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Fertility Management in Salt Affected Soils under Rice-wheat Cropping System: A Review

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ABSTRACT

Specific soil conditions such as salinity/ alkalinity are considered to be the major global concern causing a serious threat to sustainability of a particular production system. Salt affected soils are mainly characterized by low organic matter content, poor soil fertility with respect to available macro and micronutrients. Therefore, judicious management of nutrients in addition to reclamation of these soils is considered to be the need of an hour for enhancing agricultural productivity while sustaining our resources. The crop response to added nutrients also varies considerably due to their diverse chemical composition and behavior in such soils which in turn affect the precipitation-dissolution reactions and adsorption-desorption kinetics and thereby affecting their availability to crops during growing season. This review paper attempts to review the efficient fertility management techniques in problematic soils particularly the salt affected soils under rice -wheat cropping system.

Key words: Alkalinity, Macronutrients, Management practices, Rice-wheat cropping system.

Salt-affected soils are characterized by high electrical conductivity (EC), sodium adsorption ratio (SAR) and pH, calcareousness, low organic matter, low biological activity and poor physical conditions (Murtaza *et al*., 2014). These soils occur in arid and semi-arid areas where evapotranspiration exceeds the precipitation rates. The accumulated ions which cause salinity or sodicity are sodium, calcium, magnesium, potassium, chlorides, carbonate and bicarbonate (Aulakh and Sidhu, 2015). The origin of salt affected soils are native soil, irrigation water with high EC and pH, sea water intrusion in deltaic regions and low lying areas in humid areas. In India, area of about 6.73 M ha are salt affected soils. Out of which, 3.78 M ha are sodic soils and 2.96 M ha are saline soils (Sharma and Singh, 2015). The states which are largely affected by salinity or sodicity are Gujarat (2.20 Mha) and Uttar Pradesh (1.37 Mha). The crop growth and development reduced due to excess accumulation of salts resulting into poor crop yield (Zia-ur-Rehman *et al*., 2016).

Rice-wheat rotation is the largely followed cropping system and exhaustive feeders in Indo-Gangetic plains and occupies around 12.3 M ha of land in India followed by 2.2 Mha in Pakistan, 0.8 ha in Bangladesh and 0.5 M ha in Nepal (Ladha *et al*., 2003). In India, same cropping system is dominated in the region of states Punjab, Haryana, Uttar Pradesh, Bihar and Madhya Pradesh, provides around 75 per cent in Indian food grain production (Mahajan and Gupta, 2009). This cropping sequence when followed on salt affected soils not only decreases the crop yield but also affects the soil physico-chemical properties. The supply of sufficient quantity of essential nutrients does not ensure their optimum uptake due to the toxic effect of high concentration of salts. High pH and sodicity of rhizosphere increases the osmotic potential which leads to water stress condition in plant (Ahmed *et al*., 2017). Sodic soils are having high pH and exchangeable Na which affects the transformation, release and availability of native and applied nutrients in the soil. The crop grown in these soils generally suffer the deficiency of Ca, N, Zn and Fe (Yadav and Kumar, 1995). So, the present review discussed about interactions between specific mineral nutrients in salt affected soils under rice-wheat cropping system.

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Nitrogen (N)

The salt affected soils are poor in total, available nitrogen and very low in soil organic carbon due to rapid decomposition. They also have poor N use efficiency in presence of high amount of salts in salt affected soils. The transformation of N is slow because of poor microbial population in the soils having high pH and electrical conductivity. Urea is the major source of N extensively used by the farmers in rice-wheat cropping system. When urea is added in the field, the rate of hydrolysis of urea is very slow and the hydrolyzed product obtained is ammonia (NH_3) and CO_2. This is attributable to toxic effect of carbonates on

