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ENHANCING THE SOLUBILITY AND RECLAMATION EFFICIENCY OF GYPSUM WITH H_2SO_4

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ABSTRACT. An effective reclamation procedure of saline sodic soils is removal of undesirable Na^+ by addition of some Ca^{2+} source paralleled with leaching of this sodium out of root zone. Nevertheless, gypsum being a direct source of Ca^{2+} is relatively insoluble in water. Its solubility can be increased with addition of H_2SO_4. Therefore, three years (2015 to 2018) study was plan to find out the optimal and economical level of H_2SO_4, which can increase the solubi-lity and reclamation efficiency of gypsum for saline sodic soil in rice wheat crop-ping rotation. Treatments included were: T_1, Control, T_2, gypsum @ 100% of GR, T_3, gypsum @ 100% of GR+10 kg H_2SO_4 acre^{-1}, T_4, gypsum @ 100% of GR+50 kg H_2SO_4 acre^{-1}, T_5, gypsum @ 100% of GR+100 kg H_2SO_4 acre^{-1}. Before start of study, soil had pH_s = 8.85, EC_e = 4.85 (dS m^{-1}), SAR = 43.82 (mmol L^{-1})$^{1/2}$, GR = 4.10 (t. acre^{-1}), BD = 1.65 (Mg m^{-3}), HC = 0.33 (cm hr^{-1}). Experiment was laid out in RCBD with three replications. Sulfuric acid and gypsum were applied (once) at the start of study in the respective treatment plots. Recommended dose of fertilizers, 150-90-60 NPK kg ha^{-1} for rice (Shaheen Basmati) and 160-114-60 NPK kg ha^{-1} for wheat (Faisalabad, 2008) was applied. Yield and yield determining attributes of each crop were recorded at physical maturity. After harvest of each crop, soil samples were collected and were analyzed for EC_e, pH_s, SAR, bulk density and hydraulic conduc-tivity. Pooled data analysis revealed that maximum growth and yield determining factors of rice and wheat were recorded where gypsum was applied with H_2SO_4 at the rate of 50 and 100 kg acre^{-1}. Soil physical and chemical properties, *i.e.* pH_s, EC_e, SAR bulk density and hydraulic conductivity were also substantially improved with combined application of gypsum and H_2SO_4 at the end of study. Both levels of H_2SO_4 at the rate of 50 and 100 kg acre^{-1} with gypsum proved equally to be the best in enhancing the solubility and reclamation efficiency of gypsum and showed the statistically ($p \leq 0.05$) similar results in increasing the yield of rice and wheat crop and improving the soil physical and chemicals properties. Therefore, H_2SO_4 at the rate of 50 kg acre^{-1}

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is recommended as most economical and optimum level, which can be used with gypsum as an effective ameliorative strategy for the salt affected soils.

Keywords: salinity; rice; wheat; amelioration; amendments.

Abbreviations used: EC_e (electrical conductivity of soil extract); pHs (pH of soil saturated paste); GR (gypsum requirement); SAR (sodium absorption ratio); BD (bulk density); HC (hydraulic conductivity).

INTRODUCTION

Approximately 20% of the irrigated land is salt affected with a loss of 12 billion US$ *per annum* (Ghassemi *et al.,* 1995). Such problematic soils can be rehabilitate by calcium (Ca^{2+}) source to replace the toxic sodium (Na^+) from exchange sites, which leaches out of root zone (Oster 1982, Shainberg and Letey 1984). According to Gupta and Abrol (1990), reclamation of salt affected soils through chemical reclaiming agents is a well-established technology, in which some reclaiming agents are direct source of Ca^{2+}, whereas, others helps to dissolve the native $CaCO_3$ (Qadir and Oster, 2002).

