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Conjunctive use of different tillage implements and amendments for the reclamation of salt affected soils

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Abstract

Amelioration of undesirable conditions of salt prone degraded soils required the use of suitable amendments coupled with appropriate management practices. In this context, a field study was conducted to find out the best combination of tillage implements with gypsum and sulphuric acid for the reclamation of salt-affected soils. Implements used in the study were, T_1 Disc Plough, T_2 Rotavator, T_3 Chisel plough, T_4 Sub-Soiler. Whereas five levels of amendments were used, A_1 Control (Without amendments), A_2 Sulphuric acid equivalent to 50% GR of soil, A_3 Sulphuric acid equivalent to 100% GR of soil, A_4 Gypsum application @ 50% GR of soil, A_5 Gypsum application @ 100% GR of soil. Implements were kept in the main plots and amendments in subplots. The experiment was conducted with sorghum-oat crop rotation in split-plot design having three replications. Fresh fodder yield of sorghum and oats was recorded. The results of the study showed that fresh fodder yield of sorghum and oats was maximum with H_2SO_4 and gypsum @100 % gypsum requirement of soil and subsoiler. Soil health was also improved with the use of H_2SO_4/ gypsum and subsoiler as tillage implements. Therefore, it was concluded that deep tillage through subsoiler with H_2SO_4 and gypsum @100 % GR can be an effective technology to accelerate the reclamation process of salt-affected soils.

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Introduction

Salt stress is a major environmental factor that degraded the soil's physical, chemical and biological properties (Al Yassin, 2005). Amelioration of such degraded salt-affected soils is accomplished with use of some amendments (gypsum, acids and $CaCl_2$, organic manures, compost, etc.) and suitable management practices. Due to the presence of soluble salts and excessive Na^+, salt-affected soils are generally compact, with low infiltration rate and high bulk density. Therefore, to improve these physical and chemicals properties of such problematic soils, a suitable tillage system is a prerequisite that will not improve the efficiency of amendments but also produce the favorable crop growth conditions (Anikwe and Ubochi, 2007; Jabro *et al.,* 2009). Tillage practices during the soil preparation create the ideal conditions for plant emergence, root penetration and development (Licht and Al-Kaisi, 2005). During the reclamation process, leaching of toxic salts out of root zone is preliminary requisite, therefore the choice of suitable tillage implements during the land preparation is very critical which will facilitate the removal of salts and enhance the leaching process. Azhar *et al.* (2001) studied the combined effect of gypsum (50 and 75 % GR) and tillage implements (narrow-tine cultivator, chisel plough, disk plough and sub-soiler on reclamation process of salt-affected soils. They reported that tillage implements significantly affected the reclamation process, subsoiler was the most effective tillage implements to accelerate the reclamation process. It significantly reduced the soil penetration resistance, infiltration rate, bulk density, soil pH_s, ESP and EC_e. Gypsum application with farmyard manure and chisel plough significantly improved the physical (hydraulic conductivity, bulk density) and chemical (pH_s, SAR and EC_e) properties of saline-sodic soil and growth of fodder beet (Ahmed *et al.,* 2015). Similarly, in a study, Amin *et al.* (2014) investigated the effect of five tillage implement i.e. chisels plow, tine cultivator, moldboard plow, disk plow and rotavator. They concluded that deep tillage implements (chisel plow, moldboard plow) were more effective to improve the soil moisture contents, bulk density and penetration resistance. Sadiq *et al.* (2002) envaulted the effect of different tillage implements (rotavator, disc plough, chisel plough and cultivator) and rice stubbles on growth performance of wheat crop in salt-affected soil. They observed that among the tillage implements rotavator proved more effective in increasing the growth and yield of the wheat crop in salt-affected soil. In another study, Sadiq *et al.* (2002) studied the effect of H_2SO_4 (untreated, H_2SO_4 @ 20% GR) and tillage implements (disc plough, rotavator and cultivator) on chemical properties of saline-sodic soil under rice-wheat crop rotation. They reported that H_2SO_4 @ 20% GR gradually improved the soil properties like pH_s, SAR and EC_e. Among tillage implements, disc plough performed better over other implements and significantly improved the paddy/grain and straw yield of rice and wheat crops.

