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Impact of calcium sulphate and calcium carbide on nitrogen use efficiency of wheat in normal and saline sodic soils

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Abstract

A pot experiment was conducted to study the effect of calcium as $CaSO_4$ or CaC_2 (20 mg Ca kg^{-1} of soil from each source) on N use efficiency of wheat (Triticum aestivum L. var. Inqlab-91) under normal (ECe=0.7 dS m^{-1}, SAR=4.37 and pH=8.1) and saline-sodic soils (ECe=8.7 dS m^{-1}, SAR=21.43 and pH=9.2) in glass house at National Agricultural Research Centre, Islamabad during Kharif season 2007-08. The crop was grown to maturity and data on tillering, plant height, panicle length, grains $spike^{-1}$, straw and grain yields were recorded at the time of crop harvest. A considerable reduction in plant height (38%) and grain yield (44%) was observed when grown in saline-sodic soil (ECe=8.7 dS m^{-1}) as compared to normal soil (ECe=0.7 dS m^{-1}) while N application significantly improved plant growth and yield in both conditions. Among the treatments, N application even at lower rate supplemented with calcium as $CaSO_4$, CaC_2 or their mixture (1:1) showed better performance than that of straight N application in both soils. A 41 to 53% increase in plant growth and 36 to 44% in grain yield over control (without N) were observed through N fertilization at 25 and 50 mg kg^{-1} of soil supplemented with calcium as CaC_2 in saline-sodic soil. Similarly, calcium as $CaSO_4$ application also caused a considerable improvement in plant growth (34 to 52%) and grain yield (25 to 43%). However, the effect of mixture application of $CaSO_4$ and CaC_2 (1:1) on plant growth and yield was comparatively more pronounced for both the soils. Interestingly, lower dose of N (25 mg kg^{-1}) with calcium as CaC_2 alone or in combination with $CaSO_4$ (1:1) supplementation showed statistically equal performance to that of higher dose (N=50 mg kg^{-1}) alone. Tissue Na^+ significantly decreased while K^+ and Ca^{2+} concentrations were elevated due to N application along with calcium nutrition. Maximum N uptake and apparent N recovery were revealed from treatments where N was applied @ 50 mg kg^{-1} soil supplemented with calcium as CaC_2 or $CaSO_4$ alone or their mixture. A highly significant negative correlation (r = - 0.975) between dry matter yield and Na^+ concentration and positive correlations (r = 0.8693 and 0.9396) between dry matter yield and K^+ and Ca^{2+} concentrations, respectively in plant tissues was observed in saline-sodic soil.

Keywords: Saline-sodic soil, N application, calcium sulphate, calcium carbide, wheat yield, apparent N recovery

Introduction

Soil salinity is serious problem posing major threat to the sustainable agricultural productivity. It is estimated that about 6.63 m ha lands are salt-affected (Anonymous, 2007) in Pakistan. Such problem soils can successfully be cultivated by removing excessive soluble salts and exchangeable sodium from root zone (Mahmood and Qureshi, 2000; Ali *et al*., 2003). The other approach for economic utilization of moderately salt-affected lands is to grow salt tolerant crop varieties along with optimum use of plant nutrients, particularly N fertilizers (Mahmood and Qureshi, 2000). A high proportion of the applied N is lost (Smith and Whitefield, 1990; Shah *et al*., 1993) due to which the efficiency of N fertilizers does not exceed 45% (Craswell, 1987; Zia *et al*., 1997).

Calcium supply can increase both N use efficiency and hence plant growth as well as Na^+ exclusion by plant roots exposed to NaCl stress (LaHaye and Epstein, 1971; Aslam *et al*., 2001). In addition, root medium supplied with external Ca^{2+} facilitates to maintain plant K^+ concentration and healthy crop stand. Thus adequate Ca^{2+} is required in the medium to maintain the selectivity and integrity of cell membrane of plants grown under saline environment (Aslam *et al*., 2000). Supplemental Ca^{2+} may also have effects on intracellular membranes of root cells exposed to salinity stress (Lynch and Lauchli, 1988 a & b) and may decrease NaCl induced vacuolar alkalization in root tissues by a Ca^{2+} effect on Na^+ efflux at the plasma membrane (Martinez and Lauchli, 1993) to withstand salt stress. Proportion of Ca^{2+} becomes inadequate under saline sodic conditions and may result in reduced yields due to ion imbalance (Davitt *et al*., 1981; Aslam *et al*., 2001). Apart from this, calcium carbide (CaC_2) has been reported a plant growth promoting compound (Ahmad *et al*., 2004; Yaseen *et al*., 2005, 2006; Mahmood *et al*., 2007) in view of its dual action, i.e., nitrification inhibitor (Keerthisinghe *et al*., 1996) as well as plant hormone (Arshad and Frankenberger, 2002; Yaseen *et al*., 2006). Banerjee *et al*. (1990) have already reported that CaC_2 inhibits the *Nitrosomonas* activity to prolong the stay of N in soil as NH_4^+ ion. The