Gypsum is most common sulphate mineral extracted from the ground (Hand, 1997). This sulphate mineral is extensively used as reclaiming agents due to its ease of handling, economics, and accessibility (Amezketa *et al.,* 2005). It is commonly used to neutralize the harmful effects of Na^+ resulting in significant decrease of soil salinity indices, like EC_e and SAR (Hamza and Anderson, 2003). Gypsum application @ 100% of GR alone or in combination with organic amendments is a very effective strategy to ameliorate the salt affected soils and to increase the crop yield (Ahmed *et al.,* 2015). Shahid (1993) also reported the positive effect of subsoiling and gypsum on soil physicochemical properties. Similarly, in a study conducted by Qadir *et al.* (2017), they reported that gypsum application at the rate of 100% and 50% of GR improved the soil properties, like pH_s, EC_e, SAR, HC, BD, and yield of wheat and rice crop under saline conditions. Nevertheless, gypsum is comparatively insoluble in water and below 40ºC it has lowest solubility (Farrah *et al.,* 2004; Freyer and Voigt, 2003).

Different laboratories studies have been conducted to enhance the gypsum solubility with H_2SO_4 (Ling and Demopoulos, 2004; Dutrizac and Kuiper, 2006). The solubility of $CaSO_4$ hydrates in H_2SO_4 solutions was determined by Ling and Demopoulos (2004) and Dutrizac (2002). According to (Azimi, 2010) at temperatures of 25-45°C, gypsum solubility increases moderately with addition of H_2SO_4, while at higher temperatures, the solubility of gypsum increases monotonically with increasing concentration of acid. They stated that SO_4^{2-} concentration decreases with increasing concentration of H_2SO_4, which enhances the solubility of $CaSO_4$ to satisfy the solubility product. Different researchers also reported that addition of acids in gypsum accelerated the transformation process and enhances the solubility of gypsum (Farrah *et al.,* 2004; Freyer and Voigt, 2003; Dutrizac, 2002; Nyvlt, 1997).

Similarly, Farrah *et al.* (2007) in a study reported that maximum solubility of gypsum was observed when H_2SO_4 concentration is 36 g/kg solution, while further increase of 72 g/kg solution recorded the smaller increase in gypsum solubility. Addition of acids, like H_2SO_4 and HCl, enhances the solubility of gypsum (Azimi and Papangelakis, 2010).

So, this study was plan to find out the optimum and economical level of H_2SO_4, which can increase the solubility and reclamation efficiency of gypsum for saline sodic soils under rice wheat cropping rotation.

MATERIAL AND METHODS

A field study was conducted from 2015 to 2018, at Soil Salinity Research Institute, Pindi Bhattian, Pakistan. Before start of study, soil had pH_s = 8.85, EC_e = 4.85 (dS m^{-1}), SAR = 43.82 (mmol $L^{-1})^{1/2}$, GR = 4.10 (t.acre^{-1}), BD = 1.65 (Mg m^{-3}), HC = 0.33 (cm hr^{-1}). Treatments included were: T_1, Control, T_2, gypsum @ 100% of GR, T_3, gypsum @ 100% of GR+10 kg H_2SO_4 acre^{-1}, T_4, gypsum @ 100% of GR+50 kg H_2SO_4 acre^{-1}, T_5, gypsum @ 100% of GR+100 kg H_2SO_4 acre^{-1}.

Experimental design was RCBD having three replications. Gypsum (80% pure, 30 mesh size) and sulfuric acid (96% pure) were applied (once) at the start of study in the respective treatment plots. Land was prepared thoroughly and gypsum was broadcasted on the soil surface and H_2SO_4 was flooded according to treatment plan with irrigation of 7.5 cm depth to dissolve the gypsum. After 30 days of amendments application, during kharif season 2015 rice (Shaheen Basmati), nursery was transplanted.

Recommended dose of fertilizers (150-90-60 NPK kg ha^{-1}) as urea, single super phosphate and sulphate of potash was applied to rice.

All agronomic and plant protection measures were applied uniformly. Yield and yield determining attributes of rice crop were recorded at physical maturity of crop. After the harvest of rice crop, wheat crop (Faisalabad, 2008) was sown in same field. Recommended dose of fertilizer 160-114-60 NPK kg ha^{-1} as urea, single super phosphate and sulphate of potash was applied. All agronomic and plant protection measures were applied uniformly. Yield and yield determining attributes were recorded at physical maturity of crop. Soil samples were collected after harvest of each crop and were analyzed for pH_s, EC_e, SAR, bulk density and hydraulic conductivity according to U.S. Salinity Laboratory Staff (1954). The collected crop data (rice and wheat) was statistically analyzed.