N-transforming bacteria and high pH effects on urease enzymes activity. These soils also have poor symbiotic N-fixation due to the toxic effect of accumulated salts on rhizobia which then reduce the nodulation. The loss of NH_3 through volatilization also increases with increase in pH of soil. Kumar *et al*. (1995) found that about 10 to 60% of applied N is lost through volatilization in sodic soils. Similarly, Singh and Bajwa (1990) observed that ammonia volatilization increased with an increase in pH, EC, RSC and SAR of irrigation water and these losses may extend up to 40% sodic soils. Bhardwaj and Abrol (1978) also observed nearly 32-52% loss of applied N through volatilization in sodic soils. To overcome these losses, higher dose of N is recommended in these soils. Generally, the crop grown in these soils should be fertilized with 25% higher than the recommended dose of N. Further, the N use efficiency (NUE) can be increased with the application of N in split doses, fertilizer placement, use of slow release N fertilizer like Neem coated urea and application of urease inhibitors. When N was applied in three equal splits i.e., at basal, 3 and 6 weeks after transplanting of paddy crop resultant into higher crop yield. This is attributed to reduced N losses due to volatilization in sodic soils and increases the applied N efficiency. The application of organic and inorganic sources of N also expected to increase NUE.

The green manuring with *sesbania* every year or once in two year helps in increasing the organic matter content in the soil thereby decreasing N deficiency. The application of FYM also helps in improving the physical condition of sodic soils and improves the fertilizer use efficiency and decreases the nutrient losses. Similarly, the press mud cake from sugar factory can be used as ameliorant for sodic soils. Yaduvanshi and Sharma (2005) reported that under sodic soil, the application of organic manure *viz*., FYM or sulphitation press mud or green manuring with *sesbania* or wheat residue (5t/ha) in combination with 75% of recommended dose of fertilizer (90 kg N +19.5 kg P/ha) gave similar yield of rice to that obtain with 100% recommended dose of fertilizer (120 kg N +26 kg P/ha). Similarly, in another experiment, Yaduvanshi and Swarup (2005) also found that in gypsum amended sodic soil, the highest yield of rice-wheat was obtained with 100% NPK combined with green manuring or FYM. Their results suggested that integrated nutrient management is extremely important for sustaining rice-wheat system and improving the fertility of sodic soils. However, Wang *et al*., 2012 found that urea with wheat straw incorporation in paddy field, ammonia volatilization losses recorded was 51.9 kg N ha^{-1} and without wheat straw, it was 40.4 kg N ha^{-1}. Rate of cumulative NH_3 volatilization loss in paddy also increased significantly with raising dose of urea and straw incorporation. This might be attributed to presence of urease in the wheat straw or increase in the pH due to flooded condition in paddy soil.

Phosphorus (P)

After nitrogen, phosphorus is the next critical nutrient required for the proper growth of plant. Single superphosphate is considered as good source of P than other phosphatic fertilizers because it contains some amount of $CaSO_4$. In salt affected soils, the availability and transformation of native and applied P greatly differ than in normal soil. The P has ability to get combined with clay particle which reduces its ability to mobilize. In saline soils, P availability decreases due to precipitation, antagonism due to excess Cl^- and SO_4^{2-}. In sodic soil, Ca-P is the dominant inorganic fraction followed by Al-P, Fe-P and saloid bound P (Ali Mahmood *et al*., 2013). Under high alkalinity, the sodium carbonate and bicarbonate reacts with the insoluble calcium phosphate to form soluble sodium phosphate which is liable to be leached down (Cho-ruk and Morrison, 2004). Under continuous cropping of rice-wheat in such soil, the application of gypsum as amendment decreases the soil pH which immobilizes the soil P and result in more fixation of P. At early stage of reclamation, soil releases sufficient P into soil solution for the use of crop and crop do not respond to P application. But when surface P gets depleted, rice crop having shallow root system responds to P fertilizers.