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work of many researchers also supported the use of CaC_2 as an effective inhibitor of oxidation of NH_4^+ ion into NO^-_3 under both flooded and non-flooded soil conditions (Keerthisinghe *et al*., 1996, Freney *et al*., 2000; Ahmad *et al*., 2004; Mahmood *et al*., 2007). Keeping in view these facts, attention has been drawn to investigate the effect of $CaSO_4$ and CaC_2 on N use efficiency of applied N to wheat plants grown on normal and saline-sodic soils.

Materials and Methods

Effect of different N levels (25 and 50 mg kg^{-1} of soil) with or without calcium as $CaSO_4$ or CaC_2 (20 mg kg^{-1} from each source) on growth, yield and ionic concentration of wheat (*Triticum aestivum* L. var. Inqlab-91) in normal soil (Soil-I) and saline-sodic (Soil-II) was studied in glass house at National Agricultural Research Centre (NARC), Islamabad during Kharif season 2007-08. Soil-I and Soil-II having different physico-chemical properties (Table I) were collected from field areas of NARC, Islamabad and Pindi Bhattian (Dist. Hafizabad). Pre-sowing soil samples were analyzed for particle size distribution by hydrometer method (Bouyoucos, 1962). Calcium carbonate was estimated by acid neutralization method (FAO, 1980) and soil organic matter by oxidation with potassium dichromate in sulfuric acid medium under standardized conditions by Walkley and Black procedure (Nelson and Sommers, 1982). Soil pH was determined in water (soil water ratio 1:1). Electrical conductivity of the soil suspension was measured using conductivity meter. The available P and extractable K were determined by using AB-DTPA extraction method (Soltanpour and Workman, 1979). Total N was measured through sulphuric acid digestion. Distillation was made with Micro-Kjeldahl method (AOAC 1994).

The treatments planned for this study were as under:

T1 = Control (No N application)
T2 = 25 mg N kg^{-1} soil as urea
T3 = 50 mg N kg^{-1} soil as urea
T4 = 25 mg N kg^{-1} soil as urea + 20 mg Ca as $CaSO_4$
T5 = 50 mg N kg^{-1} soil as urea + 20 mg Ca as $CaSO_4$
T6 = 25 mg N kg^{-1} soil as urea + 20 mg Ca as CaC_2
T7 = 50 mg N kg^{-1} soil as urea + 20 mg Ca as CaC_2
T8 = 25 mg N kg^{-1} soil as urea + $CaSO_4$ and CaC_2 (1:1)
T9 = 50 mg N kg^{-1} soil as urea + $CaSO_4$ and CaC_2 (1:1)

A basal dose of P and K at 30 and 25 mg kg^{-1} soil, respectively were also applied to all the pots at sowing. Half of the N as urea and all calcium (20 mg as $CaSO_4$) were thoroughly mixed in soil of the respective pots before filling eight kilogram of soil pot^{-1}. All calcium (20 mg) as CaC_2 (powdered) was placed in root zoon (6 cm deep) in the centre of the pot and remaining half of N was applied at the time of first irrigation. Ten seeds were sown in each pot and thinned to four healthy and uniform plants per pot after seedling establishment. Tap water was used to maintain moisture at 60% water holding capacity till grain formation stage and plant protection measures were done whenever required throughout the growth period. At maturity, data on shoot height and biomass yield were recorded. Plant samples were dried in oven at 60 ºC to a constant weight and the dry matter yield was recorded. Ground plant samples were digested in perchloric-nitric acid (2:1 1N) mixture (Rhoades, 1982) to estimate Na, K and Ca by atomic absorption spectrophotometer (Perkin-Elmer, 4000). For N determination, plant samples were digested with sulphuric acid and using auto-analyzer. Nitrogen uptake by wheat was calculated on dry matter yield basis. Apparent N recovery from proportion of applied N taken up by plants and expressed in terms of percentage was determined as follows (Guillard *et al*., 1995).