The treatment mean comparison was made using Least Significant Difference Test @ 5% Probability (Steel *et al.,* 1997).

RESULTS

Rice crop

Pooled data of rice crop revealed that application of gypsum significantly influenced the growth and yield characteristics of rice crop, however, at the same time integrated use of gypsum and H_2SO_4 showed more positive effects than sole application of gypsum (*Tables 1* and *2*). Data concerning the plant height displayed that gypsum and H_2SO_4 significantly ($p \leq 0.05$) increased the plant height and maximum plant height of 133.67 cm was observed in T_5 (gypsum @ 100% of GR+100 kg H_2SO_4 acre^{-1}), which was statistically similar with T_4 (gypsum @ 100% of GR+50 kg H_2SO_4 acre^{-1}). While minimum plant height (122.00 cm) was documented in T_1 (control). Data regarding number of tillers and number of spikelet showed that maximum number of tillers and spikelet (231.33, 214.67) were observed with gypsum @ 100% of GR+100 kg H_2SO_4 acre^{-1}, followed by gypsum @ 100% of GR+50 kg H_2SO_4 acre^{-1} and statistically both treatments were alike. On the other hand, minimum number of tillers and number of spikelet (217, 202) were observed where no amendments was used, *i.e.* in control (*Table 1*).

Data for 1000 grain weight revealed that maximum 1000 grain weight (32.33 g) was documented at gypsum @ 100% of GR+100 kg H_2SO_4 acre^{-1}, however it was statistically at par with gypsum @ 100% of GR+50 kg H_2SO_4 acre^{-1}. Minimum 1000-grain weight (24 g) was recorded by control. Data about paddy and straw yield showed inclining pattern, amongst all the treatments, combination of gypsum and H_2SO_4 performed better than individual application of gypsum; H_2SO_4 @ 100 and 50 kg acre^{-1} with gypsum performed equally well in paddy and straw yield and maximum paddy (4.11 t ha^{-1}) and straw yield (11.45 t ha^{-1}) was documented in gypsum @ 100% of GR+100 kg H_2SO_4 acre^{-1}. On contrary, minimum paddy (2.02 t ha^{-1}) and straw yield (5.69 t ha^{-1}) was observed in control.

Wheat crop

Data regarding yield and yield attributes of wheat crop in (*Tables 3* and *4*) exhibited that increasing level of H_2SO_4 with gypsum significantly improved these attributes, however, H_2SO_4 remain effective only up to level of 50 kg H_2SO_4 acre^{-1} and further increase did not influnced these attributes significantlly ($p \leq 0.05$).

Data showed that taller plants (72.66 cm) were observed in gypsum @ 100% of GR+100 kg H_2SO_4 acre^{-1}, followed by gypsum @ 100% of GR+50 kg H_2SO_4 acre^{-1} and both treatments were statistically non significant ($p \leq 0.05$) from each other. Data regarding the number of tillers, grain spike^{-1} and 1000-grain weight showed that maximum number of tillers (164.67), grain spike^{-1} (31) and 1000-grain weight (34 g) were ensued by gypsum @ 100% of GR+100 kg H_2SO_4 acre^{-1}, which was statistically ($p \leq 0.05$), alike with gypsum @ 100% of GR+50 kg H_2SO_4 acre^{-1}. On the other hand, minimum number of tillers (136.33), grain spike^{-1} (26) and 1000-grain weight (22 g) were recorded in control. Yield data revealed that maximum grain (3.51 t ha^{-1}) and straw yield (4.53 t ha^{-1}) was achieved with gypsum @ 100% of GR + 100 kg H_2SO_4 acre^{-1}, followed by gypsum @ 100% of GR+50 kg H_2SO_4 acre^{-1} and these treatments were statistically ($p \leq 0.05$) non-significant from each other. Whereas, minimum grain (1.47 t. ha^{-1}) and straw (1.92 t. ha^{-1}) yield was recorded by control.

