DOI: 10.1515/cerce-2017-0002
Original Article
Available online: www.uaiasi.ro/CERCET_AGROMOLD/
Print ISSN 0379-5837; Electronic ISSN 2067-1865

Cercetări Agronomice în Moldova
Vol. L , No. 1 (169) / 2017: 19-29

COMPARISON THE EFFICIENT RECLAMATION OF DIFFERENT INORGANIC MATERIALS WITH ORGANIC AMENDMENTS TO RICE-WHEAT CROP SUSTAINABLE PRODUCTION IN SALT-AFFECTED SOILS

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Received Dec. 09, 2016. Revised: Jan. 30, 2017. Accepted: Feb. 02, 2017. Published online: Apr. 14, 2017

ABSTRACT. Amelioration of salt-affected soils requires an integrated management approach, which not only improves their effectiveness for improving soil properties, but also increases the crop production and quality of the produce. Hence, a study was planned to evaluate combined use of organic and inorganic amendments for better rehabilitation of salt affected soil in rice-wheat cropping sequence from 2013 to 2016. Treatments included T_1 - control, T_2 - gypsum @ 100 SGR, T_3 - $CaCl_2$ @ 50% SGR, T_4 - $CaCl_2$ @ 50% SGR + biogas slurry @ 10 t·ha^{-1}, T_5 - H_2SO_4 @ 25% GR, T_6 - H_2SO_4 @ 25% SGR + biogas slurry @10 t·ha^{-1}. A saline sodic field was selected, prepared and leveled. Composite soil samples were collected and analyzed for pH_s = 9.15, EC_e (dS m^{-1}) = 4.86, SAR (mmol L^{-1})$^{1/2}$ = 42.52 and GR (t·ha^{-1}) = 8.64. Experiment was laid out in RCBD with three replications. The inorganic amendments (gypsum and $CaCl_2$) were applied 30 days before rice transplanting in the respective treatment plots, followed by leaching while biogas slurry was applied 15 days before transplanting and H_2SO_4 was applied with first irrigation. Recommended dose of fertilizer 120-110-70 NPK kg ha^{-1} for wheat (Inqlab-91) and 110-90-60 NPK kg ha^{-1} for rice (Shaheen Basmati) was applied. Soil samples were collected before application of amendment and after harvesting of each crop. Straw and grain/paddy yield data were recorded at maturity. Pooled data showed that grain/paddy and straw yield of wheat and rice crop was higher in T_2 (gypsum @ 100% SGR), but statistically ($P \leq 0.05$) non significant with T_4 ($CaCl_2$ @ 50% SGR + biogas slurry @ 10 t·ha^{-1}). T_3 ($CaCl_2$ @ 50 % SGR) was at par with T_6 (H_2SO_4 @ 25% SGR + biogas slurry @ 10 t·ha^{-1}), followed by T_5 (H_2SO_4 @ 25% SGR). The minimum yield was recorded in T_1 (control). Soil analysis showed that pH_s, EC_e and SAR were significantly decreased in T_2, (Gypsum @ 100% SGR), followed by T_4 ($CaCl_2$

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@ 50% SGR + biogas slurry @ 10 t·ha^{-1}). Hence, $CaCl_2$ @ 50% SGR + biogas slurry @ 10 t·ha^{-1} may be an effective alternative reclamation strategy for areas that are restricted use because of salinity.

Keywords: gypsum; calcium chloride; reclamation; rice; wheat.

Abbreviations used: EC_e (electrical conductivity of soil extract); pH_s (pH of soil saturated paste); SAR (sodium absorption ratio); SGR (soil gypsum requirement)

INTRODUCTION

Salinity-induced soil degradation is the leading widespread threat with severe negative impact on sustainable crop production around the globe (Katerji *et al.*, 2009). Salt-affected soils occur within the boundaries of at least 75 countries (Qadir *et al.*, 2007) and assumed significant global dimension as about approximately 800 million hectares are affected by this menace (Munns, 2005). Soil salinity considerably limits crop production especially in arid to semi-arid areas due to low rainfall and high evaporative demand and the consequences are damaging in both socioeconomic and environmental terms. Pakistan is by far no different from others with more than 6.67 m ha of salt affected which is nearly 1/3rd of total cultivated area (Khan, 1998) and this figure is sharply increasing each year (Ashraf *et al.,* 2004). Generally, salt-affected soils are ameliorated through a readily available source of calcium (Feizi *et al.*, 2010) and may be used after reclamation (Chaudhary *et al.*, 2004). Flushing of Na^+ out of root zone is the most effective and familiar technique for lowering its accumulation in salt affected soils (Ghafoor *et al.*, 2008).

Nearly a century-old record reveals that several products like $CaCl_2$, H_2SO_4 and $CaSO_4$ and elemental sulphur (S) have been used as soil amendments, which can be brought back salt affected soils to a highly productive state (Hilal and Abd-Elfattah, 1987). Application of calcium amendments is a prerequisite to reclaim salt affected soils, which act as soil modifiers and improve various soil properties and prevent the development of salinity/sodicity hazards (Muhammad and Khattak, 2011). Gypsum is widely used as source of calcium, which directly replaces the exchangeable Na^+ on the clay exchange complex. Moreover owing to its accessibility, low-priced and ease of handling (Amezketa *et al.,* 2005) it is extensively practiced as reclament to counteract the injurious effects of high sodium leading to considerable decrease in electrical conductivity and sodium adsorption ratio of soil (Hamza and Anderson, 2003). However, gypsum is relatively insoluble and below 40ºC it has lowest solubility (Azimi *et al.,* 2007) in water, whereas $CaCl_2$ is more soluble in water than gypsum (Oster, 1982) and both the chemical behave similarly in calcareous soil (Shainberg *et al.,* 1982). Likewise, recently considerable research has been undertaken, which elucidate that use of organic matter is also an efficient approach for remediation of salt-affected soils (Pang *et al.,* 2010). Addition of organic amendments promotes the sustainability of agricultural system due to its long-term ameliorative effects on physical, chemical and biological properties of soil (Ould-Ahmed *et al.,* 2010).

