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# EFFICIENCY OF NITROGEN USE IN RICE-WHEAT CROPPING SYSTEM IN SALT-AFFECTED SOILS WITH CONTRASTING TEXTURE

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Considerable nitrogen (N) losses lead to lower N use-efficiency (NUE) in salt-affected soils due to leaching and volatilization. A lysimeter experiment was conducted to determine NUE in two salt-affected soils of different texture (clay loam and sandy clay loam), using various rates of N fertilizer. The experiment used a three replicate completely randomized design. The treatments included five N rates, three higher (15, 30 and 45%) and two lower (15 and 30%) than recommended rate of 125 kg $ha^{-1}$. Additionally, gypsum was added at 50 and 100% of soil gypsum requirement (SGR) in both salt-affected soils. Maximum paddy and straw yields were recorded for sandy clay loam saline-sodic soil collected from Village 132, Faisalabad (132S), using 45% higher N + gypsum at 100% SGR. Whereas clay loam saline-sodic soil, from Village 84, Faisalabad (84S) at 30% higher N rate with gypsum at 50% SGR gave the highest paddy and straw yields. In general, the clay loam soil produced more paddy yield than the sandy clay loam soil at similar N fertilization. In the sandy clay loam soil, gypsum at 100% SGR along with a 30% higher N rate increased the grain and straw yields of wheat significantly ($p < 0.05$) compared to application of gypsum at only 50% SGR. Nitrogen use efficiency was the highest with 45% higher N ($N_{145}$) with gypsum applied @ 100% SGR compared to 50% SGR in severe salt-affected (sandy clay loam) soil during rice crop. From marginal clay loam saline-sodic soil, NUE remained higher with $N_{130}$ along with gypsum @ 100% SGR which was statistically on par with gypsum @ 50% SGR. It was concluded that NUE remained highest with $N_{130}$ and $N_{145}$ with gypsum applied @ 100% SGR during rice crop from clay loam and sandy clay loam soils, respectively. Moreover, NUE was higher at recommended N fertilization when gypsum was applied at 100% SGR during wheat crop which was also attributed to improved soil chemical properties, i.e. $pH_s$, $EC_e$ and SAR.
**Keywords:** Nitrate leaching, rice-wheat rotation, gypsum, saline-sodic soils

## INTRODUCTION

While considerable information is available on N fertilizer requirements for crops grown on normal soils (non-saline/sodic), much less information is available on N requirements for crops grown on salt-affected soils which in Pakistan cover an area of approximately $11.5 \times 10^6$ ha (Economic Survey of Pakistan, 2005). 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. In Pakistan, the problem of soil and water salinity is complicated by high sodicity. This is due to a high $Na^+$: $Ca^{2+}$ ratio which is present on the exchange sites of the soil minerals. Soil salinity and sodicity suppress plant growth by inducing water stress, specific ion effects and nutrient imbalance resulting in deficiency and toxicity of some elements which decrease crop growth and ultimately economic yield (Ashraf *et al.*, 2008; Katerji *et al.*, 2009).

Decreased biomass under saline conditions may be due to reduced N availability in soil, as well as carbohydrate accumulation caused by decreases in surface area which reduce carbon assimilation (Moradi and Ismail, 2007; Thitisaksakul and Maysaya, 2008). Nitrogen fertilization improves growth which alleviates detrimental effects of moderate salinity and helps to improve economic yield of crops. Therefore, in addition to other agronomic practices, successful crop production on moderately salt-affected soils demands judicious use of N. The efficiency of N fertilizer in salt-affected soils depends upon the nature and amount of fertilizer, its mineralization pattern, soil type and soil salinity/sodicity levels (Murtaza *et al.*, 2000a). Realizing the importance of crops in moderately salt-affected soils, investigations to determine the suitable application rate of N under such soil conditions are critical (Murtaza *et al.*, 2011). Some researchers have indicated that the requirements of N and other mineral nutrients for crops in salt-affected soils are different than those on normal soils probably due to the different physical and chemical properties of soils (Lodhi *et al.*, 2009).

In Pakistan rice-wheat cultivation covers an area of $2.3 \times 10^6$ ha of which $0.8 \times 10^6$ ha are saline-sodic soils (Murtaza *et al.*, 2009). Such areas cause a loss of $2.16 \times 10^9$ and $1.60 \times 10^9$ kg of paddy and wheat grains each year, respectively. Despite the leading role of rice and wheat in food security, productivity of rice-wheat cropping system is low (Zia *et al.*, 2002). These soils receive all the agricultural inputs (seed, adequate nutrients, irrigation, weedicides/pesticides etc.) but gave low production of crops. It appears wise to study the prospects of growing rice and wheat crops during reclamation of salt-affected soils along with chemical amendments. The reclamation of saline-sodic/sodic soils using gypsum is established practice worldwide, being cost-effective and easy to implement on sustainable basis (Tejada *et al*., 2006; Makoi and Verplancke, 2010; Wong *et al*., 2009). Calcium from gypsum in salt-affected soils also decreases volatilization losses of $NH_4^+$-N which decreased soil pH. Resultantly, uptake of N and other nutrients is increased.

A few studies in Pakistan (Murtaza, 2011) and India (Yaduvanshi and Dey, 2009) have shown that crops grown in saline and/or sodic soils experienced higher yields with N fertilizer rates higher than recommended for non-saline/sodic soils mainly through dilution effect as well as through increased salt tolerance of plants (Sairam and Tyagi, 2004; Woyema *et al*., 2012). Yaduvanshi and Dey (2009) reviewed a series of experiments and recommended that rice and wheat crops grown in sodic soils should receive 25% N over and above the recommended rates for non-saline/sodic soils. Therefore, it seems imperative to determine NUE in salt-affected soils using higher rates of N along with gypsum compared to their counterpart normal soils.

## MATERIALS AND METHODS

The experiment was conducted in lysimeters filled with soils collected from two sites i.e. Village No. 132/GB (72° 5' 1 E, 31° 2' 5 N; Village No. 84/GB (73° 1' 7 E, 31° 1' 3 N) from the district of Faisalabad, Pakistan. The soils are illite dominated clays under canal water irrigation, moderately calcareous developed in alluvium under arid climate which was derived from Himalayas during Pleistocene periods. Soil samples were air-dried, ground to passed through a 2 mm sieve and analyzed for pH using a saturated soil paste ($pH_s$), EC of soil extract at saturation ($EC_e$), soluble $Ca^{2+}$ + $Mg^{2+}$ (titration method using versinate solution), $CO_3^{2-}$ and $HCO_3^-$ (titration method using $H_2SO_4$), $Cl^-$ (titration method using standard $AgNO_3$) and $Na^+$ (using flame photometer) following methods described by Ghafoor *et al*. (2004). The data is presented in Table 1. Particle-size analysis of soils was carried out using the hydrometer method (Bedaiwy, 2012). Gypsum requirement of each soil was determined by Loveday (1974) method. The amount of gypsum for soils 132S and 84S were 5.18 and 4.84 t $ha^{-1}$, respectively.

