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Response of Major Plant Nutrients to Salt Affected Environment

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ABSTRACT

Long term exhaustive cropping practice and indiscriminate use of poor quality water can result in accumulation of salts and sodium that adversely affect crop growth. Salinity and sodicity are the major soil degradation issues primarily in arid and semi-arid regions of the world. The sustainability of agriculture is a matter of deep concern due to widespread removal of nutrients in excess of their application resulting in depletion of major soil nutrient reserves. Nitrogen (N) use efficiency of applied N in saline and sodic soils is low. Adequate N fertilizer dose, method and time of application are essential to increase its efficiency. Phosphorus (P) is one of the limiting major nutrient elements in salt affected soils. In saline soils, availability of P decreases due to precipitation of applied P, higher retention of soluble P, antagonism due to excess of chlorides (Cl^-) and sulphates (SO_4^{2-}). Potassium (K) deficiency is observed under high soil-Na concentration. Phosphorus and K availability in saline and saline-sodic soil increases with crop residue incorporation. In this paper, we reviewed the major nutrients dynamics in saline and sodic environment and their proper management strategies.

Introduction

Soil salinity and sodicity are the major land degradation problems that inhibits crop yield. It is a universal concern to manage salt affected soils as these are not restricted to arid and semi-arid regions only, these can develop in humid, sub-humid and coastal regions. In India, 6.73 million hectares (Mha) area are found under salt affected soils out of which 3.77 Mha are sodic while 2.96 Mha are saline soils (Choudhary and Yaduvanshi, 2016). Most common ions present in high concentrations in these types of soils are sodium (Na^+), calcium (Ca^+), magnesium (Mg^+), chloride (Cl^-), carbonate (CO_3^{2-}), bicarbonate (HCO_3^-) etc. Salt accumulation in the soil profile may be caused due to various factors like rain, weathering of rocks, application of soil amendments and soluble fertilizers, saline irrigation water, and capillary rise of saline ground water and seawater (Rengasamy, 2010). There are generally two processes of salinization i.e., primary and secondary salinization processes. In primary salinization, salts generally originate from native soils through weathering of rocks (Rengasamy, 2006). While, secondary salinization is a consequence of anthropogenic activities such as poor quality water irrigation without sufficient leaching of salt, thus increasing salt concentration in the root zone (Ghasemi *et al.,* 1995). This also occurs as a result of shallow groundwater table together and poor drainage condition (Rhoades, 1987; Smedema and Shiati, 2002; Brinck and Frost, 2009). Apart from these, other factors behind salt accumulation includes excessive use of chemical fertilizers, overgrazing by cattle, deforestation etc. (Brenstein, 1975; Lakhdar *et al.,* 2009).

Plants present in this salt affected environment must absorb the essential nutrients from diluted source with extra energy out of the highly concentrated non essential nutrients (Choudhary and Yaduvanshi, 2016). Osmotic stress usually limits crop and microbial growth in saline soil, while under sodic soil environment, ion toxicities and adverse pH may inhibit microbial growth (Rietz and Haynes, 2003). Grattan and Grieve (1992) reported that nutrient acquisition by plants can be disrupted by excessive ions in a saline environment. It might be due to competition between ions, or by the decreased osmotic potential of the solution which reduces the mass flow of mineral nutrients to the root. While poor aeration caused due to high soil sodicity restricts absorption of plant nutrients in adequate amounts (Singh *et al.,* 1992). The sustainability of agriculture is a matter of deep concern due to widespread removal of nutrients in excess of their application resulting in depletion of soil nutrient reserves. Although nutrient dynamics in soil has been investigated in many studies, fewer studies have investigated the nutrient dynamics in saline and sodic environment. So, the objective of this paper is to discuss the nutrient dynamics of soil under saline and sodic environment and suggest suitable management practices to reduce yield loss.

Classification of salt affected soils

Salt affected soils are defined as the soils developed by the accumulation high amount of soluble and/ or exchangeable salts that have been modified adversely for the plant growth and limits crop yield. These are generally classified on the basis of their pH electrical conductivity of the saturated extract (ECe), sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) (Richard 1954; Qadir *et al.,* 2007; Rengasamy 2010). Based on these properties, salt-affected soils are thus classified as saline soil with EC $\geq$ 4 dSm^{-1}, in which higher amount of soluble salts are there; saline-sodic soil with EC $\geq$ $4dSm^{-1}$ and SAR $\geq$13 having high soluble as well as exchangeable Na; sodic soils with SAR $\geq$13 having excessive amount of Na at exchange site and soil solution (Table 1). Due to the combined effects of salinity and sodicity on soil properties and plant growth in saline-sodic soils, these soils are considered to be the most degraded form of salt-affected soil (Rengasamy, 2002).