Soil properties

Soil analysis at the end of study showed that gypsum application substantially improved the soil physical and chemical properties, however, at the same time, integrated use of gypsum with H_2SO_4 was more effective in reclaiming the salt affected soil than its sole application. Data regarding the soil EC_e revealed that maximum reduction of 56.91 % over its initial value was observed with gypsum @ 100% of GR+100 kg H_2SO_4 $acre^{-1}$, followed by gypsum @ 100% of GR+50 kg H_2SO_4 $acre^{-1}$ with a reduction of 55.88% over its initial value (*Table 5*). Whereas, minimum reduction in EC_e (10.52%) was recorded in control.

With respect to soil pH_s, maximum reduction (7.91 %) was observed with combined application of gypsum @ 100% of GR+100 kg H_2SO_4 $acre^{-1}$ and minimum reduction (0.56%) was observed where no ammendments was used, *i.e.* in control. Similarly, soil sodicity indicator, *i.e.* SAR, was also signnificantly improved by the amendments (*Table 6*).

Table 1 - Effect of amendments on rice growth (average of three seasons)

Treatments	Plant height (cm)	No. of tillers m^{-2}	No. of spikelet $panicle^{-1}$
T_1 Control	122.00 C	217.00 C	202.00 B
T_2 Gypsum @ 100 % of GR	127.33 B	224.00 B	210.67 A
T_3 Gypsum @ 100 % of GR + 10 kg H_2SO_4 $acre^{-1}$	128.33 B	225.00 B	213.33 A
T_4 Gypsum @ 100% of GR + 50 kg H_2SO_4 $acre^{-1}$	131.33 AB	227.00 AB	214.67 A
T_5 Gypsum @ 100% of GR + 100 kg H_2SO_4 $acre^{-1}$	133.67 A	231.33 A	214.67 A

Different letters in the same column indicate significant differences by LSD at $p \leq 0.05$

Table 2 - Effect of amendments on rice growth (average of three seasons)

Treatments	1000 grain weight (g)	Paddy Yield ($t.ha^{-1}$)	Straw Yield ($t.ha^{-1}$)
T_1 Control	24.00 C	2.02C	5.69C
T_2 Gypsum @ 100 % of GR	28.33 B	3.51B	9.72B
T_3 Gypsum @ 100 % of GR + 10 kg H_2SO_4 $acre^{-1}$	29.33 B	3.63B	10.02B
T_4 Gypsum @ 100% of GR + 50 kg H_2SO_4 $acre^{-1}$	30.33 AB	3.98A	11.28A
T_5 Gypsum @ 100% of GR + 100 kg H_2SO_4 $acre^{-1}$	32.33 A	4.11A	11.45 A

Different letters in the same column indicate significant differences by LSD at $p \leq 0.05$

Table 3 - Effect of amendments on wheat growth (average of three seasons)

Treatments	Plant height (cm)	No. of tillers m^{-2}	No. of grain $spike^{-1}$
T_1 Control	59.00 C	136.33 C	26.00 B
T_2 Gypsum @ 100 % of GR	64.00 B	155.33 B	29.33 A
T_3 Gypsum @ 100 % of GR + 10 kg H_2SO_4 $acre^{-1}$	65.00 B	163.67 A	29.66 A
T_4 Gypsum @ 100% of GR + 50 kg H_2SO_4 $acre^{-1}$	70.66 A	160.00 AB	30.00 A
T_5 Gypsum @ 100% of GR + 100 kg H_2SO_4 $acre^{-1}$	72.66 A	164.67 A	31.00 A

Different letters in the same column indicate significant differences by LSD at $p \leq 0.05$

Table 4 - Effect of amendments on wheat growth (average of three seasons)

Treatments	1000 grain weight (g)	Paddy yield ($t.ha^{-1}$)	Straw yield ($t.ha^{-1}$)
T_1 Control	22.00 C	1.47C	1.92C
T_2 Gypsum @ 100 % of GR	29.33 B	2.92B	3.85B
T_3 Gypsum @ 100 % of GR + 10 kg H_2SO_4 $acre^{-1}$	30.00 B	3.04B	3.98B
T_4 Gypsum @ 100% of GR + 50 kg H_2SO_4 $acre^{-1}$	33.00 A	3.46A	4.57A
T_5 Gypsum @ 100% of GR + 100 kg H_2SO_4 $acre^{-1}$	34.00 A	3.51A	4.53A

Different letters in the same column indicate significant differences by LSD at $p \leq 0.05$

Maximum reduction (79.55%) in soil SAR was recorded with gypsum @ 100% of GR+100 kg H_2SO_4 $acre^{-1}$ and minimum (7.58%) in control. Data regarding soil bulk density showed that H_2SO_4 @ 100 and 50 kg $acre^{-1}$ with gypsum @ 100% of GR performed equally in improving the soil bulk density with a maximum reduction of 5.45% over its initial value and on the other hand minimum reduction of 0.61 % was documented in control (*Fig.1*).