Aikins and Afuakwa (2012) evaluated the effect of different tillage systems on the production of cowpea and soil properties. They reported that the disc ploughing followed by disc harrowing treatment proved more superior over other treatments and produced more favorable soil conditions for the production of cowpea. Leghari *et al.* (2015) stated that cultivator is the most economical tillage implement as it reduced the bulk density (12-18%), conserving soil moisture up to 95% and increased the infiltration rate up to 61.5% in cotton-wheat rotation system as compared to disc plow. Therefore, the present study was carried out to evaluate the effect of different amendments (gypsum and H_2SO_4) and land preparation methods (disc plough, rotavator, chisel plough and subsoiler) for the reclamation of salt-affected soil.

Materials and methods

A field study was conducted from 2013 to 2016 adopting sorghum-oats crop rotation at the research farm of Soil Salinity Research Institute, Pindi Bhattian. A salt affected field {pHs = 8.62, EC_e = 4.16 (dS m^{-1}), SAR = 32.35 and soil gypsum requirement (SGR) = 2.66 t. $acre^{-1}$} was selected and prepared by using four tillage implement i.e. disc plough, rotavator, chisel plough and subsoiler according to treatment plan. Treatments tested were; T_1: Disc Plough, T_2: Rotavator, T_3: Chisel plough, T_4: Subsoiler, while five levels of amendments were; A_1: Control, A_2: H_2SO_4 50% GR of soil, A_3: H_2SO_4 100% GR of soil, A_4: Gypsum 50% GR of soil, A_5: Gypsum 100% GR of soil. Implements were kept in the main plots and amendments in subplots. The experiment was conducted with sorghum-oat crop rotation in Split Plot Design having three replications. H_2SO_4 and gypsum were applied (once) at the start of the study in the respective treatment plots. In Kharif season, sorghum crop was sown in the 2nd week of June and the recommended dose of NP (60-60 kg ha^{-1}) was applied. The crop was harvested on the second week of September, and the fodder yield was recorded. In Rabi season, oats crop was sown in the 3rd week of November and the recommended dose of NP (95-60 kg ha^{-1}) was applied. At the harvest of each crop, soil samples were collected and analyzed for pH_s, EC_e, and SAR (US Salinity Lab. Staff, 1954). Collected data were subjected to analysis of variance (ANOVA) and treatment means were compared through the least significance difference (LSD) test (Steel *et al.,* 1997) using STATISTIX 8.1 package software.

Results

Sorghum

In Kharif season 2013, fresh fodder yield (36.84 t ha^{-1}) of sorghum was significantly higher with the application of H_2SO_4 @ 100% GR of soil, however, it was insignificant with gypsum @100% GR of soil and both treatments were statistically alike (Table 1).

Table 1. Effect of tillage implements and amendments on sorghum fodder yield (t ha^{-1}) 2013.

Treatments	Amendments					Mean
	Control	H_2SO_4 @50% GR of soil	H_2SO_4 @ 100% GR of soil	Gyp. @50% GR of soil	Gyp. @100% GR of soil	
T1: Disc Plough	23.33 j	31.33 ghi	35.67 bcd	31.67 ghi	34.67 cdef	31.27 BC
T2: Rotavator	22.33 j	30.00 i	34.67 cdef	30.33 hi	33.67 defg	30.20 C
T3: Chisel plough	24.33 j	32.33 fghi	37.33 abc	33.33 defgh	35.33 bcde	32.53 AB
T4: Subsoiler	24.67j	32.67 rfghi	39.67 a	34.00 defg	38.33 ab	33.87 A
Mean	23.67 C	31.58 B	36.84 A	32.25 B	35.50 A	

LSD for Treatment = 2.1815, LSD for Amendments = 1.4445

LSD for Treatment * Amendments = 3.384.

With respect to tillage implements, the highest fresh fodder yield (33.87 t ha^{-1}) of sorghum was observed when subsoiler was used for the land preparation. Data regarding interaction revealed that H_2SO_4 @ 100% GR of soil with subsoiler produced the maximum fresh fodder yield of 39.67 t ha^{-1} which was statistically similar with gypsum @ 100% GR and subsoiler used as tillage implements. A similar trend was observed during the next two years, the maximum fresh fodder yield of sorghum (41.54 t ha^{-1}) and (44.43 t ha^{-1}) was divulged with H_2SO_4 @ 100% GR during the 2014 and 2015 respectively (Table 2 and 3).

Table 2. Effect of tillage implements and amendments on sorghum fodder yield (t ha^{-1}) 2014.

