds and cash crops to B application (0.5-2.5 kg ha^{-1}) have largely been observed on B deficient calcareous soil of Bihar, acid soils of Orissa, West Bengal and Asam and also in very light textured soils of Punjab and in few cases in salt affected soils too. However, boron toxicity could be a problem with increase in soil pH, EC and ESP. Boron hazard in sodic soils can be minimized by addition of gypsum and leaching. At high pH and ESP, B is present as highly soluble sodium metaborate which upon addition of gypsum gets converted to the relatively insoluble calcium metaborate which mitigate the problem of B toxicity.

Molybdenum

The information on molybdenum for increasing crop production is very meager in mildly alkaline soil due to increased. The solubility of Mo with increase in the pH of the soil. The Mo content in recently reclaimed sodic soils was 0.012 to 0.440 mg kg^{-1} soil in the surface (0-15 cm) layer which is much above the critical level of deficiency (0.15 mg kg^{-1}). Forage crops grown on these soils are likely to accumulate Mo in excess amounts which may prove toxic to animals feeding on them. Application of adequate amount of gypsum decreases the Mo content in plants due to the antagonistic effect of sulphate on the absorption of Mo by the plant roots. As the available literature on Mo is meager particularly in alkaline soils, it will be desirable to initiate study on the dynamics of molybdenum in sodic soils.

Conclusions

Soil salinity and sodicity are the global problems and pose a serious threat for sustainable crop production. These soils are generally low in organic matter and poor in fertility. Therefore, nutrient management is as crucial as their reclamation for achieving higher yields of the crops. Application of N fertilizers at 25% above the normal recommendation in these soils, is generally adopted to compensate the nitrogen losses. Fertilizer placement and split application are useful in reducing N losses and increasing N-use efficiency. Use of FYM and green manuring in sodic soil help increasing the soil productivity. Therefore, integrated nutrient management is important in these soils for higher crop yield and better soil health. During initial years of reclamation of salt affected soils, application of P can be omitted. Thereafter, P fertilization is must in crops grown on these soils because of reduced P availability. Application of P fertilizers in saline soils helps mitigating adverse effects of chloride toxicity. The plants grown in sodic soils more often suffer from calcium deficiency. Gypsum and organic manures supply adequate calcium to plants in these soils.

Foliar application of Fe is more effective than soil application. Three to four foliar sprays of ferrous sulphate @ 0.5 to 1.0% at 10 days interval are needed to correct iron deficiency in different crops. It will need 6-12 kg ferrous sulphate ha^{-1}. Addition of green manure, FYM and compost helps in enhancing the availability of iron. The deficiency of Mn is seldom a problem for wet land rice while it can become a limiting factor for upland crops grown after rice particularly in the coarse textured soils. As for management of Mn deficiency, soil application of 40-50 kg $MnSO_4.H_2O$ ha^{-1} is uneconomical, therefore 3-4 foliar applications of 0.5-1.0% $MnSO_4$ solution (7.5-15 kg $MnSO_4$) is recommended before the first irrigation. For efficient management of zinc, the depleted soil fertility can be restored by adding zinc fertilizers, organic manures/residues. Integrated nutrient management plays a vital role towards increasing yield due to increased nutrient use efficiency of FYM and green manuring is helpful in increasing zinc availability due to their role in reducing soil pH and sodicity. Methods of application of micronutrients are also important to harness higher nutrient use efficiency. Soil application of zinc sulphate before sowing is more suitable method to ameliorate zinc deficiency in sodic soils. Zincated urea, root dipping in 3% suspension of ZnO and spraying with 0.5% $ZnSO_4$ could also help in removing Zn deficiency. Boron deficiency is not expected rather its toxicity can be an issue with increase in salinity of the soil. Application of gypsum generally takes care of its toxicity by converting highly soluble sodium motaborate to insoluble calcium metaborate.

In edition, micronutrient efficient crops and their cultivars must be recommended to thrive well under micro-nutrient stress condition. A continued watch and consistent monitoring of soil health is extremely important to ensure sustainable crop production of reclaimed salt affected soils.

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