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# MANAGEMENT OF SALINE SODIC SOILS THROUGH CULTURAL PRACTICES AND GYPSUM

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**Abstract**

Management of saline sodic soils requires combination of agronomic practices in addition to the chemical and organic amendments. However, the relative efficiency of the amendments under variable cultural practices is not well documented. We evaluated the efficiency of gypsum, farmyard manure (FYM) and cultural practices on the yield and yield components of wheat grown in saline-sodic soil during Rabi 2003-04. The soil under study was clay loam in texture containing 0.17% organic matter with 20.5% lime content and alkaline in reaction ($pH_e$ 8.8). The electrical conductivity ($EC_e$) was 9.4 dS $m^{-1}$ with sodium adsorption ratio (SAR) of 21.4. Seven treatments viz., conventional method, Flat bed + FYM, Flat bed + Gypsum, Raised bed + FYM, Raised bed + Gypsum, Ridges + FYM, and Ridges + Gypsum were arranged in RCB design with three replications. Gypsum was applied at variable rates dependent upon the gypsum requirements of the soil, while FYM was applied @ 20 t $ha^{-1}$. Significant improvement in soil properties i.e., $EC_e$, SAR and $pH_e$ was recorded in plots treated with gypsum in ridges and resulted 42% grain yield increase over conventional method. The significantly higher grain yield (3055 kg $ha^{-1}$) may be associated with ameliorative effect of gypsum and less saline environment in ridges as irrigation next to the seed row caused movement of salts away from the seeds and into the top of the ridge. This allowed the seed to germinate and establish in less saline conditions there by increasing yield. The lowest grain yield (1781 kg $ha^{-1}$) of wheat was produced in plots grown by conventional method. The soil samples analyzed after the termination of experiment showed that gypsum + ridges sown treatment significantly reduced the soil ECe, SAR and pHe at 0-15 and 15-30 cm soil depths as compared to conventional method. There was a positive significant relation between wheat grain yield with leaf $K^+$ ($r^2$=0.70) while negative significant relationship between the grain yield with leaf $Na^+$ ($r^2$=0.745). This study suggests that wheat grown on ridges supplied with gypsum was the most useful management tool in saline-sodic conditions

## Introduction

The distribution of saline sodic and sodic soils on more than half a billion hectare worldwide, warrants attention for their efficient, economical and environmentally acceptable management practices. Based on the FAO/UNESCO Soil Map of the world, the total area of saline soils is 397 million ha and that of sodic soils is 434 million ha, which are not necessarily arable but cover all salt affected lands at global level. Most of the salt affected land lies in the arid and semiarid environment. In Pakistan alone, out of 22 Mha cultivated land, 6.28 Mha is affected by salinity at variable level. Between 2 to 3 Mha are categorized as wasteland due to high salinity and sodicity (Qureshi *et al*., 1993) but could be brought under cultivation by harnessing available water resources, improved water management, better cultivation techniques and better adopted crop varieties. The development of agricultural technologies for the degraded soils and the appreciation of the existing but under utilized knowledge of resource management will be crucial in meeting the food demand of the ever growing population in future particularly in developing countries. Salinity and sodicity has been recognized as a major process of land degradation. It was estimated from various available data (Anon., 1993) that the world is losing at least three hectares of arable land every minutes because of salinity.

Saline sodic soils are characterized by the occurrence of appreciable amount of sodium (Na+) and usually associated with high levels of both pH soluble salts (Abrol *et al*., 1988). The excessive amount of the soluble salts and exchangeable Na+ has profound negative impact on chemical and physical properties of soils and plant growth. Detail discussions of the salinity sodicity on plant growth are available (Abrol *et al*., 1988; Maas & Hoffman 1977; Pearson 1960).

Management of the salt affected soils requires a combination of agronomic practices depending on chemical amendments, water quality and local conditions including climate, crop economic political and cultural environments and existing farming system. There is usually no single way to control salinity problems in irrigated agriculture. However, several practices can be combined into integrated system that functions satisfactorily (Mashali, 1995).