Treatments	Amendments					Mean
	Control	H_2SO_4 50% GR of soil	H_2SO_4 100% GR of soil	Gyp. 50% GR of soil	Gyp. 100% GR of soil	
T_1 Disc Plough	24.50 k	34.50 hi	40.67 bcd	34.50 hi	39.00 de	34.63 C
T_2 Rotavator	23.50 jk	33.33 i	39.17 de	33.33 i	37.83 ef	33.43 D
T_3 Chisel plough	25.50 jk	35.67 gh	42.00 bc	36.33 fgh	40.17 cd	35.93 B
T_4 Subsoiler	26.17 j	36.17 fgh	44.33 a	37.17 efg	42.67 ab	37.30 A
Mean	24.92 D	34.92 C	41.54 A	35.33 C	39.92 B	

LSD for Treatment = 0.8338, LSD for Amendments= 1.0597

LSD for Treatment * Amendments= 2.1194.

Among the tillage implements, it was observed that the subsoiler performed better than all other implements and resultant fresh fodder yield was maximum with this tillage implement. Fresh fodder yield of sorghum 2014 was (37.30 t ha^{-1}) and sorghum 2015 was (40.02 t ha^{-1}) with subsoiler. The minimum fresh fodder yield of sorghum was observed with rotavator in all successive three seasons. Amendments and tillage system interaction was also observed significant and it was recorded that fresh fodder yield was 44.33 t ha^{-1} (2014) and 45.73 t ha^{-1} (2015) with subsoiler and H_2SO_4 @ 100% GR and it remained insignificant with gypsum @ 100% GR and subsoiler used as tillage implements.

Table 3. Effect of tillage implements and amendments on sorghum fodder yield (t ha^{-1})2015.

Treatments	Amendments					Mean
	Control	H_2SO_4 50% GR of soil	H_2SO_4 100% GR of soil	Gyp. 50% GR of soil	Gyp. 100% GR of soil	
T_1: Disc Plough	26.83 hi	37.95 fg	44.43 ab	37.95 fg	42.90 bcd	38.01 B
T_2: Rotavator	25.85 i	36.50 g	43.08 bcd	36.67 fg	42.03 cd	36.83 C
T_3: Chisel plough	27.00 hi	37.77 fg	44.50 ab	38.13 fg	43.45 bc	38.17 B
T_4: Subsoiler	28.78 h	38.92 ef	45.73 a	40.88 de	45.77 a	40.02 A
Mean	27.12 D	37.78 C	44.43 A	38.41 B	43.54 A	

LSD for Treatment = 0.9796, LSD for Amendments = 1.1385

LSD for Treatment * Amendments = 2.2770.

Table 4. Effect of tillage implements and amendments on oats fodder yield (t ha^{-1}) 2013-14.

Treatments	Amendments					Mean
	Control	H_2SO_4 50% GR of soil	H_2SO_4 100% GR of soil	Gyp. 50% GR of soil	Gyp. 100% GR of soil	
T1: Disc Plough	37.43 hi	44.50 ef	53.07 abc	45.13 ef	51.07 bcd	46.24 BC
T2: Rotavator	36.73 i	41.83 fgh	50.50 bcd	43.17 fg	49.30 cde	44.30 C
T3: Chisel plough	38.87 ghi	46.67 def	55.40 ab	48.67 cde	52.40 abc	48.40 AB
T4: Subsoiler	39.03 ghi	46.43 def	57.33 a	48.90 cde	56.77 a	49.69 A
Mean	38.12 C	44.86 B	54.08 A	46.47 B	52.38 A	

LSD for Treatment = 2.1815, LSD for Amendments = 1.4445

LSD for Treatment * Amendments = 3.384.

Oats

Data regarding the oats crop displayed that amendments, tillage system and their interaction significantly influenced the fresh fodder yield of oats. For oats 2013-14, fresh fodder yield (54.08 t ha^{-1}) was maximum with H_2SO_4 @ 100% GR followed by gypsum @100% GR and both the treatments were at par (Table 4).

With respect to tillage implements, the maximum fresh fodder yield (49.69 t ha^{-1}) was documented with subsoiler which was insignificant with chisel plough. Interaction of tillage system and amendments showed that the greater fresh fodder yield (57.33 t ha^{-1}) was produced by H_2SO_4 @ 100% GR with subsoiler and it was statistically at par with gypsum @100% GR and subsoiler used as tillage implements. In oat 2014-15 and 2015-16 maximum fodder yield (55.59 t ha^{-1}) and (55.91 t ha^{-1}) respectively was obtained with application of H_2SO_4 @ 100% GR (Table 5 and 6). Among the tillage implements used, it was observed subsoiler yielded maximum fresh fodder yield (51.65 t ha^{-1}) and (52.28 t ha^{-1}) during 2014-15 and 2015-16 respectively.