A known volume of canal water, depending upon the crop requirement, was used to irrigate rice and wheat crops. The N fertilizer treatments employed were: No fertilizer and no gypsum (C), No fertilizer + gypsum @ 50% and 100% soil gypsum requirement (SGR) ($C_g$), 30% less N than recommended N fertilizer rate ($N_{70}$), 15% less N than recommended N fertilizer rate ($N_{85}$), Recommended N fertilizer rate ($N_{100}$), 15% higher N than recommended N fertilizer rate ($N_{115}$), 30% higher N than recommended N fertilizer rate ($N_{130}$), 45% higher N than recommended N fertilizer rate ($N_{145}$). The recommended NPK fertilizer rates of 125, 75 and 60 kg $ha^{-1}$ as urea, triple super phosphate (TSP) and sulphate of potash (SOP) were applied, respectively. While the full doses of P and K were applied at the time of transplanting, initially only 1/3rd of N was applied while the remaining N was applied in two equal splits; 34 days after transplanting (DAT) and 46 DAT rice. During rice crop growth, five leachates were collected and analyzed for $NO_3^-$. Nitrate-N was measured spectrophotometrically using chromotropic acid (Hadjidemetriou, 1982). At physiological maturity, straw and paddy yields were recorded. After the harvest of rice, soil samples were taken from each lysimeter using a stainless steel sampling tube and soil samples were analyzed to determine the change in any physicochemical soil properties.

After rice harvest, soil in lysimeters was loosen and well-pulverized manually for seeding of next crop, i.e. wheat (cv. Faisalabad 2008). The N, P and K nutrients were applied at 120, 100 and 60 kg $ha^{-1}$ as urea, TSP and SOP, respectively. As with rice, while all of the P and K were applied at the time of sowing, 1/3rd of N was applied at the time of sowing and the remaining N was applied in two equal splits at tillering, 28 days after germination (DAG) and at booting stages (54 DAG). Five plants were maintained in each

**Table 1. Chemical and physical characteristics of soils prior to the experiment**

| Soil Characteristic/Site | 132N[a] | 132 S[b] | 84N[c] | 84S[d] |
|---|---|---|---|---|
| $pH_s$ | 8.14 | 8.62 | 8.04 | 8.45 |
| $EC_e$ (dS $m^{-1}$) | 3.36 | 9.94 | 2.98 | 6.86 |
| SAR (mmol $L^{-1})^{1/2}$ | 11.35 | 44.06 | 9.71 | 28.70 |
| Total organic carbon (%) | 0.47 | 0.43 | 0.55 | 0.48 |
| Total nitrogen (mg $kg^{-1}$) | 560 | 114 | 224 | 184 |
| Gypsum requirement (t/ha-15 cm) | | 5.18 | | 4.84 |
| Texture | Sandy Clay Loam | | Clay Loam | |

[a]Normal soil collected from Village 132 (132N); [b]Salt-affected soil collected from Village 132 (132S); [c]Normal soil collected from Village 84 (84N); [d]Salt-affected soil collected from Village 84 (84S).

lysimeter at 14 DAG and three leachates were collected for nitrate analysis during wheat crop growth. Throughout the growth period, canal water (EC = 0.34 dS $m^{-1}$, SAR = 0.71 and RSC = Nil), was used for irrigation. At maturity, grain and straw yields were recorded. The nitrogen use efficiency (NUE) was calculated using the formula:

$NUE= (Y_N-Y_0)/F_N$

Where $Y_N$ and $Y_0$ are yield with and without N application, respectively and $F_N$ is N fertilizer applied.

All data collected were statistically analyzed using ANOVA and the LSD test was applied to evaluate treatment differences (Steel *et al*., 1997).

## RESULTS AND DISCUSSION

The arid region salt-affected soils have high $pH_s$, $EC_e$, SAR, and are calcareous with poor physical conditions which limit nutrient availability and plant growth (Ghafoor *et al.*, 2004). Under these circumstances, economic crop yields and fertilizer use efficiency can be increased by adopting N management strategies.

***Nitrate leaching during crop growth from 132 soils*:** The effect of gypsum and N application rates on $NO_3^-$ leaching in 132 soils during rice growth is given in Fig. 1. The highest $NO_3^-$ (49.0 mg per 5 leachates) leaching was recorded with $N_{145}$ and the lowest being with C in 132N soil. Minimum $NO_3^-$ leaching (19.6 mg per 5 leachates) was recorded with C and maximum with $N_{130}$ along with gypsum @ 100% SGR in sandy clay loam saline-sodic soil. The treatment $N_{130}$ + 100% SGR differed significantly from other treatments. Higher than permissible level of $NO_3$-N in leachates were recorded with $N_{130}$ and $N_{145}$ along with gypsum @ 100% SGR. Nitrogen application if not to coincide with N requirement of the plant, excessive water and N use in crop production results in environment degradation and can potentially jeopardize the sustainability of the system (Fang *et al*., 2008). Baker and Johnson (1981) studied the effect of N fertilizer on $NO_3$-N in tile drainage and observed that $NO_3$-N concentration increased from 20 to 40 mg $L^{-1}$, by increasing N rate from 100-250 kg $ha^{-1}$. Addition of gypsum has increased the water percolation and hence, a greater amount of dissolved $NO_3^-$ would have been carried by the soil solution. Gharaibeh *et al*. (2009) also reported that improvement in infiltration rate and hydraulic conductivity with the use of gypsum added to soils to have adequate pore spaces through which air, water and roots move, thus accelerating $NO_3^-$ leaching.

The effect of gypsum and N application rates on $NO_3^-$ leaching in 132 soils during wheat growth is shown in Fig. 2. Nitrate leaching (211.5 mg per 3 leachates) was found to be higher with $N_{145}$ than in control (without fertilizer and gypsum, 95.59 mg per 3 leachates) in normal soil. Treatment $N_{130}$ differed significantly from other treatments but remained non-significant with $N_{100}$. The $NO_3^-$ leaching in sandy clay loam soil is likely due to the weakening of attractive forces between $NO_3^-$ and the soil matrix as well as desorption of other anions, which not only decreases NUE but may also potentially lead to the contamination of groundwater. If crops do not utilize $NO_3^-$, downward leaching cannot be avoided because of its high solubility in