Effect of saline and sodic environment on major plant nutrients

Nitrogen

Nitrogen (N) is the most important major nutrient element for plant growth and yield. A bulk of 98% N present in lithosphere and the atmosphere contains 50,000 times more N_2 than soils. There are mainly two forms of soil

N i.e., organic N (98%) and inorganic N (2%). Organic form of N consists of hydrolyzable (mineralized to mineral N) and non-hydrolyzable form (resistant to mineralization) while inorganic forms are primarily ammonium (NH_4^+) and nitrate (NO_3^-) form. Rapid decomposition of organic matter in salt affected soil leads to lower organic carbon and increase N mineralization which in turn makes soils poor in total and available N (Swarup 1998). Increasing salinity level in soil adversely affects urea hydrolysis by lowering urease activity (Singh and Bajwa 1986). Decreased rate of NO_3^- uptake by crops is mainly due to antagonistic effect of it with Cl^- and SO_4^{2-} ions in these soils and high leaching loss of NO_3^- (Choudhary and Yaduvanshi, 2016). Poor plant growth due to inadequate soil reclamation, nutritional imbalances within the plants, excessive ammonia volatilisation and denitrification losses of N are found under high soil sodicity or salinity resulting in poor crop response to applied fertilisers (Swarup, 1994). About 32-52% of applied N was lost through NH_3 volatilization under sodic soils (Bhardwaj and Abrol, 1978) and the extent of volatilization loss of NH_3 depends upon pH, calcium carbonate content of the soil as well as alkalinity of floodwater (Bajwa and Singh, 1992) (Table 2).

Salt affected soils are considered to be deficient in N and crop needs specific management practices to increase cumulative N mineralization and check its losses. Crops grown under this condition needs 20-25% higher dose of N than recommended one (Rao and Batra, 1983). It is proved that crop response to N fertilizers depends upon the extent of salts remain in soil after reclamation. Apart from dose of N fertilizers, the method and time of fertilizer application influences NH_4^+-N concentration in soils (Kumar *et al.*, 1995). Therefore, deep placement of fertilizers rather than broadcasting is efficient in sodic soils (Rao and Batra, 1983; Rao, 1987). Application of N fertilizer into three equal splits as basal, 3 and 6 weeks after transplanting or sowing under sodic water irrigated soils maximizes the yield of rice and wheat (Yaduvanshi and Swarup, 2005).

Integrated use of organic and inorganic sources enhances use efficiency of N fertilizers (Yaduvanshi, 2001). Cumulative N mineralized after 56 days of incubation was found to be increased with gypsum application along with sodic irrigation water (SW+G) over sodic water alone (SW). Among various organic amendments, green manures are most suitable one (Choudhary *et al.,* 2007). Besides, organic manures may also be useful in reclaiming sodic soil when applied in proper dose (Table 3).

Phosphorus

Availability and transformation of soil P greatly varied from salt affected to normal soils as it is one of the limiting major nutrient elements in most arid and semi arid regions. In alkaline soils, Ca-P is the dominant P fraction and reversion of soluble monocalcium phosphate to insoluble apatite depends upon Ca/P ratio (Tiwari, 2012) (Table 4). Under highly sodic environment, conversion of insoluble Ca-P into soluble Na-P was lower because of high pH and low organic matter content of these soils (Choudhary and Yaduvanshi, 2016).

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-} (Chhabra *et al.*, 1976). Phosphorus is relatively immobile in saline soils as increasing salinity level restricts root growth that in turn, reduces the root surface area of the crop in contact with soil P (Chhabra *et al.*, 1986). Thus, the availability of P is truly a function of plant root characteristics and the antagonistic behaviour of excess Cl^- on P absorption by roots. In most cases, salinity decreases the bioavailability of P (Sharpley *et al.,* 1992). Moreover, soil environment and crop genotypes play a major role in P uptake (Grattan and Grieve, 1994). Fageria *et al.,* (2011) reported that P uptake in plants reduced with increasing salt concentration in lowland rice where 93% decrease at 15 dS m^{-1} and 19% at 10 dS m^{-1} were observed in genotype CNA 810098 and CNA 810162, respectively. So, P availability in saline and saline-sodic soil can be enhanced by conjunctive application of P fertilizers and organic amendments like crop residues (Mahmood *et al.,* 2013).