Table 5. Effect of tillage implements and amendments on oats fodder yield (t ha^{-1}) 2014-15.

Treatments	Amendments					Mean
	Control	H_2SO_4 50% GR of soil	H_2SO_4 100% GR of soil	Gyp. 50% GR of soil	Gyp. 100% GR of soil	
Disc Plough	38.13 i	45.80 gh	53.30 cd	46.47 gh	51.77 cdef	47.09 C
Rotavator	37.30 i	44.93 h	53.17 cde	44.03 h	49.97 ef	45.88 D
Chisel plough	40.00 i	49.07 fg	57.07 ab	50.40 def	54.80 bc	50.27 B
Subsoiler	40.20 i	51.13 def	58.83 a	50.40 def	57.67 ab	51.65 A
Mean	38.91D	47.73 C	55.59 A	47.82 C	53.55 B	

LSD for Treatment =1.133, LSD for Amendments = 1.7208

LSD for Treatment * Amendments = 3.4416.

Table 6. Effect of tillage implements and amendments on oats fodder yield (t ha^{-1}) 2015-16.

Treatments	Amendments					Mean
	Control	H_2SO_4 50% GR of soil	H_2SO_4 100% GR of soil	Gyp. 50% GR of soil	Gyp. 100% GR of soil	
Disc Plough	39.97 k	44.90 i	53.97 c	49.37 g	53.50 cd	47.74 C
Rotavator	35.50 k	44.33 i	53.37 cd	47.30 h	52.03 de	46.51 D
Chisel plough	37.20 jk	50.13 fg	57.27 ab	51.10 efg	57.13 b	50.57 B
Subsoiler	38.90 j	51.63 def	59.03 a	53.10 cd	58.67 ab	52.28 A
Mean	37.14 D	47.75 C	55.91 A	50.22 B	55.33 A	

LSD for Treatment = 1.2962, LSD for Amendments = 0.7674

LSD for Treatment * Amendments = 1.5347.

Interactive effect of amendments and tillage implements depicted that the highest fodder yield was observed using the subsoiler with H_2SO_4 @ 100% GR however it remained insignificant with gypsum @ 100% GR and subsoiler in first, second and third oat crop. The minimum fodder yield of oat was observed with rotavator + H_2SO_4 @ 50% GR for all three seasons.

Table 7. Effect of tillage implements and amendments on soil pH_s at the end of study.

Treatments	Control	H_2SO_4 50% GR of soil	H_2SO_4 100% GR of soil	Gyp. 50% GR of soil	Gyp. 100% GR of soil
T_1: Disc Plough	8.59	8.50	8.48	8.50	8.48
T_2: Rotavator	8.61	8.53	8.50	8.52	8.49
T_3: Chisel plough	8.58	8.50	8.46	8.49	8.45
T_4: Subsoiler	8.57	8.48	8.44	8.48	8.44

Soil properties

Data regarding the soil salinity index i.e (pH_s, EC_e and SAR) showed that amendments, tillage implements and their interaction significantly improved these properties at the end of the study (Table 7-9). With respect to soil pH_s a minimum value of 8.44 was recorded where subsoiler was used with H_2SO_4 and gypsum @ 100% GR and it was under the safe limits as compared to its initial value of 8.62. Similarly, EC_e and SAR were also improved remarkably with the use of subsoiler and amendments. Minimum EC_e and SAR were 3.19 and 22.91 respectively in the treatments where subsoiler and H_2SO_4 @ 100% GR were used in combination.

Discussion

Soil degradation due to salinity is a common phenomenon of arid to semi-arid regions of the world. The hyper salinized environment adversely affects the soil chemical, physical and biological activities and ultimately the soil productivity. Hence, long term improvement of such problematic soils to restore their original potential for crop production is a challenging and required an effective management strategy. Saline sodic soils are generally dense with low hydraulic conductivity and high bulk density than normal soil and required an appropriate tillage system to improve these physical properties. Salt affected soil due to their poor physical properties need to be tilled (Birkas *et al.,* 2008). However. Different tillage systems have different impacts on soil properties and crop growth conditions (Jabro *et al.,* 2011). Different soil properties affected by tillage practices are soil infiltration rate, porosity, bulk density air capacity and water holding capacity (Strudley *et al.,* 2008).