Soil hydraulic conductivity was also significantly influenced by application of amendments. Maximum increase (42.42%) in hydraulic conductivity was noted where gypsum was applied at the rate of 100% of soil gypsum requirement +100 kg H_2SO_4 $acre^{-1}$. On contrary, minimum increase of 3.03% was observed in control (*Fig. 2*).

DISCUSSION

Increase in growth and yield characteristics of rice/wheat crops with gypsum + H_2SO_4 application clearly depicted the ameliorative role of these amendments, however, at the same time increasing levels of H_2SO_4 showed more positive effects on these attributes.

Application of gypsum accelerated the leaching of salts out of root zone and promotes the flocculation of dispersed soil (Qadir *et al.,* 2001; Zaka *et al.,* 2005). Removal of exchangeable Na^+ by Ca^{2+} provided by gypsum improve the soil physical and chemical properties (Muhammad and Khattak, 2011).

Improvement in the soil physical and chemical properties may be the possible reasons for increased yield and yield contributing factors of rice and wheat crops in the treatments receiving the combined application of gypsum and H_2SO_4. Our results are in consistent with previous findings that gypsum application with organic and inorganic amendments improved the crop yield and salinity sodicity indices of salt affected soils (Qadir *et al.,* 2001; Ghafoor *et al.,* 2008; Qazi *et al.,* 2009; Nan *et al.,* 2016; Murtaza *et al.,* 2017).

Table 5 - Effect of amendments on soil chemical properties at the end of study

Treatments	EC_e	% decrease over initial value	pH_s	% decrease over initial value
T_1 Control	4.34	10.52	8.80	0.56
T_2 Gypsum @ 100 % of GR	3.65	24.74	8.28	6.44
T_3 Gypsum @ 100 % of GR + 10 kg H_2SO_4 acre^{-1}	2.62	45.98	8.26	6.67
T_4 Gypsum @ 100% of GR + 50 kg H_2SO_4 acre^{-1}	2.14	55.88	8.15	7.91
T_5 Gypsum @ 100% of GR + 100 kg H_2SO_4 acre^{-1}	2.09	56.91	8.15	7.91

Different letters in the same column indicate significant differences by LSD at $p \leq 0.05$

Table 6 - Effect of amendments on soil chemical properties at the end of study

Treatments	SAR	% decrease over initial value
T_1 Control	40.50	7.58
T_2 Gypsum @ 100 % of GR	11.92	72.80
T_3 Gypsum @ 100 % of GR + 10 kg H_2SO_4 acre^{-1}	11.96	72.71
T_4 Gypsum @ 100% of GR + 50 kg H_2SO_4 acre^{-1}	9.08	79.28
T_5 Gypsum @ 100% of GR + 100 kg H_2SO_4 acre^{-1}	8.96	79.55

Different letters in the same column indicate significant differences by LSD at $p \leq 0.05$

Positive effect on crop growth and yield due to gypsum application with increasing levels of H_2SO_4 may also be ascribed, as the addition of H_2SO_4 results in a significant increase in the calcium sulphate solubility, compared to that in water (Azimi *et al.,* 2007), because gypsum is comparatively insoluble in water and below 40ºC it has lowest solubility (Freyer and Voigt, 2003; Farrah *et al.,* 2004; Azimi *et al.,* 2007). While the addition of H_2SO_4 increases the solubility of gypsum up to 10 times in water over the temperature range of 25–250ºC (Azimi, 2010). This increased solubility of gypsum also increases its reclamation efficiency and consequently a notable improvement in physical and chemical properties of salt affected soil was recorded where gypsum was applied with H_2SO_4 at rate of 50 and 100 kg acre^{-1}. So, this positive effect of gypsum in combination of H_2SO_4 was responsible for the improved yield of wheat and rice crops in these treatments. In addition, crop was also benefited through improved nutritional status of soil, as gypsum application also increases the solubility of essential plant nutrients like N, K, Ca, Mg and S (Elrashidi *et al.*, 2010).