Potassium

Potassium helps in osmoregulation, enzyme activation and charge balance in plants. Thus, decrease in K uptake by plant is harmful for plant metabolism. In saline-sodic and sodic soils, Na concentration present at a threshold level degraded soil physical properties and decrease K uptake by plants (Qadir and Schubert, 2002). Because of similar physicochemical properties and ionic size, K and Na have the potential to compete with one another for plant uptake under high Na concentration in soil (Wakeel *et al.,* 2011; Wakeel, 2013). Sodium stimulates K outflow resulting in electrical potential gradient across plasma membrane in plants (Kaya *et al.,* 2002). As Na is applied to the soil, non-exchangeable K release in soil is increased (Wang *et al.,* 2010).

Effects of Na on plant growth can be divided into two phases: one is osmotic effects leading later to Na toxicity and other phase determines the yield reduction. Under osmotic stress condition, plant follows adaptive mechanism like expanded and deeper root systems for higher plant uptake (Munns and Sharp, 1993). Potassium deficiency is observed under high soil-Na concentration. So, K fertilizer application is highly recommended (Miransari and Smith, 2007). Deleterious effects of salinity on corn yield do not eliminate due to potassium fertilization despite increased K content in the plant and reduced the Na: K ratio in the plant tissue while increasing salinity reduces K concentration in the plant dry matter (Bar-Tal *et al.,* 1991). Feigenbaum *et al.,* (1990) derived a linear relationship between exchangeable potassium percent (EPP) and potassium adsorption ratio (PAR) in sandy loam soil of Nordiya and silty loam soils of Gilat, Israel regardless of salinity level or SAR value. Furthermore, irrespective of any experimental method and Na concentration, corn yield was maximised with K fertilizer application as competition among monovalent cation like K preferred over the divalent cations like Ca and Mg in both soils (Fig 3).

Gul *et al.,* (2016) observed that K release as a whole found to be higher in clay loam soils while release was higher in case of sandy loam soils initially. So, it was suggested to avoid NaCl addition in soil because it induces non-exchangeable K release to soil solution that resulted in elimination of the effect of K fertilization under salt stress.

Depletion of K by plant uptake in salt affected environment can be organically subdued by crop residue incorporation (Li *et al.,* 2014). So, returning straw to the field (Kaur and Benipal, 2006) and application of FYM can improve available K in soil (Habib *et al.,* 2014) to satisfy the vast demand of K inputs when applied with K fertilizers.

High concentration of soluble and exchangeable ions and low organic matter in salt-affected soil depletes its fertility. Nutritional disorders in plants are the result of competitive uptake, transport, partitioning of major essential nutrients as affected by saline and sodic environment. So, proper amendments along with nutrient management practice are highly required to get reasonable crop production and to maintain environmental sustainability. It is very important to apply organic manure and inorganic fertilizers in an integrated way to maintain a steady supply of nutrients and reduce their loss.

Table.1 Chemical characteristics of salt affected soils

Soil type	Soil pH (pHs)	ECe (dS/m)	SAR	ESP	Soil physical condition
Normal	<8.5	<4	<13	<15	Flocculated
Saline	<8.5	>4	<13	<15	Flocculated
Sodic	>8.5	<4	>13	>15	Dispersed
Saline-sodic	<8.5	>4	>13	>15	Flocculated

(Source: Richards 1954)

Table.2 Effect of amendments on ammonia volatilization losses in sodic soil

Treatments (1:2 soil: water)	Soil pH	Ammonia volatilization loss (%)
Control	9.55	32.4
Gypsum	9.00	10.1
Pyrites	9.25	14.7
H_2SO_4	8.85	5.5

(Source: Bajwa and Singh 1992)

Table.3 Effect of different methods and levels of N application on wheat yield (t ha^{-1}) in sodic soil

Method of N application	N levels (kg ha^{-1})		
	60	**120**	**180**
All drill before sowing (DBS)	3.47	4.16	4.47
All broadcast before sowing (BBS)	3.03	3.61	3.99
½ DBS+ ½ top-dressed (TD)	3.55	4.18	4.66
$2/3^{rd}$ DBS+ $1/3^{rd}$ TD	3.44	3.95	4.21
Control	1.98		
CD (p= 0.05)	0.46		