On addition of organic manure into field, the organic matter gets decomposed and releases the carbonic and humic acid which helps in dissolving native P minerals or conversion of unavailable form of P to available form (Ahmad *et al*., 2014). Therefore, municipal solid waste compost, pressmud, farm yard manure and poultry manure are considered as important organic source input which could help to improve the health of salt affected soils with extra benefit on yield of rice-wheat crops. The integrated application of poultry manure and phosphorus fertilizer (1:1) on soil need basis has been proved to be effective in improving the growth and yield of crop under rice-wheat cropping system by Ahmed *et al*. 2017 and they concluded their balanced effect on nutrient status under salt affected soils. It has capability to improve paddy yield by 31.7 per cent and wheat grain yield by 27.5 per cent over P application on soil need basis *i.e*., @ 80 kg ha^{-1} when average of four seasons was taken. Khalil *et al*., 2010 also found combined application of P-nutrient through organic and inorganic sources can significantly improve the P use efficiency, hydraulic conductivity with reduction in bulk density of soil.

Potassium (K)

So far, the sodic soils of Indo-Gangatic plain where rice-wheat cropping is mainly followed did not respond to K application because of presence of micaceous and illite minerals in the soil. Under these conditions the available K status did not change even after the crops were grown without K application, because K removed by the plant was replenished by release of K from non-exchangeable form of K from illite clay minerals. Generally, the increased exchangeable Na and deficiency of Ca in these soils decreases the K uptake by plant but plant remained above the lower critical value. However, due to intensive cultivation of rice-wheat crops, these soils have depleted in K status and may start responding to K application (Singh *et al*., 2003). It is also suggested for improving Na induced K deficiency in plants for sodic soils having medium to high exchangeable K, to add sufficient amount of amendment to correct Ca: Na balance and K content of plant instead of only applying K fertilizer.

Lal and Swarup (2005) studied the K balance and release kinetics of K in long term fertilizer experiment under rice-wheat cropping system. Their results suggest, Potassium fertilizer should also be applied along with N and P fertilizers in sodic soils for sustaining soil K fertility status of Indo-Gangatic plains. Similarly, in saline soils, the adverse effect of salinity in rice crop can be reduced with more addition of Potassium and Zinc (Zn) ($K_{200}Zn_{200}$ treatment) which increases the nutrient uptake and maintain higher K^+/Na^+ ratio (Kibria *et al*., 2015). They documented with increase in K concentration the paddy yield increased by 22 per cent compared to control practice with higher uptake of K and Zn by paddy crop. Similar effect was found in wheat crop (Mehdi *et al*., 2007).

Several studies have suggested that organic matter addition affects the biological activities in soil and biological activities affect the release pattern of K in the soil. Singh *et al*., 2002 concluded the conjunctive use of N fertilizer and organic manure in saline soils could help to release the non-exchangeable K and increased its concentration into soil solution. Avalos *et al*., (2012) conducted an experiment in soil prone to water erosion and susceptible to degrade by reduction of organic matter and nutrient content through runoff. They examine greater soil loss in bare soils as compared to soil incorporated with corn straw residue @ 3 and 4 t ha^{-1}. The total K value of runoff sample collected varies from 0.82 g m^{-2} (in amended soils) to 2.68 g m^{-2} (in bare soil). But effect of corn residue on dissolved K was found insignificant.

Calcium (Ca)

Choudhary and Yaduvanshi (2017) summarized that the dominance of carbonate equilibria in sodic soils results in deficiency of available calcium despite the presence of calcite in the soil. The plants grown in sodic soils suffer more often due to lack of available calcium than due to toxicity of excess sodium. Excess application of P-fertilizers reduces Ca availability to plants due to Ca-P complex formation in saline soils.

Choudhary *et al*., (2011) conducted a long term experiment using sodic water under rice-wheat system on calcareous soil and proved that sole application of organic matter (FYM followed by *Sesbania* green manure and wheat straw) could solubilize the native Ca and fixed Ca as calcium carbonate and can achieve sustainable yield of crops. Gypsum and organic manures together supply adequate levels of calcium apart from lowering pH of the soils that further increases the availability of calcium as well as other nutrients in the soil. Avalos *et al*., (2012) concluded addition of corn residue could significantly reduce the Ca losses *i.e*., total Ca in collected runoff water ranges from 0.74 to 2.36 g m^{-2}, whereas dissolved Ca varies between 0.45 and 0.95 g m^{-2} in with and without amendment soils, respectively. As Ca has ability to bind with the soil particles and wash out with the running water but corn residue helps to retain the nutrient content and significantly reduce the Ca loss.