Studies in the past have compared the effectiveness of various amendments at improving the physical and chemical properties of saline sodic and sodic soils (Amezketa *et al*., 2005; Hanay *et al*., 2004; Mace *et al*., 1999; Khan, 1992). The relative effectiveness of gypsum and sulfuric acid has received the most attention because they are widely used as reclamation amendments. Most recently, crops or crops residues and synthetic polymers have been included in efficiency studies (Hanay *et al*., 2004; Zahow & Amrhein 1992). Gypsum is mainly blamed for its slow reaction but much popular due to its low cost and availability. One of the major shortcomings in gypsum use is its application at uniform rates, which lower its efficiency because of the special variability under the salt affected soil conditions. The efficiency can be increased if applied at variable rates according to the gypsum requirements of the soil but again it needs extra analysis that may not be economical in some cases.

The significance of organic matter has been proven through its effect on improving the physical conditions of soils for crop growth besides its role as fertilizers. Various organic amendments such as manure and compost have been investigated for their effectiveness of reclamation of saline sodic soils (Diez & Krauss 1997; Wahid *et al*., 1998). In general, the additions of organic amendments alone have very little effect on reclaiming saline sodic or sodic soils. However, there effectiveness in improving the physical properties is well documented in literature (Ibrahim & Shindo 1999; Mamo *et al*., 2000; Naeni & Cook 2000).

The agronomic practices have not been well documented in the literature. The raised –bed technology has been shown to be particularly valuable on low permeable soils subject to water logging and salinity and in areas short of irrigation water supply (Qureshi & Aslam, 1988), although unsuited to well drain soils. Shafiq *et al*., (2001) reported 68% yield advantage of summer-sown maize on sodic soil on raised bed compared to flat bed soils. The raised bed produced a better root environment, reducing water logging and increasing irrigation efficiencies. Our objective was to compare the effects of variable gypsum rate and farm yard manure under different sowing techniques on the growth and yield of wheat and reclamation of saline sodic soil. Additionally an effort was made to apply the gypsum at variable rates i.e., according to gypsum requirements instead of uniform application. The inclusion of cultural practices was due to the waterlogging problem after irrigation or heavy rainfall events.

## Materials and Methods

The experiment was conducted on farmer's field located in Kot Kashmir village of Lakki Marwat district of North West Frontier Province in Pakistan during Rabi 2003-4. The soil is classified as saline-sodic fine loamy calcareous, haplargid. Composite soil sample was collected before the initiation of experiment which reveals that the soil of the experimental site was clay loam in texture containing 0.17% organic matter with 20.5% lime content and alkaline in reaction ($pH_e$ 8.8). The electrical conductivity ($EC_e$) was 9.4 dS $m^{-1}$ with sodium adsorption ratio (SAR) of 21.4.

The seven treatment included an untreated control i.e., conventional method (T1), flat bed + FYM (T2), flat bed + gypsum (T3), raised bed + FYM (T4), raised bed + gypsum (T5), ridge + FYM (T6) and ridge + gypsum (T7). The experiment was arranged in RCB design with three replications. The plot size was 10 x 9 m.

Before the initiation of experiment, the experiment layout was made and soil samples were collected from each treatment plots for the gypsum requirement. The gypsum requirements varied from 8.5-to 15.3 t $ha^{-1}$ (30 cm soil depth) (Table 1). After randomization, the plots assigned to gypsum treatments were treated with gypsum according to gypsum requirements equal to the amount given in the table (figures with bold face in the Table 1). Gypsum (70% pure, 2 mm mesh size) was applied one month before the crop sowing. Gypsum was surface applied through broadcasting and was thoroughly mixed with soil. A well-decomposed FYM (two year old heap consisting of animal manure, wheat and sorghum straw) was also applied a month before crop growing at the rate of 20 tons $ha^{-1}$. Both gypsum and FYM were mixed with soil and irrigated. Ridges (cone shaped) were formed with the help of ridger that were 46 cm high and 30 cm apart. Raised beds were formed manually with 50 cm height and 46 cm flat top. Two rows of seed were sown on the top of the bed. Conventional method was included as a control plot that was treated as the practices followed by farmers in the locality. A basal dose of N P & K @ 120, 90 and 60 kg $ha^{-1}$ as urea, DAP and $K_2SO_4$ was applied, respectively. The full dose of P and K and half of N was applied at the time of sowing and remaining half of N was applied at knee-high stage of wheat. Before crop sowing, the seedbed was deeply ploughed with disc plough and twice with rotavator.