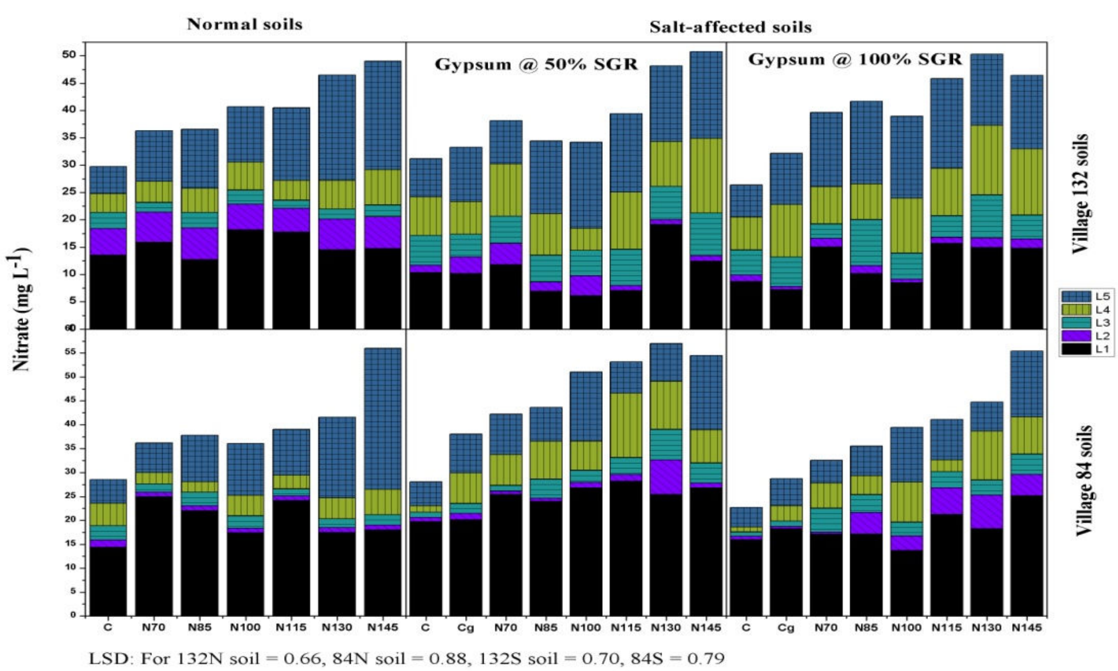
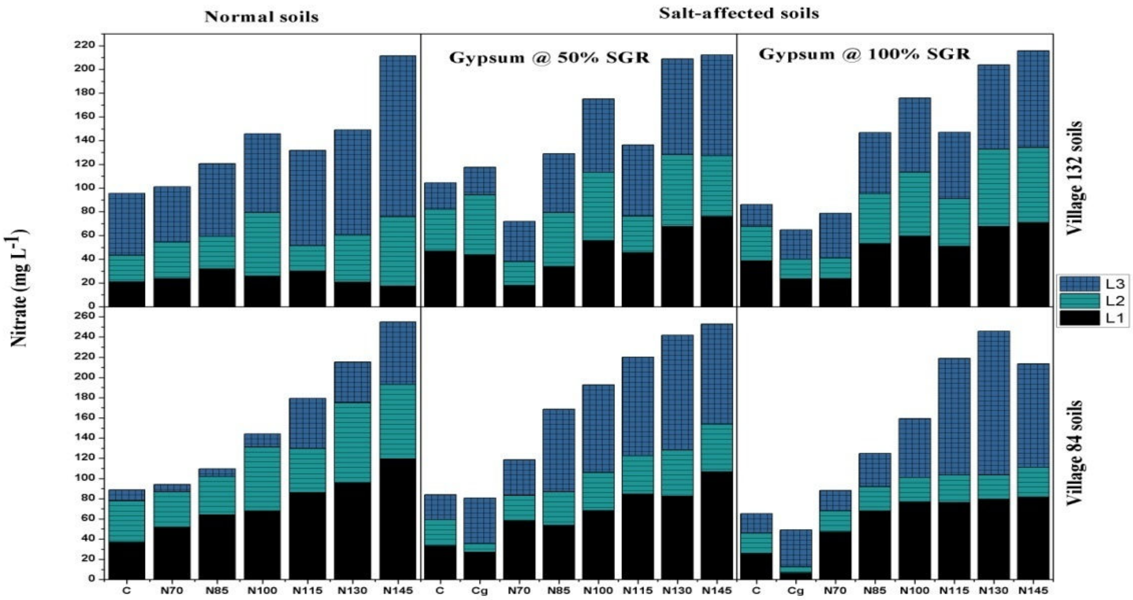



**Figure 1. Effect of N and gypsum application rates from 132 and 84 soils during rice crop.**




LSD: For 132N soil = 2.22, 84N soil = 2.19, 132S soil = 2.18, 84S soil = 2.46.

**Figure 2. Effect of N and gypsum application rates on nitrate leaching from 132 and 84 soils during wheat crop.**

water and low retention in soil (Zhou *et al.*, 2008), particularly in Pakistani soils, in which clays have net negative charge on their surfaces (Murtaza *et al*., 2000b).

In saline-sodic soil, maximum $NO_3^-$ (50.8 mg per 3 leachates) was observed with $N_{145}$ along with gypsum @ 50% SGR. This was statistically on par with $N_{130}$ along with gypsum @ 50% SGR. Minimum $NO_3^-$ leaching (18.8 mg per 3 leachates) was recorded with $C_g$ (no fertilizer + gypsum @ 100% SGR) and maximum with $N_{145}$ (62.6 mg per 3 leachates) along with gypsum @ 100% SGR. These findings vary from the pattern observed for the 132S soil which had a higher SAR value. Generally, more $NO_3^-$ leaching occurs in coarse textured soils than in fine soils where the highest $NO_3^-$ leaching in clay loam soil was due to high aggregate stability associated with carbonates (Boix-Fayos *et al.*, 2001). The negative surface charge on clay particles increases with pH, increasing particle repulsion. This also suggested that external application of gypsum is useful to sustain the electrolyte concentration in soil solution; as de-flocculation in response to decreased electrolyte concentration in soil solution could impair the effective leaching of salts in saline-sodic soils. It also decreases the pH of saline-sodic soils (Bronick and Lal, 2005). The level of exchangeable $Na^+$ is decreased, which lessens the hydrolysis of clay to form hydroxides and also there is release of the acid ions.

***Nitrate leaching during crop growth from 84 soils*:** The effect of gypsum and N application rates on $NO_3^-$ leaching in Village 84 soils during rice cultivation is shown in Fig. 1. The maximum $NO_3^-$ leached (56.0 mg per 5 leachates) was recorded for $N_{145}$, while the minimum leached nitrogen occurred with the control (58.3 mg per 5 leachates) in clay loam normal soil. The highest $NO_3^-$ contents (48.5 mg per 5 leachates) were recorded with $N_{145}$ along with gypsum @ 100% SGR in salt-affected soil which was differed significantly from all the treatments. In case of gypsum @ 50% SGR, $NO_3^-$ leaching was found to be greater with $N_{130}$ compared to their control and remained non-significant with gypsum @ 100% SGR.

The effect of gypsum and N application rates on $NO_3^-$ leaching in 84 soils during wheat is given in Fig. 2. The leachates were collected 31, 60 and 95 DAS. The highest $NO_3^-$ level was recorded in $N_{145}$ and the lowest in C. Maximum $NO_3^-$ (254 mg per 3 leachates) was observed with $N_{145}$. The amount of nitrate leached during the 1st leachate was much higher than that subsequently leached in the 2nd and 3rd sampling periods. These results are in conformity with Hansen and Djurhuus (2007) who calculated $NO_3$-N leaching at different N rates by installing ceramic cups at 80 cm depth. The average annual $NO_3^-$ leaching was 38 and 52 kg N $ha^{-1}$ when N was applied 60 and 120 kg $ha^{-1}$, respectively. They also concluded that a 50% decrease in N application reduced the yield by 26%, while $NO_3^-$ leaching decreased by 27%. Oad *et al*. (2002) also reported that infiltration rate (IR) for carrying dissolved $NO_3^-$ through the soil was high during the initial stages of soil wetting but decreased exponentially with time towards a constant rate. Two main factors responsible for this were 1) a decrease in the matric potential gradient, which occurs as infiltration proceeds, and 2) formation of a seal/ crust at the soil surface.

In arid and semi-arid regions, organic matter is generally low, soil structure is unstable, and soil crusting is major factor which determines the steady-state IR.