Table I: Physico-chemical analysis of the soils

Parameter	Unit	Soil-I	Soil-II
pH	–	8.10	9.20
ECe	dS m^{-1}	0.70	8.70
SAR	(m mol$_c$ L^{-1})½	4.37	21.43
$CaCO_3$	%	1.23	1.31
OM	%	0.30	0.29
N	%	0.04	0.02
Available P	mg kg^{-1}	3.47	2.10
Extractable K	mg kg^{-1}	46.50	15.40
Sand	%	22.10	12.50
Silt	%	35.60	34.20
Clay	%	42.30	53.30
Textural Class	–	Clay Loam	Clay

$$\text{ANR (\%)} = \frac{\text{N uptake Fertilized} - \text{N uptake Control}}{\text{N uptake Fertilized}} \text{ X } 100$$

The data thus obtained were subjected to statistical analysis according to Gomez and Gomez (1984) using completely randomized design (factorial) with three replications.

Results and Discussions

Growth and Yield

A significant reduction in growth and yield components, straw and grain yields of wheat grown under normal (ECe = 0.7 dS m^{-1}, SAR = 4.37 and pH = 8.1) and saline-sodic (ECe = 8.7 dS m^{-1}, SAR = 21.43 and pH = 9.2) soils was observed while N application along with 20 mg calcium as $CaSO_4$ or CaC_2 supplementation caused a considerable improvement in plant height, straw and grain yields (Figures 2 & 5). Among the treatments, N application even at lower rate supplemented with calcium as $CaSO_4$ or CaC_2 showed better performance than that of straight N application in both normal and saline-sodic soils. A 41 to 53% increase in plant growth and 36 to 44% in grain yield over control (without N application) were observed with N fertilization at 25 and 50 mg kg^{-1} of soil along with calcium as CaC_2 supplementation to wheat plants grown in saline-sodic soil (ECe=8.7 dS m^{-1}). Similarly, calcium supplementation as $CaSO_4$ also caused a significant improvement in plant growth (34 to 52%) and yield (25 to 43%). However, the effect of calcium as $CaSO_4$ and CaC_2 mixture application (1:1) in improving plant growth and yield was comparatively more pronounced for both the soils. It is clear from the data that plant response to lower dose of N fertilization with calcium as CaC_2 alone or mixture with $CaSO_4$ (1:1) was comparatively better than that of calcium as $CaSO_4$ supplementation. Furthermore, lower dose of N supplemented with calcium as CaC_2 alone or in combination with $CaSO_4$ produced statistically similar grain yield as that of higher dose of straight N application probably due to better N use efficiency and reduced N losses in case of calcium as CaC_2 addition (Ahmad *et al*., 2004, Yaseen *et al*., 2006, Mahmood *et al*., 2007). This improvement in growth, yield contributing parameters and straw and grain yields (Figures 1-6) with calcium as CaC_2 or mixture with $CaSO_4$ (1:1) supplementation is presumably due to enhanced N utilization because of better Ca^{2+}/Na^+ ratio reducing the adverse effect of Na^+. Calcium carbide is considered a powerful nitrification inhibitor (Banerjee *et al*., 1990) and thus reduces N losses substantially (Arshad and Frankenberger, 2002). Further, calcium has been reported to have a definite impact on plant establishment in saline environment because of increased nutrients availability to the plants. Roots supplied with external Ca^{2+} maintain their K^+ concentration and healthy crop stand due to increased N use efficiency and hence plant growth as well as Na^+ exclusion of plant roots exposed to NaCl stress (LaHaye and Epstein, 1971, Aslam *et al*., 2001; Ali *et al*., 2003). Supplemental Ca^{2+} may decrease NaCl induced vacuolar alkalization in root tissues by Ca^{2+} effect on Na^+ efflux at the plasma membrane (Martinez and Lauchli, 1993, Kinraide, 1999) and hence improve plants ability to withstand salt stress. Furthermore, calcium improves K^+/Na^+ selectivity of membranes and prevents the soil from invasion of toxic ion (Cramer *et al*., 1990; Kinraide, 1998; Aslam *et al*., 2000; Kaya *et al*., 2002).