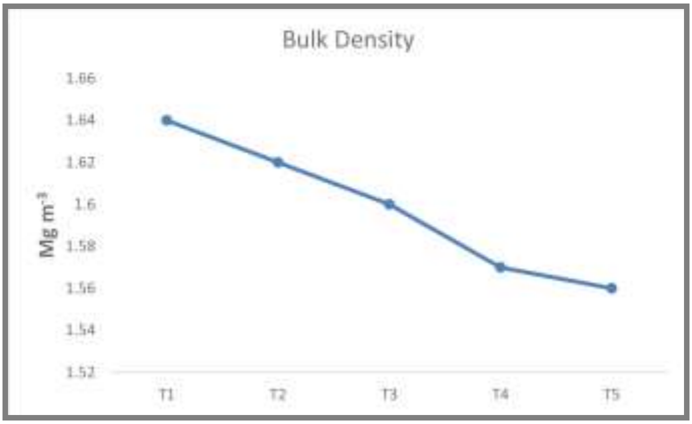

Figure 1 - Effect of gypsum and H_2SO_4 on bulk density (Mg m^{-3}) of soil at the end of study. T_1 (control), T_2 (Gypsum @ 100% of GR), T_3 (Gypsum @ 100% of GR + 10 kg H_2SO_4 acre^{-1}), T_4 (Gypsum @ 100% of GR + 50 kg H_2SO_4 acre^{-1}), T_5 (Gypsum @ 100% of GR + 100 kg H_2SO_4 acre^{-1})

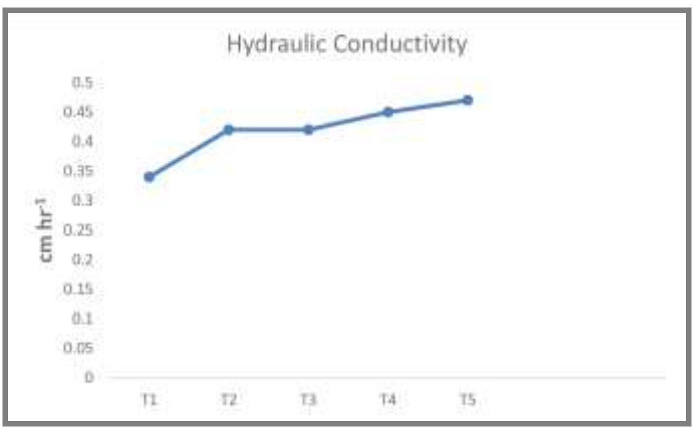

Figure 2 - Effect of gypsum and H_2SO_4 on hydraulic conductivity (cm hr^{-3}) of soil at the end of study. T_1 (control), T_2 (Gypsum @ 100% of GR), T_3 (Gypsum @ 100% of GR + 10 kg H_2SO_4 acre^{-1}), T_4 (Gypsum @ 100% of GR + 50 kg H_2SO_4 acre^{-1}), T_5 (Gypsum @ 100% of GR + 100 kg H_2SO_4 acre^{-1})

Combined application of gypsum and H_2SO_4 significantly improved the soil physical and chemical properties, as compared to control and gypsum alone. Results of the current study demonstrated that integrated use of gypsum and H_2SO_4 significantly lowered the soil pH_s. Application of gypsum with H_2SO_4 at the rate of 50 and 100 kg acre^{-1} reduces the soil pH_s 7.91%, as compared to initial soil pH_s value. This lowered value of pH_s due to gypsum application was the result of replacement of Na^+ by Ca^{2+} and formation of soluble salts of SO_4^{2-} (Abdel-Fattah, 2012). Sharp decline in pH_s of soil due to H_2SO_4 + gypsum may be ascribed as addition of acid create the conditions, which increases the solubility of gypsum owing to enhanced activity of coefficient of Ca^{2+} and SO_4^{2-}, as a result of increased ionic strength of solution (Calmanovici *et al.,* 1993; Abdel-Fattah, 2012), furthermore, addition of acid has direct effect on lowering the soil pH_s.