The highest amount of $NO_3^-$ (196.6 per 3 leachates) leaching in 84S soil was recorded with $N_{145}$ along with gypsum at 50% SGR. This differed significantly from the amount of nitrate leached from all the treatments with gypsum @ 100% SGR. The minimum $NO_3^-$ (49.3 mg per 3 leachates) was found with $C_g$ and the maximum with $N_{130}$ (245.8 mg per 3 leachates) along with gypsum @ 100% SGR. Higher than permissible levels of $NO_3$-N in leachates was recorded with $N_{130}$ and $N_{145}$ which received gypsum @ 100% SGR. This seems to be due to the fact that gypsum decreased the swelling and cracking associated with high levels of exchangeable $Na^+$ on the clays. As $Na^+$ is replaced by $Ca^{2+}$ from clays, these swell less and, therefore, do not easily clog the pore spaces through which air, water and roots move (Murtaza *et al.*, 2006).

**Growth Response of Crops**

***Paddy and straw yields from normal soils*:** Paddy yield significantly increased with N application for both 132N and 84N soils (Fig. 3). The highest paddy yield (10 g $pot^{-1}$) was recorded with $N_{145}$ for the sandy clay loam soil which was not statistically different from the yield observed with $N_{130}$. In comparison for the clay loam soil, paddy yield was the highest (16.4 g $pot^{-1}$) with $N_{130}$ which differed non-significantly from neither $N_{115}$ or $N_{145}$. The lowest paddy yield of 5.4 and 11.6 g $pot^{-1}$ was recorded for the controls of both132N and 84N soils, respectively. Paddy yield followed the diminishing law of return (in all productive processes, adding more of one factor of production, while holding all others constant, will result a point where yield is lower per-unit returns) in clay loam soil, i.e. yield decreased beyond $N_{130}$ treatment. Application of higher rates of N fertilizer than recommended makes plants susceptible to lodging and enhances attacks by insect pest and diseases (Islam *et al.*, 2007).

The findings of this study are in agreement with Singh *et al.* (2011) who reported that farmers targeting higher yield tend to use higher doses of N, however, such doses not always add to the yield. Thus application of N needs to be considered carefully to reduce excessive N losses to the environment and potential contamination issues. In this respect fertilizer rate, right time and split application have all proven to be beneficial in terms of yield, thus improving NUE.

Straw yield differed significantly with the application rate of N (Fig. 3). The highest straw yield was obtained with $N_{145}$ from sandy clay loam and clay loam soils and was minimal in the control. At higher rates of N, i.e. $N_{130}$ and $N_{145}$ differed non-significantly ($p > 0.05$) from each other while yield was significantly more than the control. In clay loam soil, $N_{130}$

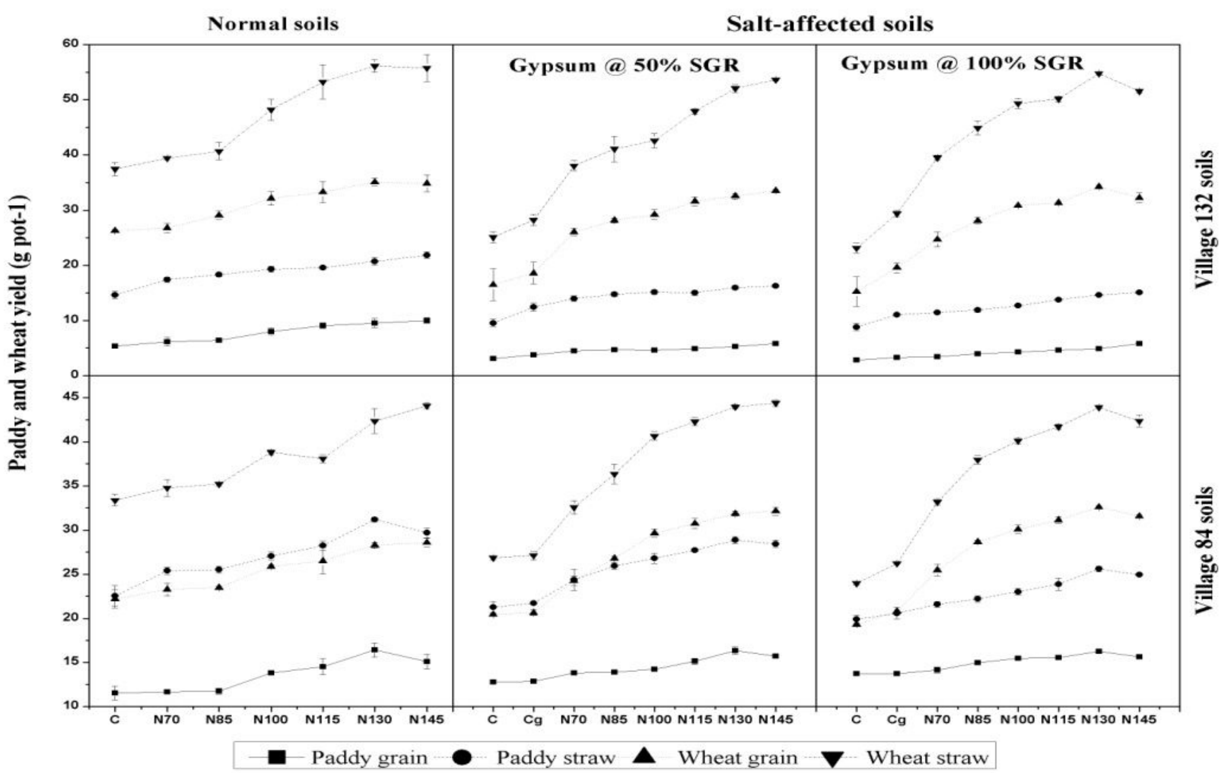



**Figure 3. Effect of N and gypsum application rate on paddy and wheat yields from normal and salt-affected soils.**

produced the highest straw yield but was not significantly different than $N_{115}$ and $N_{145}$. It appears that application of N fertilizers improved both growth and yield of wheat and rice (Murtaza, 2011).

***Paddy and straw yields from salt-affected soils*:** In salt-affected soils, paddy yield differed significantly with the application rates of N (Fig. 3). Application of fertilizer N increased yield significantly over that of the control. The highest paddy yield of 6.3 and 9.2 g pot$^{-1}$ was obtained with $N_{145}$ and $N_{130}$ from sandy clay loam and clay loam soils, respectively, which differed non-significantly with $N_{130}$ for gypsum @ 50% SGR. The lowest paddy yield of 3.1 and 4.8 g pot$^{-1}$ was obtained with the control treatment for 132S and 84S soils, respectively. The decrease in paddy yield in control was due to high EC and SAR values of soils where rice was grown (Abbas *et al*., 2007). The observed yield increase following application of N and gypsum was potentially due to an increased cation exchange capacity of roots and induced dilution effect that promoted tolerance against the prevalent EC and SAR stresses (Qadir *et al.*, 2006). The relatively higher yield of crops receiving gypsum with canal water irrigation may be attributed to enhancement of favorable effects on soil physical and chemical properties, particularly with favorable $Ca^{2+}$: $Na^{+}$ ratios in the soil solution (Murtaza *et al.*, 2009).