Ionic Composition

High Na^+ and low K^+ and Ca^{2+} concentrations were noted in plant tissues grown in salt-affected soil while the effect of calcium application on Mg^{2+} contents in plant tissues was statistically non-significant (Figures 7-10). The maximum Na^+ concentration was found in plants grown in saline-sodic soil while K^+ and Ca^{2+} contents decreased due to increase in salinity. Similar conclusions have been reported by Kupier (1984) and Ali *et al*. (2003) explaining that the root medium salinity interferes with the absorption and translocation of K^+ and Ca^{2+} by plants. The data indicates that lower rate of N application supplemented with calcium as CaC_2 or $CaSO_4$ or their mixture (1:1) performed statistically equal to that of higher rate of straight N application in both the soils. Nitrogen application particularly with calcium as CaC_2 decreased Na^+ contents significantly and increased K^+ and Ca^{2+} concentrations in plant tissues. This was probably due to selective K^+ transport compared to that of Na^+ in the presence of calcium supply resulting in less Na^+ and more K^+ contents in plant tissues. In addition, plant tissue K^+ and Ca^{2+} concentration increased significantly with N application especially when supplemented with calcium as CaC_2 or $CaSO_4$ in both saline-sodic and normal soils. External Ca^{2+} supply in saline root medium presumably enhances Na^+ exclusion ability of plants to suppress Na^+ transport. This inference is supported by the results of Ali *et al*. (2001) and Aslam *et al*. (2001) who have documented that at relatively higher concentration of Ca^{2+}, plants absorbed and translocated relatively more K^+ and less Na^+ than at lower concentration of Ca^{2+}, demonstrating the positive role of Ca^{2+} in alleviating the hazardous effects of salinity on sunflower growth.

Figure I a & b illustrate a significant negative correlation (r = – 0.914 under normal and r = – 0.975 under saline-sodic soil) between dry matter yield and Na^+ concentration in plant tissues which is indicative of growth inhibition due to increased Na^+ content in tissues. The accumulation of Na^+ was decreased by N application supplemented with 20 mg calcium as CaC_2 or $CaSO_4$ or their mixture under both the soils and increased K^+ and Ca^{2+} contents that is clear from the Figures II and III a & b. A significant positive correlation (r = 0.9544 under normal) and (r = 0.8693 under saline-sodic soil) between dry matter yield and K^+ concentration in plant tissues. It indicates higher K^+ accumulation with the increasing dry matter yield. Similarly, a significant positive correlation (r = 0.8957 under normal) and (r = 0.9396 under saline-sodic soil) between dry matter yield and Ca^{2+} concentration in plant tissues. The analysis showed that K^+ was transported preferentially to Na^+ in the presence of calcium supply and selectivity became more pronounced in the presence of calcium as CaC_2 or its mixture with $CaSO_4$ (1:1) in the root

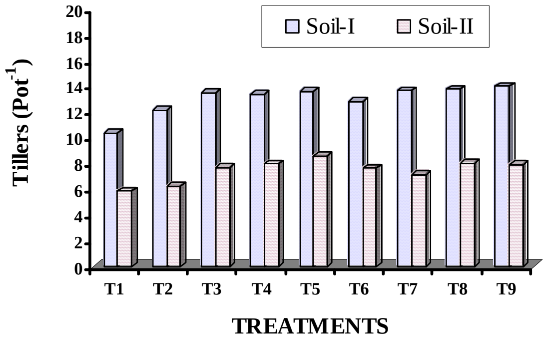

Figure 1. Number of tillers influenced by N application supplemented with calcium under normal and saline-sodic soils

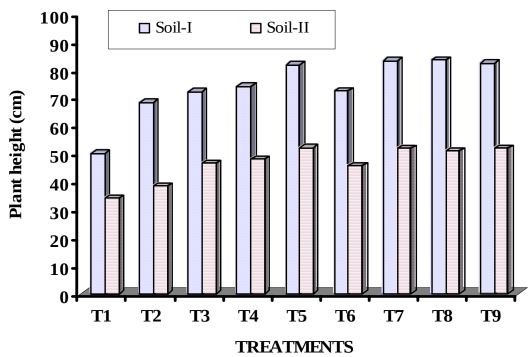

Figure 2. Plant height influenced by N application supplemented with calcium under normal and saline-sodic soils

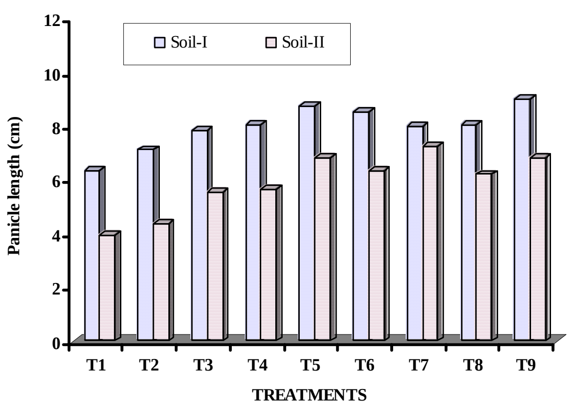

Figure 3. Penicle length influenced by N and Calcium application under normal and saline-sodic soils