The seeds of wheat variety Bakhtawar- 2000 were sown @ 110 kg $ha^{-1}$ at the end of October 2003. All the plots were irrigated five times using tube-well water (EC = 1.7 dS $m^{-1}$) while strong partitions were made to separate main plots to avoid the over flow of irrigation water.

**Yield data collection:** Data on crop yield parameters like total grain yield (kg $ha^{-1}$), biological yield (kg $ha^{-1}$), thousand grain weight (g), number of tillers $m^{-2}$ and number of grains $spike^{-1}$ was collected during crop growth and after harvesting. The yield and yield parameter data was collected from the entire plot and the calculations were made on hectare basis.

**Table 1. Gypsum requirement (t ha$^{-1}$ -30cm soil depth).**

| Treatment No. | R1 | R2 | R3 |
|---|---|---|---|
| 1 | 11.0 | 12.7 | **12.2** |
| 2 | 8.5 | **11.8** | 12.7 |
| 3 | **10.2** | 9.3 | **11.0** |
| 4 | 11.8 | 10.2 | 11.8 |
| 5 | **11.0** | 11.0 | 12.7 |
| 6 | 9.3 | 11.0 | 10.2 |
| 7 | 10.2 | **14.4** | 15.3 |

**Soil sampling and analysis:** The composite sample collected before the experimental set up was air dried ground with the help of wooden mortar and then passed through 2 mm sieve. Textural analysis was performed using the hydrometer method (Gee & Bauder, 1986). Soil pH and EC were determined in soil extract (Richard, 1954). Organic matter content was determined by method of Nelson & Sommer (1982). Lime content was determined by acid neutralization method (Black, 1965). Sodium Adsorption Ratio (SAR) and gypsum requirements (GR) were determined following USDA HB 60 (Richard, 1954). Soil samples were also collected from 0-30 cm soil depths from each treatment at three different intervals i.e., at the time of sowing wheat crop, knee high stage and after wheat harvesting and analyzed for EC, SAR and pH.

**Leaf sampling and analysis:** Third fully matured leaves were collected from each treatment plants. Before analysis, the plant materials were washed twice with distilled water to clean it from dirt and dust. After air-drying, the leaf samples were oven dried for 24 hours at 70$^{o}$C, grounded and stored for analysis. Wet digestion method ($HNO_3$ + $HCLO_4$) was followed to determine the leaf tissue concentrations of Sodium ($Na^+$) and Potassium ($K^+$). Sodium and Potassium were determined by flame photometer (Richard, 1954).

**Statistical analysis:** The data collected was subjected to statistical analysis following ANOVA technique and treatment differences were differentiated using LSD test (Steel & Torrie, 1980).

## Results and Discussion

**Chemical properties of soil:** The results of $EC_e$, SAR and $pH_e$ analyzed at three different times are given in Fig. 1 (a, b and c respectively). The results of sowing time (28 days after treatment application) showed that EC, SAR and pH were above the set criteria of US Salinity Laboratory values (Richard, 1954) and the soil fall in the category of saline sodic. The soil under test was lying barren from the last 15-20 years. As was expected, there were no significant variation in any salinity parameters and the data is presented for the comparison purpose. The non-significant variations are due to spatial soil variability.

The soil $EC_e$, SAR and $pH_e$ in samples collected at the crop knee high stage (two months after sowing) remained statistically non significant and were similar to sowing time in all the treatments. The reclamation effect of the treatments was statistically non significant. The non-significant variation may be due to a short period of time whereby leaching was not accomplished. Murtaza *et al*., (1996) Mahmood *et al*., (2001) and Hussain *et al*., (1993) also noted non-significant variations due to the addition of amendments on the salinity parameters.