Rice is a salt susceptible crop at both the seedling and reproductive stages, and may exhibit decreases in yield more than 50% at an $EC_e$ of 6.65 dS m$^{-1}$ (Cha-um *et al.*, 2011; Moradi and Ismail, 2007; Zeng *et al.*, 2001). Wang (2012) studied the effects of salt-affected soil on N metabolism and ion balance in rice plants by measuring the total amino acids, $NO_3^-$ and inorganic ions contents in the stressed seedlings finding that the roots are more sensitive to salt stress and therefore that plant growth and development was affected.

Straw yield increased significantly with N and gypsum application rates (Fig. 3). Maximum straw yield (16.3 g pot$^{-1}$) was recorded with $N_{145}$ from 132S soil and 22.7 g pot$^{-1}$ with $N_{130}$ from 84S soil. Straw yield from sandy clay loam soil, with $N_{145}$ differed non-significantly from the $N_{130}$ treatment, but remained significantly different from the control and other lower rates of N. At 100% SGR, higher N application rates than recommended produced more straw compared to lower rates of N fertilizer. In the clay loam soil, straw yield increased significantly with $N_{130}$ along with gypsum @ 50% and 100 % SGR. Minimum straw yields of 8.5 and 14.5 g pot$^{-1}$ were recorded from the control of 84S and 132S soils, respectively. From both the soils, straw yield was more with 50% SGR compared to 100% SGR. It seems that gypsum @ 50% SGR is sufficient to obtain high paddy and straw yields on marginal salt-affected soils.

***Grain and straw yields of wheat from normal soils*:** Grain yield was significantly ($p < 0.05$) increased with increasing N application rates both for 132N and 84N soils (Fig. 3). The highest grain yield (35.1 g pot$^{-1}$) was recorded with $N_{130}$ in sandy clay loam soil. In clay loam soil, grain yield was highest (28.6 g pot$^{-1}$) with $N_{145}$ but differed from $N_{100}$ and $N_{115}$ treatments ($p > 0.05$). The minimum grain yields (26.3 and 22.2 g pot$^{-1}$) were recorded with the control in the sandy clay loam and clay loam soils, respectively. The grain productivity per kg N applied increased with subsequent cropping cycles, which showed that yield decreased for the control plot, due to a decline in the inherent fertility of the soil (Hari *et al.*, 2008). The grain yield followed the diminishing law of return in clay loam soil, i.e. yield increased but with decreasing trend per unit return. For the sandy clay loam soil, yield decreased beyond $N_{130}$ treatment (Fig. 3). It means that yield reduction is observed under excessive N input due to greater pest incidence, disease damage and lodging. Fertilizer use patterns in the rice-wheat cropping system are region specific and farmers are using more than the recommended levels of N (130 to 195 kg N ha$^{-1}$) in the Trans-Gangetic Plain and in parts of the upper Gangetic Plain in India (Yadav *et al.*, 2000; Sheoran *et al.*, 2004). Recent district wise fertilizer data was collected from Punjab Province of Pakistan by Rashid (2013) also indicated higher N use in the Multan District of Punjab, Pakistan.

Straw yield increased significantly with increasing N application rate (Fig. 3). Maximum straw yield was obtained with $N_{130}$ from both soils while yield was minimal for the control, C. Straw yield of all treatments differed significantly from the control while higher rates of N fertilizer performed better compared to lower rates of N.

***Grain and straw yields of wheat from salt-affected soils*:** Grain yield differed significantly with N application and gypsum rates (Fig. 3). The highest grain yields of 37.1 and 33.2 g pot$^{-1}$ was obtained with $N_{130}$ from a sandy clay loam and clay loam soils, respectively. The higher rates of N along with gypsum @ 100% SGR differed non-significantly ($p < 0.05$) with each other but remained significant from control for 132S soil. At 50% SGR, grain yield for $N_{115}$, $N_{130}$ and $N_{145}$ differed non-significantly from each other but were all significantly different from the control and the other lower rates of N fertilizer. In 84S soil, grain yield for $N_{130}$ and $N_{145}$ were not statistically different, but did differ significantly from other treatments with 50% SGR. The grain yield in $N_{130}$ differed significantly from all the other treatments along with 100% SGR. Grain yield was low (16.5 and 13.6 g pot$^{-1}$) for controls in both 132S and 84S soils, respectively.

In salt-affected soils, the high pH/sodicity of soils adversely affects biological transformations of fertilizer-N by inhibiting enzyme (urease) activity, and $HCO_3^-$ and $CO_3^{2-}$ ions exerting a toxicity effect on N-transferring bacteria (Yaduvanshi and Dey, 2009). The low yield in the control with high SAR might be due to nutritional imbalance and antagonistic effect of $Na^+$ on other nutrients like $K^+$, $Zn^{2+}$, $Ca^{2+}$ (Qadir *et al.*, 2003). Overall, the $N_{130}$ treatment performed better with gypsum @ 100% SGR.

Although rice proved to be a better crop for soil reclamation, wheat produced better grain yield which was attributed to improved physical and chemical properties of soil. As the paddy yield of preceding rice crop was low due to very high EC and SAR of soil at the time of its transplanting (Table 1). The initial high EC and SAR decreased significantly during rice growth, thereby, having a favorable effect on the subsequent wheat crop. Gypsum improved soil infiltration rate which was more beneficial for wheat growth and less beneficial for rice growth. However, economic yields of rice were below the varietal potential (<6 t $ha^{-1}$).

Straw yield increased significantly with increasing N and gypsum application rates (Fig. 3). The highest straw yield (49.7 g $pot^{-1}$ and 59.3 g $pot^{-1}$) was recorded with $N_{130}$ for sandy clay loam and clay loam soils, respectively. With 50% SGR, while straw yield from $N_{130}$ and $N_{145}$ differed non-significantly for each other, straw yield differed significantly from the control and other treatments for 132S and 84S soils. In the clay loam soil, $N_{130}$ along with gypsum at 100% SGR increased straw yield best which differed significantly from all other treatments. The smallest straw yields of 25.1 and 20.5g $pot^{-1}$ were recorded for control treatments for both 132S and 84S soils, respectively.

In 84S and 132S soils, straw yield increased with the percentage of gypsum applied. Saline-sodic soils are known to adversely affect almost all stages of crop growth and development, flowering and fruit set, ultimately causing low economic yields and low quality of the produce (Ashraf and Harris, 2004). Limited success in increasing the yield of crops grown on salt-affected soils seems to be due to a minimal understanding of how salinity and other abiotic stresses affect the most fundamental processes of cellular function – including cell division, differentiation and expansion – which have a substantial impact on plant growth and development (Hasegawa *et al.*, 2000; Zhu, 2001).

***Nitrogen use efficiency during crop growth from normal soils*:** The highest NUE (1.178 and 1.38 g $g^{-1}$) was observed with treatments $N_{115}$ and $N_{130}$ during rice crop from sandy clay loam and clay loam soils, respectively. In comparison, the lowest NUE (0.423 and 0.06 g $g^{-1}$) was observed with treatment $N_{70}$ (Table 2). Nitrogen application above $N_{115}$ decreased NUE due to $NO_3$-N leaching losses. For wheat, the maximum NUE was attained with treatment $N_{130}$ for both soils. In the North-west Indian states of the Punjab, the common practice is to use more N than 150 kg N $ha^{-1}$ to rice which follows wheat, where grain yield of 10-12 t $ha^{-1}$ $annum^{-1}$is obtained from rice-wheat cropping systems. Similar trends in N use (180, 159 and 103 kg N $ha^{-1}$) in the rice-wheat zone of irrigated Haryana, India have also been reported by other workers (Bijay-Singh and Nayyar, 2003; Erenstein *et al.*, 2007).