Micronutrients

Imbalanced use of fertilizer, little or no inclusion of micronutrient enriched fertilizer in practices, continuous rice-wheat cultivation, less organic matter and low microbial activity results into deficiency of zinc, iron and manganese in rice-wheat cropping system (Kumar *et al*., 2016; Nayyar *et al*., 2001). In salt affected soils, the availability of nutrients to plant reduces because of presence of soil components which has ability to fix nutrients (Mehdi *et al*., 2007). However, integrated application of organic and inorganic sources of nutrient are suggested to combat the toxic ion effect, saline and sodic effect on crops. The role of organic and inorganic micronutrient sources with respect to rice-wheat cropping system have been discussed below in brief.

Zinc (Zn)

Under sodic condition, the high pH, higher concentration of CO_3^{-2} and HCO_3^{-1}, presence of $CaCO_3$ and low organic matter favors the zinc deficiency in soil and plants (Rose *et al*., 2013). Zn gets precipitated as hydroxide, carbonate and bicarbonate at high pH. A Rice-Wheat crop in the sodic soils shows Zn deficiency unless the proper amount zinc fertilizer is added in the soil. In saline sodic soil, sodium occupies the exchangeable sites and zinc becomes more prone to leaching. The application of 10 to 20 kg $ZnSO_4$/ha for initial 2-3 years for both rice and wheat crops is recommended. Later depending on soil test value, the Zn may be applied in alternate years. Applying Zn to the soil in sufficient amount improves grain yield, while applying Zn as foliar during the booting stage enhances Zn content and its bioavailability in wheat grain (Hussain *et al*., 2012).

Zinc deficiency is also prominent in calcareous soils because upto 90% of applied Zn get adsorbed on soil colloid and get precipitated out which will reduce its availability to plant. But the effect of phosphorus induced zinc deficiency on plants reduced in calcareous soil as compared to Non calcareous soil because P get adsorbed by calcite mineral instead of with Zn on Iron oxide (Sacristan *et al*., 2019). Laik *et al*., 2019 studied zinc fertilization effect in rice-wheat cropping system under Zn deficient upland calcareous soil and found Zn applied in alternate year at the rate 7.5 kg ha^{-1} and 10 kg ha^{-1} or every year at 5-10 kg ha^{-1} obtained highest rice equivalent yield over with zinc treatment. Amanullah (2016) reported that the application of organic manure *viz*., FYM and *sesbania* green manure prevents the occurrence of Zn deficiency in rice grown on sodic soil. This is due to its ability to reduce pH and sodicity. The study conducted on the method of Zn application showed that application of Zn along with FYM was superior to the application $ZnSO_4$ alone, root dipping, Zn spray and zincated urea (Swarup, 1998). Ahmad *et al*., 2012 found that Zn-enriched farm yard manure has positive effect over $ZnSO_4$ or Zn-EDTA solo application in paddy crop under saline-sodic soils and highlighted the substantial effect of addition of organic matter through FYM by improving crop yield and soil health.

Iron (Fe)

Iron deficiency is most common in crops grown under sodic condition of arid region. The solubility of Fe is mainly controlled by soil pH, oxidation-reduction reaction, $CaCO_3$ and organic matter content. The increase in soil pH decreases the solubility of Fe compounds. When soluble Fe salts are added in the sodic soils they become unavailable because of rapid oxidation and precipitation. Addition of $FeSO_4$ is often ineffective unless it is accompanied by change in oxidation state with the help of addition of easily decomposable organic matter and prolonged submergence. The high pH and excess of CO_3^{-2} and HCO_3^{-1} causes the iron chlorosis in rice seedling. Application of organic manure *viz*. FYM, green manuring or compost which helps in providing the reducing conditions (decline in redox potential) are useful to overcome iron chlorosis in rice nursery. The other alternative is to flood the rice nurseries and apply pyrites when iron deficiency is seen. Application of FYM, rice husk and green manure increased the 10 to 15-time extractable Fe with corresponding decrease in reducible forms in Sodic soils (Swarup, 1984). Therefore, addition or organic manure is beneficial for ameliorating the rice deficiency.