The results of soil samples collected after harvesting the crop showed that the differences among various treatments for lowering soil ECe, SAR and pHe were statistically significant. Maximum reduction in EC (52%) was noted in T7 (Fig. 1a) that was comparable with T6 but significantly ($p \leq 0.005$) lower than all other treatments. This decrease might be the result of improved infiltration due to better seedbed preparation and gypsum addition. However, this trend was not true in the plots receiving the addition of FYM. There were no changes in EC in plots sown by either conventional method or plots sown on flat bed regardless of the addition of amendments. Similar to the ECe, the soil SAR was significantly affected by the addition of amendments and cultural practices. Minimum soil SAR was noted in T7 (ridges + gypsum) that was 46% lower (Fig. 1b) compared to control plots. The post harvest pH was also significantly reduced by the different treatment and again T7 was more effective than all other treatments.

From these results it can be seen that gypsum applied to plots ridges was effective in lowering the chemical parameters that might be due to substitution of exchangeable Na by Ca that produced more soluble salts (NaCl, or $Na_2SO_4$) and was leached by the irrigation water (Lebron *et al.*, 1994; Robbins, 1986). The leaching of salts beyond the root zone might have been facilitated by the formation of ridges while the same might have happened in the flat beds or raised bed but the leaching of salt may be incomplete. The superiority of gypsum application over organic amendments has also been reported by Hanay *et al.*, (2004) however; in their study it was found that application of gypsum alone, beyond its ability to improve soil chemical properties worsen the physical properties of soil. Various organic amendments such as mulch, manures and compost have been investigated for their effectiveness on remediation of saline sodic soils (Diez & Krauss1997, Wahid *et al.*, 1998). In general, organic amendments have a very little effect on improving soil salinity and sodicity when they are applied alone (Madejone *et al.*, 2001). On the other hand, its effectiveness in improving many soil physical properties is well documented in literature (Ibrahim & Shando 1999; Mamo *et al.*, 2000; Naeini & Cook 2000; Hanay *et al.*, 2004). The effectiveness of ridge sowing method on lowering the EC and SAR is reported by Shafiq *et al.*, (2000) & Khan *et al.*, (2004).

**Wheat growth characteristics**

**Number of tillers $m^{-2}$:** Number of tillers in wheat is one the most important yield component that is adversely affected by salts in soil. The results of the present investigations revealed that there were significant ($p \leq 0.05$) differences in number of tillers $m^{-2}$ among treatments (Table 2). Maximum counts (396) for number of tillers $m^{-2}$ were noted in plots receiving gypsum and where ridges were formed that was 23% higher than the plots sown by conventional method. There were no significant differences in number of tillers on ridges supplemented with FYM. The reason of more tillers on ridges may be the results of low saline environment and the ameliorative effect of amendments. However, this trend was not observed in flat bed and raised bed amendment plots. The reason of fewer tillers on flat bed may be due to high salinity while on raised bed the apparent reason seems to be that there were fewer plants in one square meter area because only two rows were sown on the top of the ridge which were 23 cm apart while in case of ridges, the distance between row to row was only 15 cm. The superiority of ridge sowing method over flat bed and furrow method has been reported by Khan *et al.*, (1988) and Khan *et al.*, (2001). Aslam *et al.*, (1995) reported the interactive effect of salinity and hypoxia on wheat and found significant reduction in number of tillers due to the combined stress. It was further concluded from these results that there were no significant differences with respect to the addition of either gypsum or FYM (El-Maghra *et al.*, 1996; Mitchell *et al.*, 2000 and Mushtaq *et al.*, 2001).