The NUE was found to be better with 30% higher N rate than recommended in both the normal soils for rice and wheat crops, which implicitly states that N rates in lysimeter seems to be higher than the farm level rates.

***Nitrogen use efficiency during crop growth from salt-affected soils*:** Nitrogen use efficiency was the highest with $N_{145}$ treatment with gypsum applied @ 100% SGR from the sandy clay loam soil during rice crop. This seems because of leaching losses of applied N in submerged soil condition receiving gypsum @ 100% SGR. From clay loam soil, NUE was found to be higher with $N_{130}$ along with gypsum @ 100% SGR than in control. The NUE with $N_{130}$ along with gypsum @ 100% SGR differed non-significantly ($p > 0.05$) with gypsum @ 50% SGR (Table 3). The dose of N is directly related to the yield of the rice crop as the N requirement of rice crop will depend upon the targeted yield (Prasad, 2006) as well as rice type.

The N availability to rice plants is regulated by ion exchange reactions. Using Schofield's ratio law, we investigated whether rice plants grown under flooded soil conditions drive their N solely from the labile pool of ammonium or whether there are other forms of ammonium, which can be utilized.

During wheat crop, the highest NUE was associated with $N_{100}$ along with gypsum @ 100% SGR from 132S and 84S soils. While with 50% SGR, the maximum NUE was associated with $N_{115}$ from the sandy clay loam and with $N_{100}$ for the clay loam soil. This indicates that during the 2nd cropping, NUE was the highest when applying the recommended amount of N together with gypsum @ 100% SGR.

**Table 2. Effect of N treatments on NUE of wheat and rice from normal soils**

| Treatment/Crop | Rice | | Wheat | |
|---|---|---|---|---|
| | **132N[a]** | **84N[b]** | **132N[a]** | **84N[b]** |
| $N_{70}$ | 0.42 | 0.06 | 0.27 | 0.60 |
| $N_{85}$ | 0.46 | 0.09 | 1.26 | 0.58 |
| $N_{100}$ | 0.97 | 0.84 | 2.26 | 1.42 |
| $N_{115}$ | 1.18 | 0.95 | 2.34 | 1.44 |
| $N_{130}$ | 1.18 | 1.38 | 2.59 | 1.79 |
| $N_{145}$ | 1.18 | 0.90 | 2.31 | 1.72 |
| SET* | 0.144 | 0.038 | 0.040 | 0.038 |

*Standard error of treatment means (SET).

[a]Normal soil collected from Village 132 (132N); [b]Normal soil collected from Village 84 (84N).

**Table 3. Effect of N rates and gypsum on NUE during crop growth from salt-affected soils**

| Treatment/Crop | Rice | | Wheat | |
|---|---|---|---|---|
| | 132S | 84S | 132S | 84S |
| Gypsum @ 50% SGR | | | | |
| $N_{70}$ | 0.40 | 0.55 | 4.09 | 2.12 |
| $N_{85}$ | 0.42 | 0.47 | 4.32 | 2.96 |
| $N_{100}$ | 0.33 | 0.54 | 4.08 | 3.70 |
| $N_{115}$ | 0.37 | 0.77 | 4.35 | 3.60 |
| $N_{130}$ | 0.44 | 1.04 | 4.11 | 3.52 |
| $N_{145}$ | 0.53 | 0.77 | 4.02 | 3.30 |
| Gypsum @ 100% SGR | | | | |
| $N_{70}$ | 0.08 | 0.33 | 3.02 | 3.73 |
| $N_{85}$ | 0.29 | 0.80 | 4.14 | 5.18 |
| $N_{100}$ | 0.37 | 0.93 | 4.69 | 5.23 |
| $N_{115}$ | 0.45 | 0.86 | 4.25 | 5.05 |
| $N_{130}$ | 0.49 | 1.04 | 4.67 | 5.09 |
| $N_{145}$ | 0.68 | 0.71 | 3.68 | 4.24 |
| SET[*] | 0.031 | 0.050 | 0.072 | 0.074 |

[*]Standard error of treatment means (SET).
[a]Salt-affected soil collected from Village 132 (132S); [b]Salt-affected soil collected from Village 84 (84S).

**Table 4. Effect of treatments on chemical properties of salt-affected soils (data after the harvest of experiment)**

| **Treatment** | **$pH_s$** | | **$EC_e$ (dS $m^{-1}$)** | | **SAR (mmol $L^{-1})^{1/2}$** | |
|---|---|---|---|---|---|---|
| | **132S** | **84S** | **132S** | **84S** | **132S** | **84S** |
| Gypsum @ 50% SGR | | | | | | |
| $C_g$ | 8.61 b-e | 8.11 a-d | 7.22 b | 4.98 c | 23.33 b | 19.34 b |
| C | 8.75 abc | 8.19 ab | 8.10 a | 5.91 a | 34.45 a | 24.76 a |
| $N_{70}$ | 8.83 a | 8.22 a | 7.01 c | 5.22 b | 22.00 c | 19.12 b |
| $N_{85}$ | 8.77 ab | 8.05 cde | 6.51 e | 5.21 b | 21.13 d | 17.68 de |
| $N_{100}$ | 8.61 b-e | 8.07 bcd | 6.49 e | 4.88 cde | 19.81 e | 17.64 de |
| $N_{115}$ | 8.57 b-e | 8.05 cde | 6.44 ef | 4.71 e | 18.19 g | 17.46 e |
| $N_{130}$ | 8.54 de | 8.03 cde | 5.34 h | 4.01 g | 15.31 I | 13.10 h |
| $N_{145}$ | 8.70 a-d | 7.87 fg | 5.30 h | 4.06 j | 15.91 j | 12.90 h |
| Gypsum @ 100% SGR | | | | | | |
| $C_g$ | 8.60 b-e | 8.02 cde | 6.98 c | 4.88 cd | 21.19 d | 18.33 c |
| C | 8.75 abc | 8.19 ab | 8.10 a | 5.91 a | 34.45 a | 24.76 a |
| $N_{70}$ | 8.67 a-d | 8.13 abc | 6.78 d | 5.19 b | 18.90 f | 17.98 cd |
| $N_{85}$ | 8.60 b-e | 7.93 ef | 6.30 fg | 5.01 c | 18.86 f | 17.00 f |
| $N_{100}$ | 8.56 cde | 7.93 efg | 6.27 fg | 4.72 de | 18.09 g | 16.29 g |
| $N_{115}$ | 8.53 de | 8.00 de | 6.20 g | 4.34 f | 17.41 h | 15.92 g |
| $N_{130}$ | 8.51 de | 7.80 g | 5.19 h | 3.92 g | 14.13 k | 12.19 I |
| $N_{145}$ | 8.45 e | 7.66 h | 5.20 h | 3.93 g | 14.10 k | 11.92 I |
| LSD | 0.20* | 0.12* | 0.18* | 0.17* | 0.43* | 0.42* |

The differences of rice and wheat responses could be attributed to relatively high SAR tolerance of rice than wheat but high salinity tolerance of wheat than rice. Now it seems appropriate to conclude that rice as a first crop during soil reclamation using gypsum @ 100% SGR needs higher N than recommended but this will contaminate the lower soil horizon or even ground water. Nitrogen along with gypsum @ 50% and 100% SGR, elevated the $Ca^{2+}$ levels in soils, which protected the plant from NaCl toxicity by reducing the displacement of membrane associated $Ca^{2+}$ (Cramer *et al.*, 2006). This could be due to improvements in soil properties, i.e. $EC_e$ and SAR decreased from 9.94 to 6.27 dS $m^{-1}$ and 44.06 to 18.09 (mmol $L^{-1})^{1/2}$ for 132S soil, while for 84S soil 6.86 to 4.72 dS $m^{-1}$ and 28.70 to 16.29 (mmol $L^{-1})^{1/2}$, respectively (Table 4).