Table 8. Effect of tillage implements and amendments on soil EC_e (dSm^{-1}) at the end of study.

Treatments	Control	H_2SO_4 50% GR of soil	H_2SO_4 100% GR of soil	Gyp. 50% GR of soil	Gyp. 100% GR of soil
T_1: Disc Plough	3.97	3.51	3.35	3.52	3.34
T_2: Rotavator	4.13	3.60	3.47	3.59	3.46
T_3: Chisel plough	3.81	3.35	3.27	3.36	3.28
T_4: Subsoiler	3.75	3.30	3.19	3.31	3.20

Nevertheless, deep tillage alone is not useful to reclaim such salt-affected soils and some suitable amendments are required in combination with deep ploughing (Azhar *et al.*, 2001). Therefore, in the present study, we used gypsum and H_2SO_4 with different tillage implements to reclaim the salt-affected soil. Results of our study elaborated that the fodder yield of sorghum and oats crops increased gradually and was the highest in 3rd year where the H_2SO_4 and gypsum were applied @ 100% GR. Among the tillage implements, the subsoiler showed its supremacy over all other tillage implements.

Table 9. Effect of tillage implements and amendments on soil SAR at the end of study**.**

Treatments	Control	H_2SO_4 50% GR of soil	H_2SO_4 100% GR of soil	Gyp. 50% GR of soil	Gyp. 100% GR of soil
T_1: Disc Plough	28.45	25.85	23.95	25.82	23.96
T_2: Rotavator	28.84	26.19	24.82	26.21	24.71
T_3: Chisel plough	28.10	25.48	23.51	25.47	23.48
T_4: Subsoiler	27.96	25.11	22.91	25.08	22.95

The greater fresh fodder yield of sorghum and oats crops in treatment receiving H_2SO_4 and gypsum@ 100% GR may be attributed to ameliorative effect of H_2SO_4 and gypsum, H_2SO_4 react with the native $CaCO_3$ formed $CaSO_4$, which replaced the Na^+ out of root zone (Sharma *et al.*, 1996), consequently lowered the soil pH_s, EC_e and SAR as shown in our study (Table 7-9).

Furthermore, deep tillage through subsoiler increased the soil permeability and soluble salts leached out from root zone, cut off the capillary movement of groundwater and prevented the rise of dissolved salts to the soil surface (Xiong *et al.,* 2012). Similar results were reported by Sadiq *et al.* (2006) who reported that H_2SO_4 application along disc plow accelerated the amelioration process of salt-affected soils by lowering the soil pH_s, EC_e and SAR and promoted the paddy/grain yield of rice-wheat crops. H_2SO_4 is more efficient than gypsum in lowering the soil ESP (Vadyanina and Roi, 1971) which reinforced the findings of the present study. Positive effects of gypsum on soil health by improving the chemical and physical properties have been reported by several researchers (Lim *et al.,* 2011; Singh *et al.,* 2014; Kim *et al.,* 2016).

The favorable soil conditions for plant growth and microbial activities depend on its physical and chemical properties (Mulumba and Lal, 2008). The deep tillage and amendments application produced the conditions that were conducive for crop production and sustainability that is why the fodder yield of sorghum and oat was maximum with H_2SO_4/gypsum and subsoiler. The deep tillage may increase wheat yield 8% to12% (Khokhar and Nizami, 1987) which supports the findings of the current study. Amelioration of saline-sodic by deep tillage, green manuring and gypsum significantly increased the grain and straw yield of wheat (Singh *et al.,* 2014) which is in agreement with our results. Islam *et al.* (2015) also reported that gypsum with organic manure and tillage is the right choice to manage the silty-loam soils. Gypsum application with disc harrowing in sodium affected soil improved the SAR, bulk density and infiltration of water and increased the yield of sunflower crop as compared to with no-till without gypsum (Costa *et al.,* 2016) which are inconsistent with findings of the current study.

Conclusion

Soil is a natural resource and its health for crop production is determined by the integrated effect of management techniques. Amelioration of saline-sodic soil to preserve the soil quality is a complex phenomenon and required a mechanical intervention with suitable amendments. In this study we used different tillage systems with gypsum and H_2SO_4. From the above results, it can be concluded that the application of H_2SO_4 and gypsum @ 100 % gypsum requirement of soil with subsoiler can be a very effective technology to accelerate the reclamation process of salt-affected soil and is recommended to farmers for adoption to achieve production potential of salt-affected soils.

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