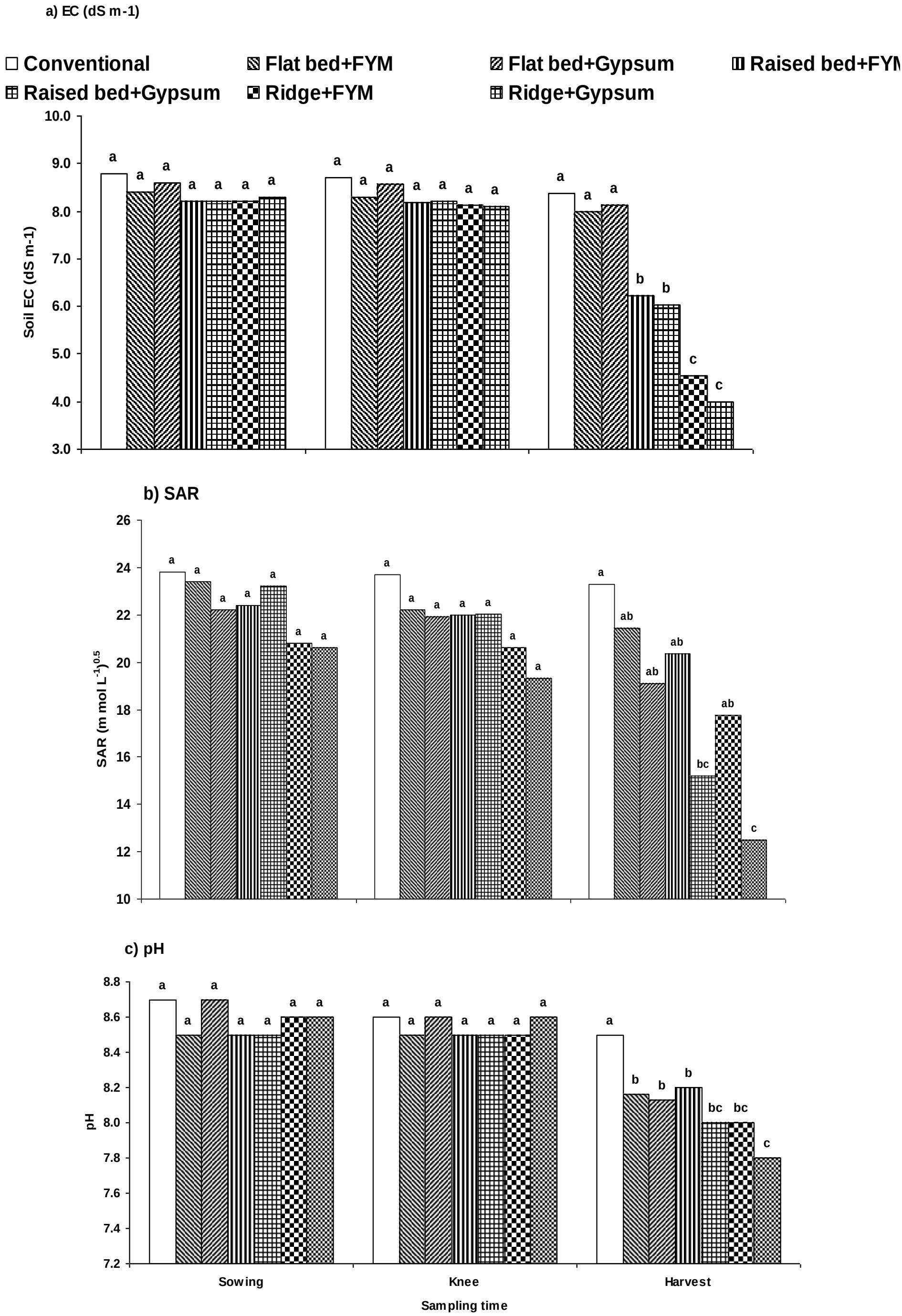


Fig 1. Changes in chemical properties of soils with time as influenced by treatments.

**Table 2. Yield components of wheat as affected by different treatments.**

| No. | Treatment | Tillers $m^{-2}$ | Grains $spike^{-1}$ | 1000-grain wt. (g) |
|---|---|---|---|---|
| 1. | Conventional method | 304.0 d | 42.6 e | 27.3 e |
| 2. | Flat bed + FYM | 310.6 d | 50.3 cd | 29.3 ef |
| 3. | Flat bed + Gypsum | 338.3 c | 49.0 d | 30.0 de |
| 4. | Raised bed + FYM | 344.6 c | 52.6 c | 32.0 cd |
| 5. | Raised bed + Gypsum | 379.6 b | 52.0 c | 33.3 bc |
| 6. | Ridges + FYM | 392.6 a | 56.3 b | 35.0 b |
| 7. | Ridges + Gypsum | 396.0 a | 67.6 a | 40.0 a |
| | LSD value at 5% | 9.90 | 2.817 | 2.054 |

Means of the same categories sharing same letters are statistically non significant at 5% level of probability.