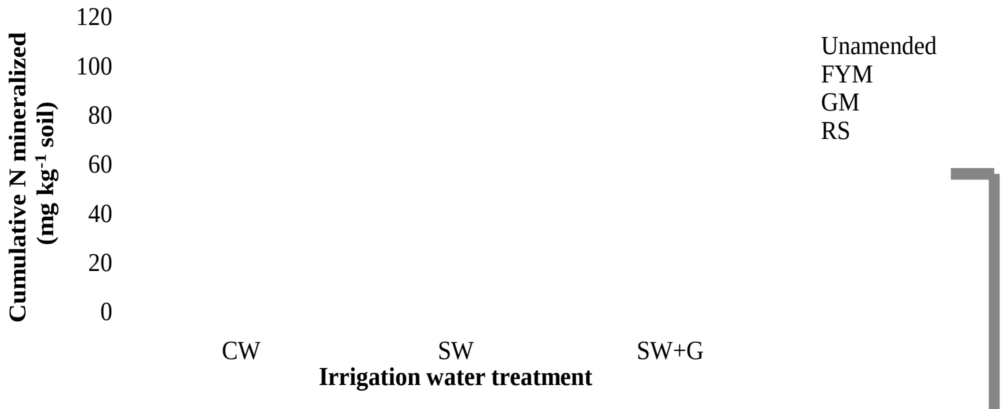
(Source: Choudhary and Yaduvanshi, 2016)

Table.4 Reversion of soluble phosphate to insoluble apatite under alkaline condition

P-reaction products	Basicity (Ca/P ratio)
Monocalcium phosphate	0.5
Dicalcium phosphate	1.0
Octacalcium phosphate	1.33
Tricalcium phosphate	1.50
Hydroxy apatite	1.67

(Source: Tiwari, 2012)

Fig.1 Cumulative N mineralization as affected by poor quality water irrigation and amendments **(**Source: Choudhary *et al.*, 2007)



FYM @ 20 t ha^{-1}, GM (*Sesbania aculeata*) @ 20 t ha^{-1} , RS @ 5 t ha^{-1}
CW: Canal water, SW: Sodic irrigation water @RSC= 10 meq l^{-1}, SW+G: SW+ 50% of GR

Fig.2 Influence of salinity on the bioavailability of P in two lowland rice genotype (Source: Fageria *et al.* 2011)

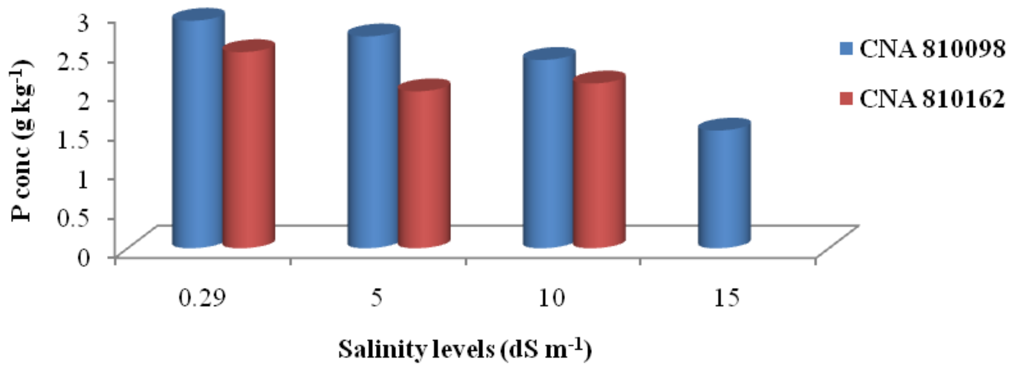


Fig.3 Exchangeable potassium percentage as a function of the potassium adsorption ratio in the solution of soil paste under three salinity levels (Source: Feigenbaum *et al.*, 1990)