Data also illustrated that application of gypsum also reduces the soil EC_e, however sharp decline in soil EC_e was observed where gypsum was applied with H_2SO_4 and maximum reduction of 56.91% over initial value was recorded where gypsum was applied with H_2SO_4 at rate of 100 kg acre^{-1}. The possible reason for this lowered value of EC_e could be the leaching of soluble salts out of root zone (Ghafoor *et al.,* 2008). Similar findings are reported by Van-Camp *et al.,* 2004; Blum *et al.,* 2004; Chitravadivu *et al.,* 2009, which reinforced the findings of current study. Similarly, same trend was observed in case of SAR, maximum reduction in SAR was noted where gypsum was applied with H_2SO_4 at rate of 50 and 100 kg acre^{-1}. Increased exchangeable Ca^{2+} due to enhanced dissolution of gypsum with H_2SO_4 replaces the Na^+ and consequently a sharp decreased in soil SAR was observed. Our results are in agreement with findings of Muhammad and Khattak (2011), who observed a significant reduction in soil SAR with gypsum application.

Soil physical properties, *i.e.* bulk density and hydraulic conductivity, were also positively influenced with application of gypsum and H_2SO_4. Bulk density was reduced by 5.45% and hydraulic conductivity was increased by 42.42%, as compared to its initial value at the start of study with combined application of gypsum and H_2SO_4 at rate of 100 kg acre^{-1}.

Application of Ca^{2+} as gypsum ($Ca\ SO_4.2H_2O$) replaced the Na^+ from clay complex that was pushed into soil solution and subsequently leached down into lower profile. The effect of soil EC_e, pH_s and SAR is directly translated into increase or decrease of soil hydraulic conductivity and bulk density. The higher value of BD indicates harder and less porous soil. Generally, BD of saline sodic soil with dominancy of Na^+ are higher than equivalent normal soil. As stated earlier the decrease in soil pH_s, EC_e and SAR with application of gypsum and H_2SO_4 decreased soil dispersion, increase soil porosity and resultant net reduction in BD was recorded (*Fig.1*).

An improvement in soil porosity through gypsum application was also obtained by Shainberg *et al.* (1989). Similarly decreased BD values with the use of calcium sources were previously reported (Peters and Kelling, 2002). Hydraulic conductivity plays its role in water relation of soil and plants in general, but is of prime importance in soil reclamation process. Because if water cannot permeable in to lower profile it will not take salt with it. The initial soil data presented very low value of HC. It was as low as 0.33 cm hr^{-1}.

However, it increased manifold during three years with a maximum of 0.47 cm hr^{-1} (42.42 % increase), when gypsum and H_2SO_4 at rate of 100 kg $acre^{-1}$ were applied in combination (*Fig. 2*). It might be due to reduction in SAR, which resultantly decrease soil dispersion and encouraged coagulation of soil particles. The increase in pore spaces caused by aggregation increased the HC (Kauraw and Verma, 1982). Various research workers have reported an appreciable increase in HC due to application of inorganic or organic amendments, cultural practices and growing of crops (Qadir and Schubert, 2002; Carter *et al.,* 2004; Evanylo *et al.,* 2008).

CONCLUSION

An effective reclamation procedure of saline sodic soils is removal of undesirable Na^+ by addition of some Ca^{2+} source paralleled with leaching of this sodium out of root zone. Nevertheless, gypsum being a direct source of Ca^{2+} is relatively insoluble in water. Its solubility can be increased with addition of H_2SO_4. Combination of gypsum with H_2SO_4 at the rate of 50 and 100 kg $acre^{-1}$ proved equally to be the best in enhancing the solubility and reclamation efficiency of gypsum; however, H_2SO_4 at the rate of 50 kg $acre^{-1}$, is the most economical and optimum level for reducing soil pH, salinity, SAR and improving bulk density and hydraulic conductivity. So ultimately, the paddy and grain yield of rice and wheat increased with the improvement of soil health. The message derived for the farmers from this study is that they can effectively rehabilitate their salt affected lands to obtain original potential if they apply gypsum at the full rate (100% GR) by combining it with H_2SO_4 at the rate of 50 kg $acre^{-1}$.

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