**Number of grains $spike^{-1}$:** Analysis of variance regarding number of grains $spike^{-1}$ exhibited the same trend as noted for number of tillers (Table 2) and the results were significant ($p \leq 0.05$). Higher counts (67.6) of grains $spike^{-1}$ were recorded in the ridge + gypsum sown plots, while the lowest (42.6) counts were noted in the plots sown by conventional method (Table 7). The highest number of grains $spike^{-1}$ was due to low salt concentration in root zone of the crop providing the crop essentially less saline environment in the root as shown by the post harvest value of ECe and SAR in Table 2. This is in agreement with results obtained earlier (Boeam *et al*., 1994). Further more, gypsum application proved better than FYM on ridges while on raised and flat bed sown plots, the effect of either amendments was comparable.

**Thousand grain weight:** The data in the Table 2 shows 1000-grain weight as affected by different treatments. The significantly ($p \leq 0.05$) higher (40 g) 1000-grain weight was obtained from ridges + gypsum followed by ridges + FYM and the lowest (27 g) was noted in plots sown by the conventional method. The reason of highest 1000 grain weight at ridge + gypsum was due to its effect on lowering the SAR and ECe of the soil.

**Grain yield (kg $ha^{-1}$):** Grain yield was significantly ($p \leq 0.05$) influenced by different cultural practices and amendments (Fig. 2). The highest grain yield (3055 kg $ha^{-1}$) was obtained from the plots sowing on ridges and amended with gypsum (T7) followed by plots on ridge sowing supplemented with FYM (T6). The increase in yield by T7 and T6 over conventional sowing method (T1) was 42 and 32% respectively. Lowest yield of 1781 kg $ha^{-1}$ was obtained form T1 but statistically comparable with flat bed sown plot regardless of the gypsum or FYM application. The grain yield obtained from raised bed amended plots was better than flat bad and conventional method but significantly lower than ridge sowing method. The increase in yield on the ridges supplemented with gypsum may be due to ameliorative effect of gypsum that lowers the SAR and ECe. The FYM treatment was not as affective as gypsum that might be due to either low rate of FYM or it may need sufficient time to improve the physical properties of soil for better growth (Bhagwandin & Bhatia, 1980; Khan *et al*., 1988; Singh & Agarwal, 1994; Khan *et al*., 2000). By comparing the ridges with raised bed, it can be seen that ridges were more effective than raised bed. By visual observation of the treatment plots, we found that the crop stand on raise bed was much better but there was a wide gap between the rows on raised bed (only two rows were sown). Thus the total area harvest was less than the area harvest from ridges. Earlier study (Shafiq *et al.*, 2001a, b) reported 68% maize yield advantage after sowing on raised bed compared to conventional method but their study did not include ridges. Vyn *et al.*, (1990) reported inconsistent response of maize when grown on ridges for three consecutive years. This inconsistent response may be the results of maize sensitivity to salinity levels and the variation of salinity over a three years period. In the words of Russel Thomson (Australia Salt Magazine Issue No.7) “A few years ago if any one had mentioned raised bed, I would have thought they were talking about fashion in furniture. But now, I see the raised bed as one of the best idea that turn salt affected waterlogged country into good cropping land. However, in our case it was true for ridges and not for the raised bed.

**Concentration of $Na^+$, $K^+$ and $K^+$:$Na^+$ ratio in wheat leaf:** Both $Na^+$ and $K^+$ concentration in leaves varied significantly ($p \leq 0.05$) with sowing methods and amendments applied. The highest (421.7 mmol $kg^{-1}$) amount of $Na^+$ was accumulated by leaves when sown by conventional method and the lowest value (95.67 mmol $kg^{-1}$) was noted in ridge + gypsum sown plot (Table 3). The opposite trend of K accumulation was noted being maximum in the ridge + gypsum sown plots and minimum in leaves collected from the plot sown by conventional method (Table 3). This may be the possible reason of superiority of ridge sown crop over rest of the methods in saline sodic soils and which provide plausible explanation to the better yield and yield parameters under ridge sowing supplemented with gypsum. Results of low yield due to high $Na^+$ uptake in saline conditions were also noted by Khan *et al*., (2000); Huang & Redmann (1995) Sharma & Gill (1994).