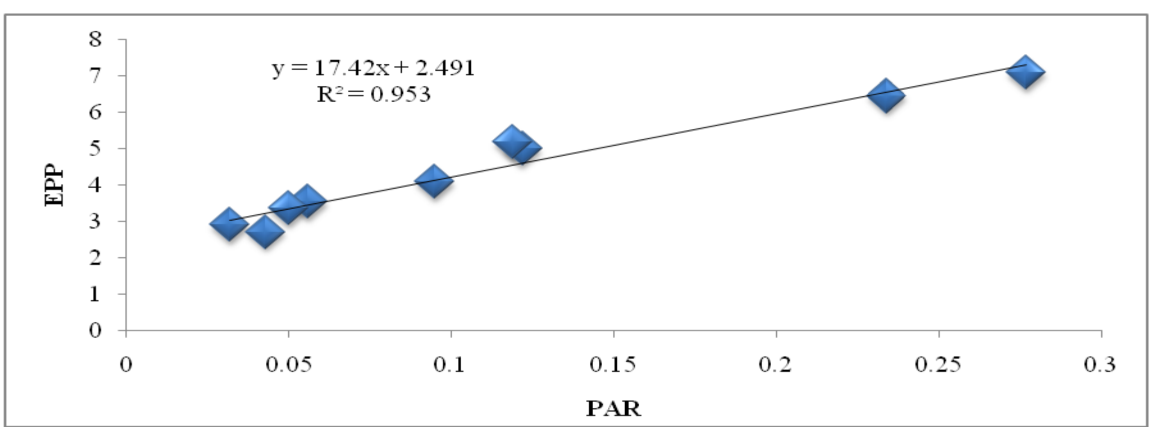
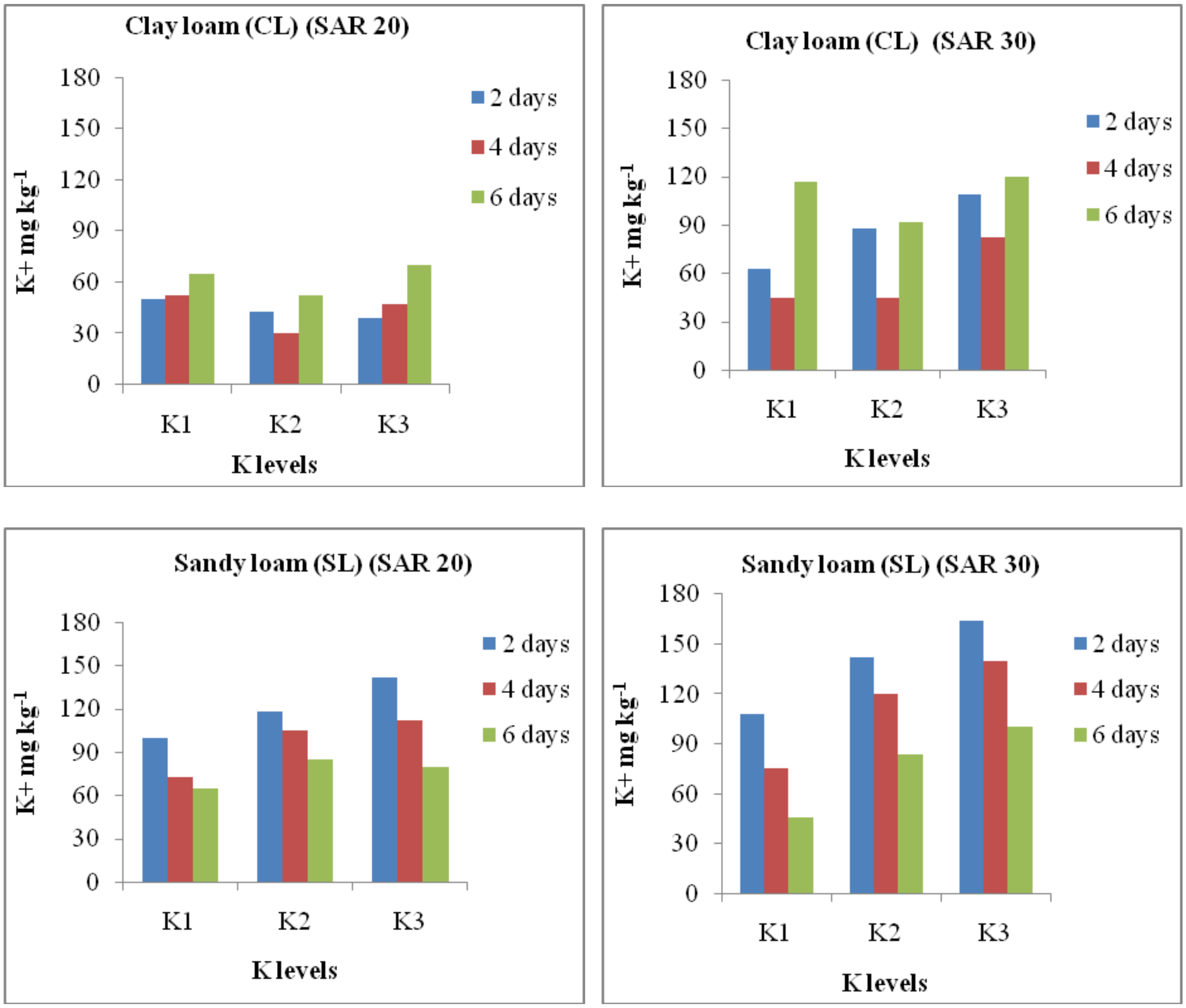


Fig.4 Amount of potassium released due to NaCl addition (Source: Gul *et al.*, 2016)



K levels 40, 80 and 120 kg K ha^{-1} as K1, K2, K3 respectively.

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