Under saline conditions, paddy soils suffer Fe deficiency because of low release of Fe-chelating compounds which results into appearance of Fe deficiency in Rice. Abbas *et al*., 2015 found under salinity and deficient Fe conditions, the physiological parameters of rice are affected such as reduction in root and shoot growth, lesser photosynthetic and transpiration rate, low chlorophyll content and stomatal conductance. Cha-um and Kirdmanee, (2015) evaluated the effect of organic matter (Mixture of FYM and Green manure in 1:1 ratio) on rice under saline soil and suggested organic matter treatment on soils having 2 percent salt level could significantly improve the total chlorophyll content, photosynthetic rate, nutrient status and crop yield over control.

Manganese (Mn)

Under rice-wheat cropping system, when rice soils are submerged, the Mn get solubilized on reduction and is leached down to lower layers and the subsequent wheat crop suffers from Mn deficiency (Lu *et al*., 2004). Soil pH affects Mn availability because higher pH facilitates adsorption of Mn^{2+} with soil particles, making it unavailable to plants (Fageria *et al*., 2002). At pH 8, chemical auto oxidation of Mn^{2+} occurs, resulting in the formation of other forms such as MnO_2, Mn_2O_7, Mn_3O_4 and Mn_2O_3 that are unavailable to plants (Humphries *et al*., 2007). The major cause of Mn deficiency in soil is low OM content. The addition of organic manure to soil has a reducing potential, resulting in a significant and rapid increase in exchangeable Mn (Andrade *et al*., 2002). Soils having coarse texture and high pH are more prone for Mn leaching (Lu *et al*., 2004). Because of reversion of applied Mn to higher oxide in alkaline soil, the soil application is less effective than foliar application. Repeated spray of 0.5 to 1% $MnSO_4$ solution for 3-4 times is needed to correct Mn deficiency of wheat. Deep ploughing to mix sub-soil with surface soil helps in re-distribution of soil and increases Mn availability. Nayak *et al*., 2013 studied the efficacy of phosphogypsum and Mined Gypsum amendment under Sodic Soil conditions and observed phosphogypsum application @ 10 Mg ha^{-1} could reduce the soil pH by increasing the Ca^{+2} concentration in soil solution and increase the H^+ concentration by forming residual Sulphuric acid. As phosphogypsum treatment reduces the soil pH and add the extra micronutrient contained in phosphogypsum, which affects the availability of Mn positively.

CONCLUSION

Soil salinity and alkalinity has been considered a serious threat to sustainable crop production. These soils are poor in nutrient status and low in low soil organic matter. That is why nutrient management has become important along with reclamation measures followed in salt affected soils. Split application of N, fertilizer placement, use of slow release N fertilizer like neem coated urea and application of urease inhibitors helps to improve NUE while application of 25% higher dose of N fertilizer helps to compensate N losses. Adoption of integrated nutrient management technique has proven to be useful in improving nutrient use efficiency as well as better soil health. Soil application of zinc before sowing improves grain yield while foliar application of Zn at booting stage increases its bioavailability and Zn content in wheat grain. FYM and green manuring with *sesbania* reduces multi-micronutrient deficiencies in sodic soils. Due to reversion of applied Mn into higher oxide form under alkaline condition, soil application is considered as less effective than foliar application. Therefore, three-four sprays of 0.5 to 1% $MnSO_4$ is required to correct Mn deficiency.

Conflict of interest: None.

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