One way of tolerance of salinity by the crop is maintenance of high leaf $K^+$ concentration and low $Na^+$ concentrations (Khan & Glenn, 1996, Glenn *et al*., 1997; Huang & Redmann, (1995). The reason of high yield on ridges sowing supplemented by gypsum may be associated with the maintenance of higher K concentration relative to Na content. This is evident from the K to Na ratio (Table 3). The grain yield data was plotted against K and Na (Fig. 3) showed a significant relationship (positive with K and Negative with Na).

## Conclusion and Recommendations

The experimental soil under study was calcareous and saline-sodic with alkaline in reaction. The effect of various amendments and management practices was significant on the yield and yield components of wheat. Ridge sowing with gypsum application improved the soil chemical properties by reducing the ECe, SAR and pH. Sodium concentrations in and leaves decreased while K/Na ratio and K concentration increased in ridge + gypsum sown crop suggested that maintenance of high K concentration in leaves and low concentration of Na may be possible reason of higher yield. In case of FYM, it should be applied well before the crop sowing and mixed thoroughly with soil that may help in improving infiltration thereby increasing salts removal and thus increasing yield.

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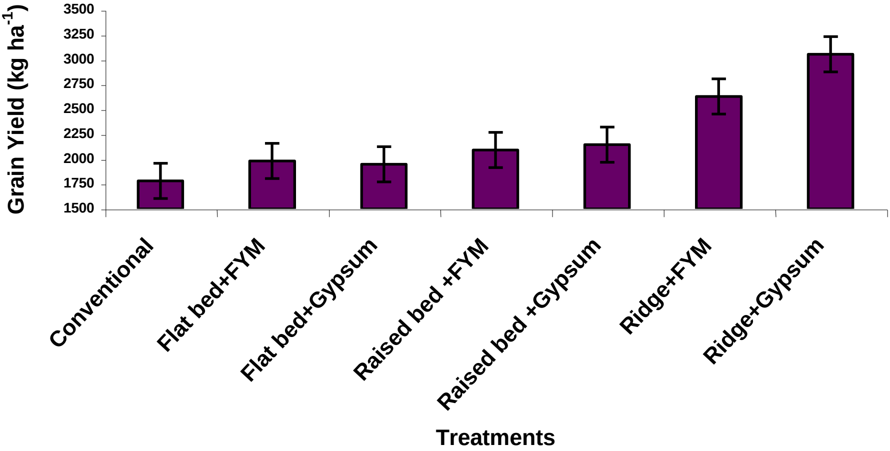


Fig. 2. Grain yield response to sowing methods supplemented with amendments.

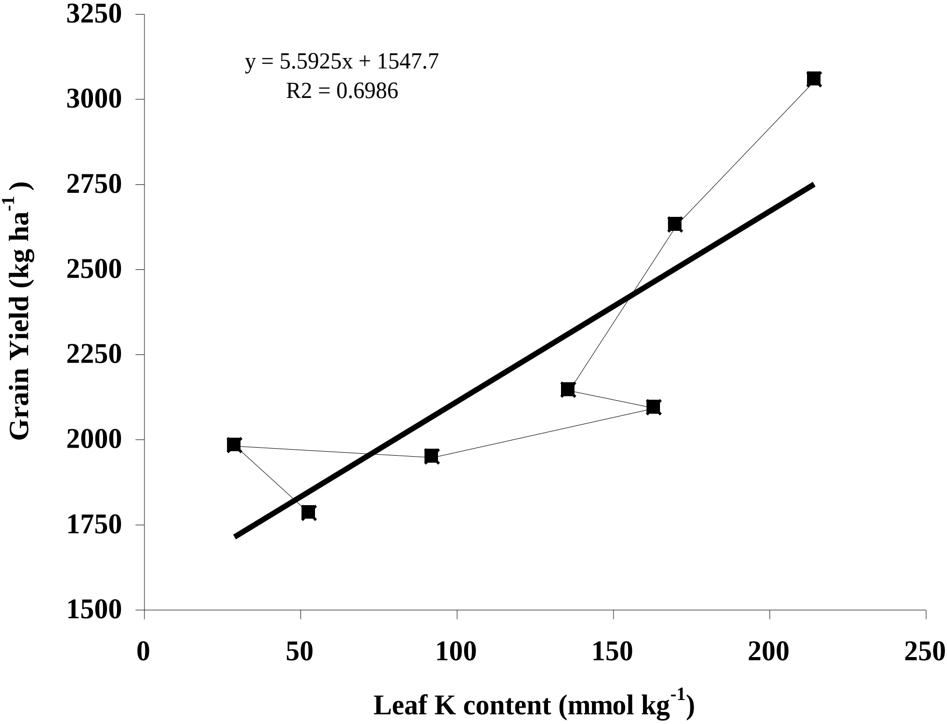


Fig. 3. Relationship of grain yield with leaf $K^+$ content.