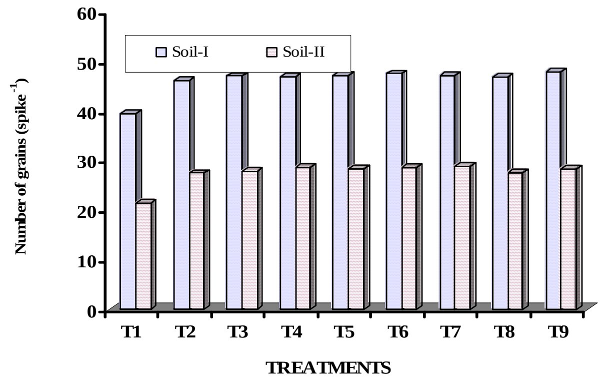

Figure 4. Grains spike^{-1} influenced by N application supplemented with calcium under normal and saline-sodic soils

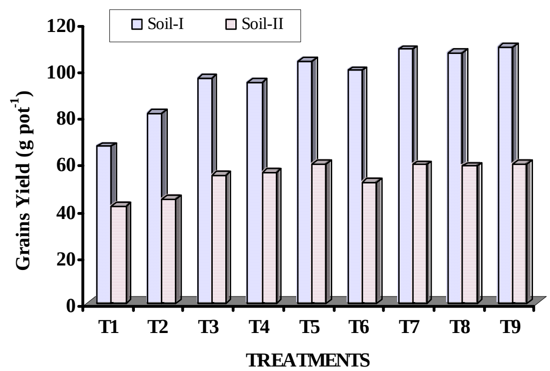

Figure 5. Grains yield (g pot^{-1}) influenced by N and calcium application under normal and saline-sodic soils

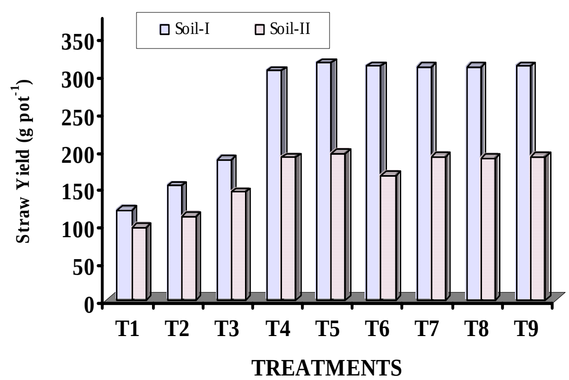

Figure 6. Straw yield (g pot^{-1}) influenced by N and calcium application under normal and saline-sodic soils

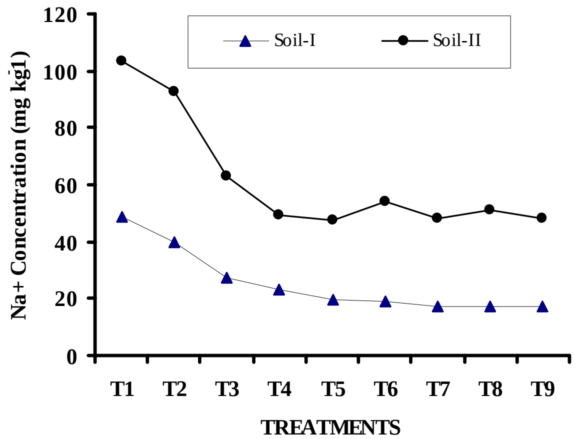

Figure 7. **Na^{+} concentration in plant tissues influenced by N application and calcium supplementation under normal and saline-sodic soils**

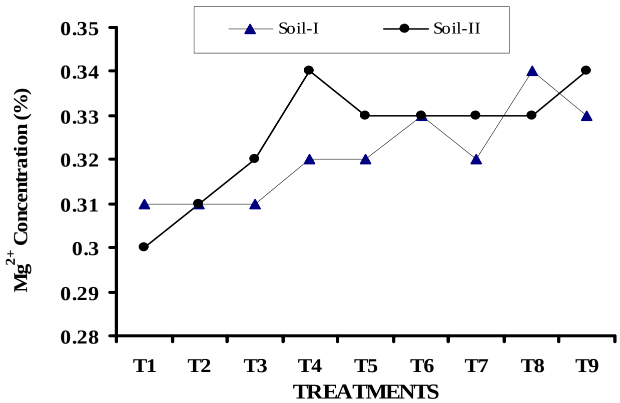

Figure 10. **Mg^{2+} concentration in plant tissues influenced by N application and calcium supplementation under normal and saline-sodic soils**