Fisher (2011) reported that higher rates of N along with gypsum amendment significantly improved the NUE. Khan *et al*. (2010) concluded that application of gypsum improved the physical conditions of saline-sodic/ sodic calcareous soils and enhanced the root development and proliferation. Resultantly, uptake of N and other nutrients increased. Arshad (2012) pointed out that addition of gypsum increased the grain yield by decreasing $NH_3$ volatilization which decreased soil pH. Similar results were reported by Choudhury and Kennedy (2005) who concluded that addition of $Ca^{2+}$ salts to urea decreased $NH_3$ volatilization by as much as 90%.

***Conclusions*:** Our data showed that with higher rates of N fertilizer ($N_{130}$ and $N_{145}$) together with gypsum application, paddy yield was decreased in salt-affected soils during reclamation compared to normal soils. However, during the second crop (wheat), grain yield from salt-affected soils became comparable to normal soils with the use of higher rates of N fertilizer ($N_{130}$ and $N_{145}$) together with gypsum application. The NUE was the highest when applying the recommended N fertilizer along with gypsum at 100% SGR from a sandy clay loam and clay loam soils for wheat crop. The results from this study are beneficial in improving the long-term NUE and (rice-wheat) crop productivity in the salt-affected soils; the farmers could use judiciously N fertilizer for optimum crop production under salt-affected soil conditions with rice-wheat crop rotation.

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**REFERENCES**

Abbas, S.T., M. Sarfraz, S.M. Mehdi, G. Hassan and Obaid-Ur-Rehman. 2007. Trace elements accumulation in soil and rice plants irrigated with the contaminated water. Soil Till. Res. 94:503-509.

Economic Survey of Pakistan. 2005. Agricultural Statistics of Pakistan (2004-05). Ministry of Food, Agriculture and Livestock, Government of Pakistan, Islamabad, Pakistan.

Arshad, M. 2012. Nitrogen nutrition management and fertilizer use efficiency in wheat under different soil conditions. Ph.D. Thesis. Dep. Biol. Sci., Quaid-i-Azam University, Islamabad, Pakistan.

Ashraf, M. and P. Harris. 2004. Potential biochemical indicators of salinity tolerance in plants. Plant Sci. 166:3-16.

Ashraf, M., H. Athar, P. Harris and T. Kwon. 2008. Some prospective strategies for improving crop salt tolerance. Adv. Agron. 97:45-110.

Aslam, M. 1998. Waterlogging and salinity management in the Sind Province, Pakistan. Supplement IA: Improved water management practices for the rice-wheat cropping systems in Sindh Province, Pakistan IWMI, Lahore, Pakistan.

Baker, J. and H. Johnson. 1981. Nitrate-nitrogen in tile drainage as affected by fertilization. J. Environ. Qual. 10:519-522.

Bedaiwy, M.N.A. 2012. A simplified approach for determining the hydrometer's dynamic settling depth in particle-size analysis. Catena. 97:95-103.

Bijay-Singh, Y.S. and V. Nayyar. 2003. Rice-wheat cropping systems in the Indo-gangetic plains of India: Characteristic features, fertilizer use and nutrient management issues. Nutrient management for sustainable rice-wheat cropping system. Nat. Agric. Tech. Project, Indian Coun. Agric. Res., New Delhi, India and Punjab Agric. Univ., Ludhiana, Punjab, India, pp 1-17.

Boix-Fayos, C., A. Calvo-Cases, A. Imeson and M. Soriano-Soto. 2001. Influence of soil properties on the aggregation of some Mediterranean soils and the use of aggregate size and stability as land degradation indicators. Catena. 44:47-67.

Bronick, C.J. and R. Lal. 2005. Soil structure and management: A review. Geoderma 124:3-22.

Cha-um, S., Y. Pokasombat and C. Kirdmanee. 2011. Remediation of salt-affected soil by gypsum and farmyard manure: Importance for the production of Jasmine rice. Aust. J. Crop Sci. 5:458-465.

Choudhury, A.T.M.A. and I.R. Kennedy. 2005. Nitrogen fertilizer losses from rice soils and control of environmental pollution problems. Comm. Soil Sci. Plant Anal. 36:1625-1639.

Cramer, G.R., E. Epstein and A. Laouchli. 2006. Effects of sodium, potassium and calcium on salt stressed barley. I. Growth analysis. Physiol. Plant. 80:83-88.

Erenstein, O., U. Farooq, R.K. Malik and M. Sharif. 2007. Adoption and impacts of zero tillage as a resource conserving technology in the irrigated plains of South Asia. Colombo, Sri Lanka: Int. Water Manag. Inst. 55p. (Comprehensive Assessment of Water Management in Agriculture Research Report 19).

Fang, Q., L. Ma, Q. Yu, R. Malone, S. Saseendran and L. Ahuja. 2008. Modeling nitrogen and water management effects in a wheat-maize double-cropping system. J. Environ. Qual. 37:2232-2242.

Fisher, M. 2011. Amending soils with gypsum. Crops and Soils Magazine. Am. Soc. Agron. pp. 4-9.

Ghafoor, A., M. Qadir and G. Murtaza. 2004. Salt-Affected Soils: Principles of Management. Allied Book Centre, Urdu Bazar, Lahore, Pakistan.

Gharaibeh, M.A., N.I. Eltaif and O.F. Shunnar. 2009. Leaching and reclamation of calcareous saline-sodic soil by moderately saline and moderate SAR water using gypsum and calcium chloride. J. Plant Nutr. Soil Sci. 172:713-719.

Hadjidemetriou, D. 1982. Comparative study of the determination of nitrates in calcareous soils by the ion-selective electrode, chromotropic acid and phenoldisulphonic acid methods. Analyst. 107:25-29.

Hansen, E.M. and J. Djurhuus. 2007. Nitrate leaching as affected by long term N fertilization on a coarse sand. Soil Use Manage. 12:199-204.

Hari, O., R.S. Chauhan, R.K. Malik, V.P. Singh, Dilbag Singh, O.P. Lathwal, S.P. Goyal, S.K. Yadav and Sher Singh. 2008. Diversification through Farming System Approach. Technical Bulletin (30), KrishiVigyan Kendra, Kurukshetra and Directorate of Extension Education, CCS Haryana Agricultural University, Hisar, India.

Hasegawa, P.M., R.A. Bressan, J.K. Zhu and H.J. Bohnert. 2000. Plant cellular and molecular responses to high salinity. Ann. Rev. Plant Biol. 51:463-499.