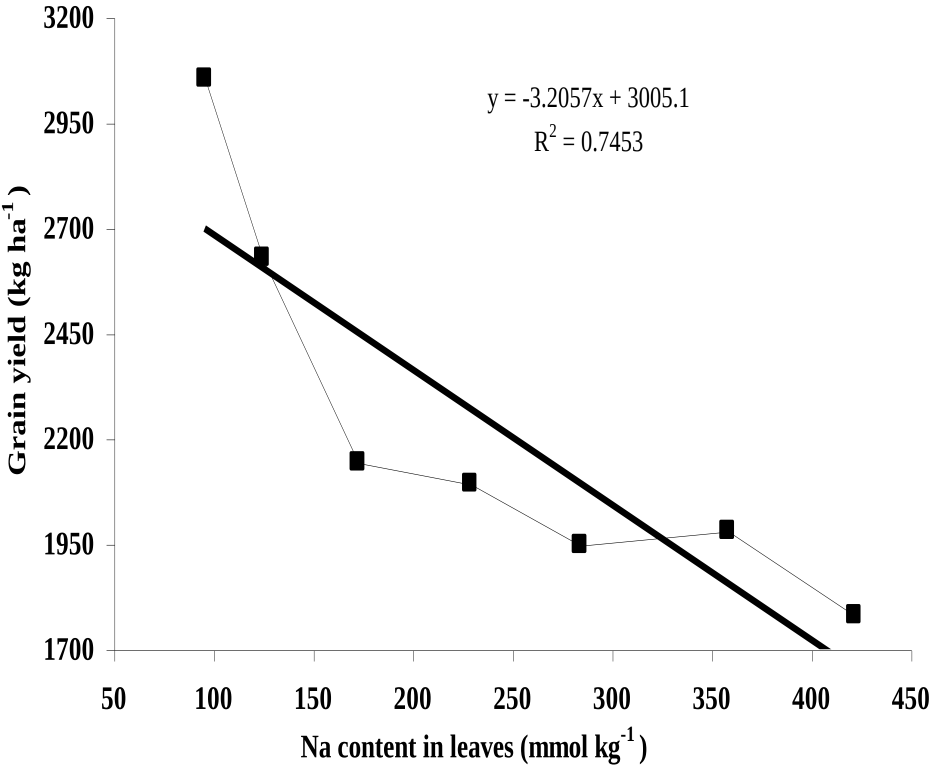


Fig. 4. Relationship of grain yield with leaf $Na^+$ contents.

**Table 3. Concentration of $Na^+$, $K^+$ and $K^+/Na^+$ ratio in wheat leaf as affected by different treatment under saline-sodic field conditions.**

| No | Treatment | Leaf $Na^+$ (Mmol $kg^{-1}$) | Leaf $K^+$ (mmol $kg^{-1}$) | Leaf $K^+/Na^+$ Ratio |
|---|---|---|---|---|
| 1. | Conventional method | 421.7 a | 53.0 f | 0.125 d |
| 2. | Flat bed + FYM | 358.0 b | 29.2 e | 0.193 d |
| 3. | Flat bed + Gypsum | 284.0 c | 92.3 d | 0.323 d |
| 4. | Raised bed + FYM | 228.9 b | 163.2 b | 0.713 c |
| 5. | Raised bed + Gypsum | 172.5 e | 135.9 c | 0.819 c |
| 6. | Ridges + FYM | 124.6 f | 170.1 b | 1.376 b |
| 7. | Ridges + Gypsum | 95.67 f | 214.5 a | 2.298 a |
| | LSD value at 5% | 29.62 | 14.96 | 0.382 |

Means followed by same letters are statistically non significant at 5% level of probability.

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