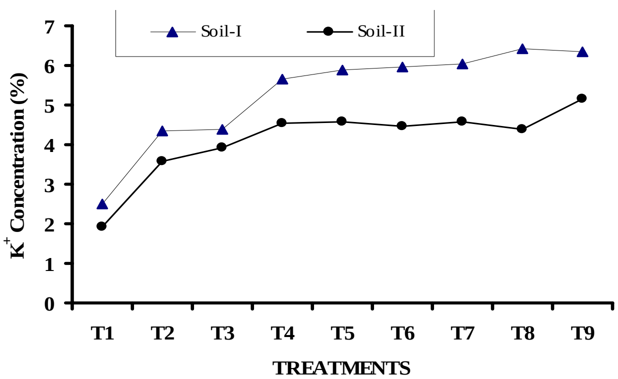

Figure 8. **K^{+} concentration in plant tissues influenced by N application and calcium supplementation under normal and saline-sodic soils**

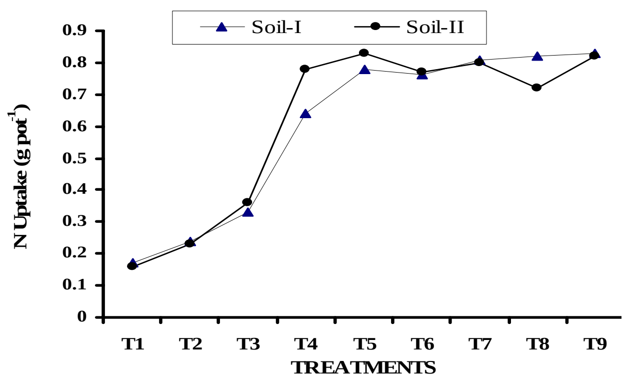

Figure 11. **N uptake by wheat plants influenced by N application and calcium supplementation under normal and saline-sodic soils**

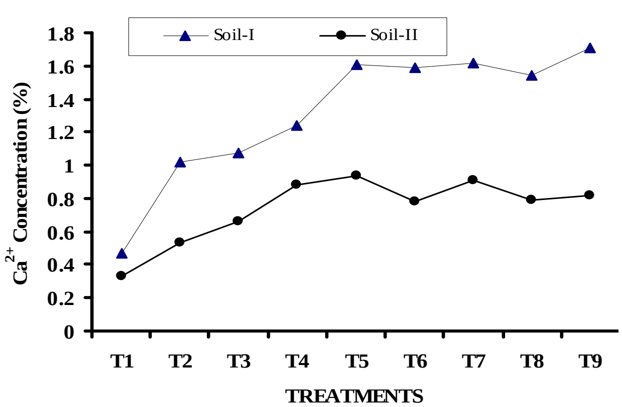

Figure 9. **Ca^{2+} concentration in plant tissues influenced by N application and calcium supplementation under normal and saline-sodic soils**

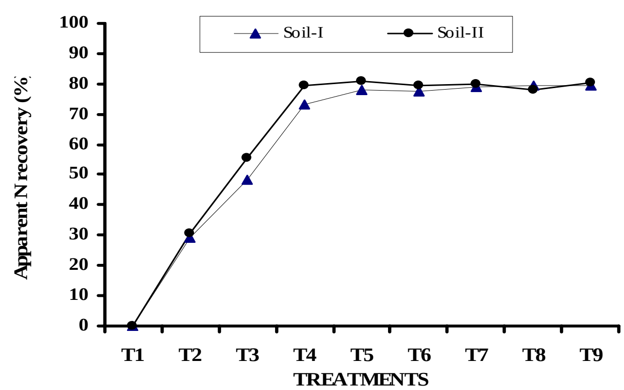

Figure 12. **Apparent N recovery by wheat influenced by N application and calcium supplementation under normal and saline-sodic soils**