Islam, Z., B. Bagchi and M. Hossain. 2007. Adoption of leaf color chart for nitrogen use efficiency in rice: Impact assessment of a farmer-participatory experiment in West Bengal, India. Field Crops Res. 103:70-75.

Katerji, N., M. Mastrorilli, J. Van Hoorn, F. Lahmer, A. Hamdy and T. Oweis. 2009. Durum wheat and barley productivity in saline-drought environments. Eur. J. Agron. 31:1-9.

Khan, M.J., M.T. Jan, A.U. Khan, M. Arif and M. Shafi.2010. Management of saline sodic soils through cultural practices and gypsum. Pak. J. Bot. 42:4143-4155.

Lodhi, A., M. Arshad, F. Azam, M. Sajjad and M. Ashraf. 2009. Changes in mineral and mineralizable N of soil incubated at varying salinity, moisture and temperature regimes. Pak. J. Bot. 41:967-980.

Loveday, J. 1974. Methods for analysis of irrigated soils. Tech. Commun. no. 54. Commonwealth Agric. Bur., Farnham Royal, UK.

Makoi, J. and H. Verplancke. 2010. Effect of gypsum placement on the physical and chemical properties of a saline sandy loam soil. Aust. J. Crop Sci. 4:556-563.

Moradi, F. and A.M. Ismail. 2007. Responses of photosynthesis, chlorophyll fluorescence and ROS-scavenging systems to salt stress during seedling and reproductive stages in rice. Ann. Bot. 99:1161-1173.

Murtaza, G. 2011. Optimization of nitrogen use-efficiency in rice-wheat cropping system on tile drained salt-affected soils with different textures. First Annual Technical Progress Report for Higher Education Commission (HEC) funded project (July 2010 to June 2013). Inst. Soil Environ. Sci., Univ. Agric., Faisalabad, Pakistan.

Murtaza, G., N. Hussain and A. Ghafoor. 2000a. Growth response of rice (*Oryza sativa* L.) to fertilizer nitrogen in salt-affected soils. Int. J. Agric. Biol. 2:204-206.

Murtaza, G., A. Ghafoor, M. Qadir and S. Muhammed. 2000b. Charge characteristics of soils as affected by pH and neutral electrolytes. J. Indian Soc. Soil Sci. 48:433-437.

Murtaza, G., A. Ghafoor and M. Qadir. 2006. Irrigation and soil management strategies for using saline-sodic water in a cotton-wheat rotation. Agric. Water Manag. 81:98-114.

Murtaza, G., A. Ghafoor, G. Owens, M. Qadir and U.Z. Kahlon. 2009. Environmental and economic benefits of saline-sodic soil reclamation using low quality water and soil amendments in conjunction with a rice-wheat cropping system. J. Agron. Crop Sci. 195:124-136.

Oad, F., Z. Abro, A. Siyal, N. Oad and A. Siyal. 2002. Water depletion effects on water infiltration rate, salt behavior, and leaching requirements in saline soil. Pak. J. Appl. Sci. 2:351-354.

Prasad, R. 2006. Nitrogen uptake pattern as a guide for nitrogen application practices in rice. Ind. J. Fert. 2:39-41.

Qadir, M., D. Steffens, F. Yan and S. Schubert. 2003. Proton release by $N_2$ fixing plant roots: A possible contribution to phytoremediation of calcareous sodic soils. J. Plant Nutr. Soil Sci. 166:14-22.

Qadir, M., A. Noble, S. Schubert, R. Thomas and A. Arslan. 2006. Sodicity-induced land degradation and its sustainable management: Problems and prospects. Land Degrad. Dev. 17:661-676.

Rashid, M. 2013. Synthesis of available fertilizer trials data for site-specific recommendations and diagnostic survey for low adoption of fertilizer use technology. Available at http://www.fertilizeruaf.pk/User/About.aspx.

Sairam, R. and A. Tyagi. 2004. Physiology and molecular biology of salinity stress tolerance in plants. Curr. Sci.-Bangalore. 86:407-421.

Sheoran, P., K. Singh, R. Malik and M. Kumar. 2004. Comparative performance of leaf color chart with other nitrogen scheduling practices. Int. Rice Res. Not. 29:60-61.

Singh, S., R. Malik, J. Dhankar, R. Garg, P. Sheoran, A. Yadav and B. Kamboj. 2011. Survey of nitrogen use pattern in rice in the irrigated rice-wheat cropping system of Haryana, India. J. Environ. Biol., Acad. Environ. Biol. Ind. 32:43-49.

Steel, R.G.D., J.H. Torrie and D.A. Dickey. 1997. Principles and Procedures of Statistics: A Biometrical Approach. McGraw Hill Book Co. Inc. New York.

Tejada, M., C. Garcia, J. Gonzalez and M. Hernandez. 2006. Use of organic amendment as a strategy for saline soil remediation: Influence on the physical, chemical and biological properties of soil. Soil Biol. Biochem. 38:1413-1421.

Thitisaksakul, W.P. and Maysaya. 2008. Effect of salinity stress on growth and carbohydrate metabolism in three rice (*Oryza sativa* L.) cultivars differing in salinity tolerance. Ind. J. Exp. Biol. 46:736-742.

Wang, H., Z. Wu, Y. Zhou, J. Han and D. Shi. 2012. Effects of salt stress on ion balance and nitrogen metabolism in rice. Plant Soil Environ. 58:62-67.

Wong, V.N., R.C. Dalal and R.S. Greene. 2009. Carbon dynamics of sodic and saline soils following gypsum and organic material additions: A laboratory incubation. Appl. Soil Ecol. 41:29-40.

Woyema, A., G. Bultosa and A. Taa. 2012. Effect of different nitrogen fertilizer rates on yield and yield related traits for seven Durum Wheat (*Triticumturgidum* L. var Durum) cultivars grown at Sinana, South Eastern Ethiopia. Afr. J. Food Agric. Nutr. Dev. 12: 6079-6094.

Yadav, J.S.P. and G.B. Singh. 2000. Natural resource management for agricultural production in India. Int. Conf. on Managing Natural Resources for Sustainable Agri. Production in the 21st Century. 14-18 February, 2000. Indian Soc. of Soil Sci., New Delhi, India.

Yaduvanshi, N. and P. Dey. 2009. Nutrient management in sodic soils. p. 84-108. In: G. Singh, A. Qadar, N.P.S. Yaduvanshiand and P. Dey (eds.). Enhancing nutrient use efficiency in problem soils. Central Soil Salinity Res. Inst. Karnal, New Delhi, India.

Zeng, L., M.C. Shannon and S.M. Lesch. 2001. Timing of salinity stress affects rice growth and yield components. Agric. Water Manag. 48:191-206.

Zhou, S.L., Y.C. Wu, Z.M. Wang, L.Q. Lu and R.Z. Wang. 2008. The nitrate leached below maize root zone is available for deep-rooted wheat in winter wheat summer maize rotation in the North China Plain. Environ. Poll. 152:723-730.

Zhu, J.K. 2001. Plant salt tolerance. Trends Plant Sci. 6:66-71.

Zia, M.S., F. Hussain, M. Aslam, N. Hashmi and A. Hameed. 2002. Integrated plant nutrition system for sustainable rice-wheat cropping sequence. Int. J. Agric. Biol. 4:175-182.