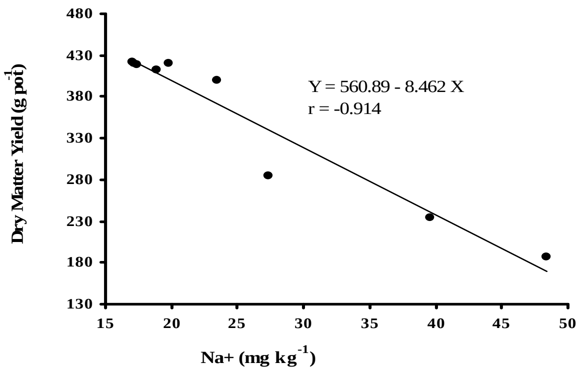

Figure I a: Correlation of Na^+ and Dry matter yield as affected by N application supplemented with $CaSO_4$ and CaC_2 under normal soil

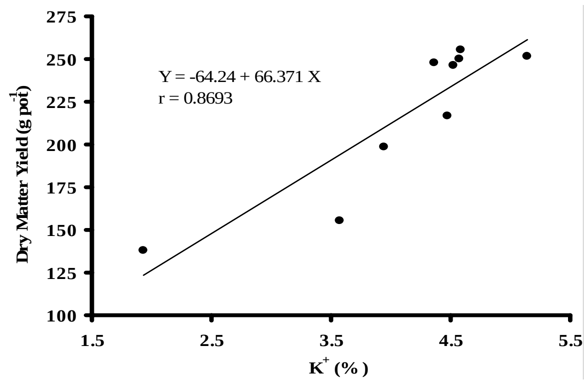

Figure II b: Correlation of K^+ and Dry matter yield as affected by N application supplemented with $CaSO_4$ and CaC_2 under saline-sodic soil

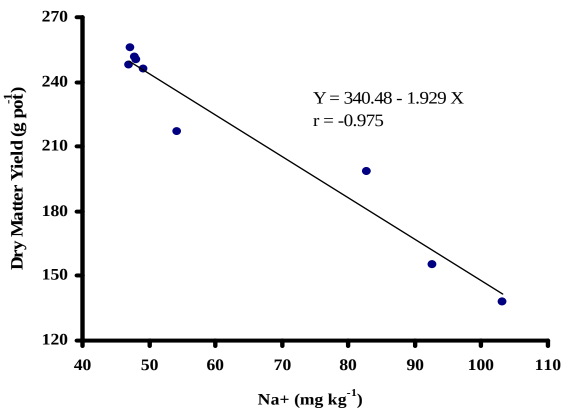

Figure I b. Correlation of Na+ and Dry matter yield effected by N application supplemented with $CaSO_4$ and CaC_2 under saline-sodic soil

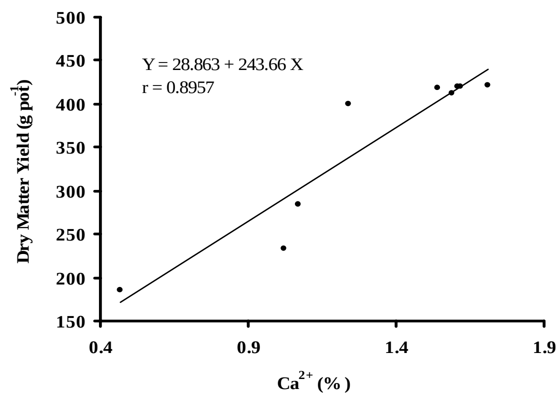

Figure III a: Correlation of Ca^{2+} and Dry matter yield as affected by N application supplemented with $CaSO_4$ and CaC_2 under normal soil

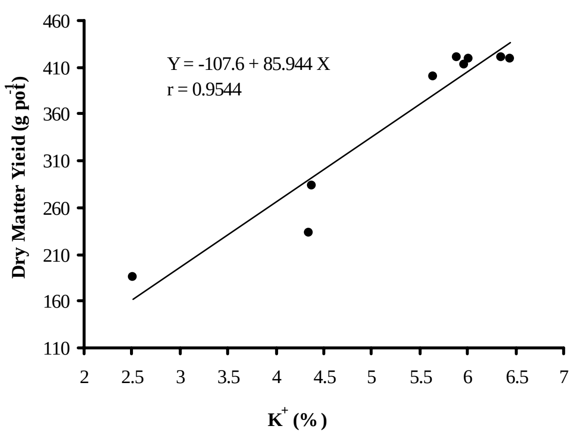

Figure II a: Correlation of K^+ and Dry matter yield as affected by N application supplemented with $CaSO_4$ and CaC_2 under normal soil

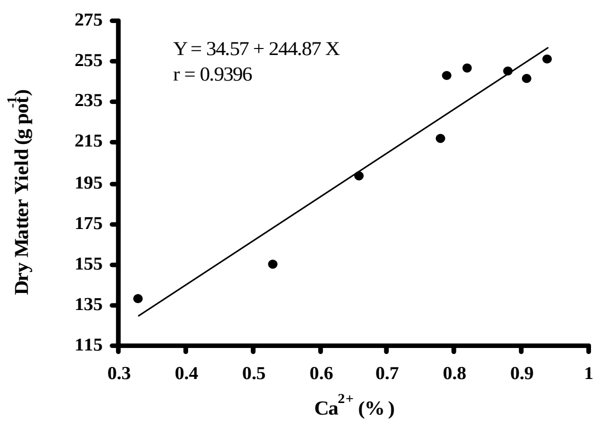

Figure III b: Correlation of Ca^{2+} and Dry matter yield as affected by N application supplemented with $CaSO_4$ and CaC_2 under saline-sodic soil

medium. Maathuis and Amtmann (1999) concluded that K^+ uptake at the root/soil boundary is via highly K^+ selective pathways whereas Na^+, at least in part, appears to move through a less selective system, which in some cases is blocked by Ca^{2+}. They also mentioned the direct effect of Ca^{2+} on the movement of Na^+ which is manifested by voltage-independent channels. Such findings provide an explanation of how increased Ca^{2+} leads to the lower Na^+ uptake and therefore helps to establish high K^+/Na^+ selectivity. Similar conclusions have also been documented by Ali *et al*. (2001) and Hussain *et al*. (2003).

Apparent N Recovery

In saline-sodic soil, maximum apparent N recovery (80.72%) was observed for plants to which N was applied at 50 mg kg^{-1} of soil supplemented with 20 mg calcium as $CaSO_4$ closely followed by 80.49% with higher N rate (50 mg kg^{-1}) supplemented with calcium as mixture of CaC_2 and $CaSO_4$ (1:1) and 80% in case of 20 mg calcium as CaC_2 supplementation (Figure 12). However, lower dose of N (25 mg kg^{-1}) fertilization supplemented with different sources of calcium showed statistically equal performance to that of higher rate (50 mg N kg^{-1}) as compared to straight N application. Similar trend was noted under normal soil (ECe=0.7 dS m^{-1}). This means that calcium plays an important role in improving N use efficiency in terms of apparent N recovery. As it has been discussed earlier that roots supplied with external Ca^{2+} often maintain their K^+ concentration and eventually healthy crop stand due to selectivity and integrity of cell membrane of plants grown under saline environment (Kinraide, 1999; Aslam *et al*., 2000). Supplementad Ca^{2+} may also have effects on intracellular membranes of root cells exposed to salinity stress (Lynch and Lauchli, 1988 a & b) and may decrease NaCl induced vacuolar alkalization in root tissues by a Ca^{2+} effect on Na^+ efflux at the plasma membrane (Martinez and Lauchli, 1993). The average apparent N recovery in wheat was significantly higher in both soils with the treatment of calcium as $CaSO_4$ or CaC_2 or their mixture (1:1). Comparatively lower efficiency of N application alone compared with that supplemented with calcium may be due to differences in N volatilization (Vlek and Craswell, 1981; Hamid and Ahmad, 1987, 1988; Mahmood and Qureshi, 2000). Since it is clear from the data (Figure 11) that maximum N uptake (0.83 g pot^{-1} under normal soil) was observed from the pots where N was applied at 50 mg kg^{-1} soil supplemented calcium as mixture of CaC_2 and $CaSO_4$ (1:1) and (0.83 g pot^{-1} under saline-sodic soil) with Ca as $CaSO_4$ alone, which conclusively resulted in enhancing apparent N recovery. Zia *et al.* (1992, 1997, 2000), Fiez *et al.* (1995), Hamid *et al.* (1998) and Haq *et al.* (2001) have also reported similar inferences.

Conclusion

Half rate of N application (25 mg kg^{-1} soil) produced statistically similar yields as that of its double rate when was supplemented with all sources of calcium under saline-sodic soil. It could thus be concluded that the efficiency of N fertilization can be improved through calcium as CaC_2, $CaSO_4$ or their mixture (1:1) supplementation under moderately saline-sodic soil conditions. Further investigation regarding the impact on yield under naturally salt-affected field conditions is still needed.

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