Biogas slurry is by product of biogas production and considered as a good source of mineral nutrients for plant growth, which helps to improve the quality and quantity of crop production (Liu *et al.,* 2008). As it contains organic matter contents and essential nutrients, hence it can be used as soil ameliorant for improving soil health (Garg *et al.,* 2005). It not only precludes the salt prone degradation of soil, but also preserves its productivity and fertility status (Rekhi *et al.,* 2000). Being rich nitrogen source, biogas slurry can also improve the quality of crop residues and grass silage of poor quality. There are several evidences supporting the fact that the productivity of agricultural land can be increased dramatically with the use of manure produced from biogas (Krishna, 2001). Therefore, using biogas slurry is, generally, seen as an important issue for improving the soil health and sustainability of agricultural land (Yu *et al.,* 2010). Hence, biogas slurry application is a practicable strategy for improving the physical and chemical properties of soil and nutritional quality of crop production in sustainable agriculture (Ding *et al.,* 2011).

Acid or acid forming material like H_2SO_4, HCL, HNO_3, S can also be used as amendment, which mobilizes the native Ca^{2+} of calcareous soils and enhanced the conversion of $CaCO_3$ into more soluble $CaSO_4$, $Ca(HCO_3)_2$, or $CaCl_2$ (Singh *et al.,* 1981; Ghafoor and Muhammad, 1981). Acids (H_2SO_4, HCl, HNO_3) may prove more efficient in decreasing the soil pH_s, EC_e and ESP than gypsum (Ghafoor and Muhammad, 1981). Previously, it was shown that application of gypsum, H_2SO_4, HCl and $CaCl_2$ all @ 75 SGR were equally effective in decreasing EC_e and SAR of sandy clay loam soil, however gypsum produced better yield of wheat and H_2SO_4 that of rice (Ghafoor *et al.,* 1986). Finally, different chemical amendments act as direct or indirect source of Ca^{2+}, however choice of amendment depend on its cost, handling, time of application and its relative effectiveness for improvement of soil health and crop production.

Keeping the above fact in viewed, a three year experiment was carried out to determine the effectiveness of different amendments in combination or individually for amelioration of saline sodic soil in rice-wheat cropping sequence.

MATERIALS AND METHODS

Description of experimental site

A field study was carried for three consecutive years (2013 to 2016), following rice-wheat crop rotation, i.e. starting in mid-July 2013 (rice) and ending in April 2016 (wheat) at Soil Salinity Research Institute, Pindi Bhattian, Pakistan (altitude 184 m, latitude 31.8950° N and longitude 73.2706° E), to investigate the comparative effectiveness of different amendments in improving soil properties and productivity of rice wheat crop under salt affected conditions. The experimental site was saline-sodic and sandy loam in nature. At the beginning of experiment, the soil had pH_s = 9.15, EC_e (dS m^{-1}) = 4.86 and SAR (mmol $L^{-1})^{1/2}$ = 42.52 with soil gypsum requirement (SGR) of 8.64 t ha^{-1} for 0-15 cm soil depth. The average weather conditions were: 12.9 ± 3.4°C minimum temperature, 40.7 ± 3.5°C maximum temperature, 37.5 ± 4.8% minimum relative humidity, 70.6 ± 5.5% maximum relative humidity, maximum sunshine hours, 14 h and 10 min and minimum sunshine hours, 7 h and 35 min.

Treatment details

The treatments applied in randomized complete block design (RCBD) were: T_1 = control; T_2 = gypsum @ 100% GR; T_3 = $CaCl_2$ @ 50 % GR; T_4 = $CaCl_2$ @ 50% GR + biogas slurry @ 10 t·ha^{-1}; T_5 = H_2SO_4 @ 25% GR; T_6 = H_2SO_4 @ 25% GR + biogas slurry @ 10 t·ha^{-1}.

Net plot size was of 4 m x 6 m with three replications and three crops each of rice and wheat were grown in rotation within the same field. Rice cultivar "Shaheen Basmati" was transplanted in 2nd week of July and wheat cultivar "Inqlab-91" was sown in 3rd week of November. Recommended dose of the fertilizer applied was 110-90-70 and 120-110-70 NPK kg ha^{-1} for rice and wheat, respectively, as urea, single super phosphate and sulphate of potash. Gypsum (80% pure, 30 mesh size) and $CaCl_2$ (90% pure) were applied one month before transplanting of rice seedlings in respective treatment plots and were leached with canal water while biogas slurry was applied 15 days before transplanting and H_2SO_4 was applied with first irrigation according to treatment plan. There was no addition of any amendments in control plots.

Observations recorded

Composite soil samples were collected before the start of experiment and after the harvest of each crop in each season and were analyzed for determination of pH_s, EC_e and SAR, by following the methods as described by the US Salinity Lab. Staff (1954). Paddy/grain and straw yield was recorded at time of harvesting of each crop.

Statistical analysis

The data collected during three years was pooled up and statistically analyzed following analysis of variance (ANOVA) technique under randomized complete block design, while the least significance difference (LSD) test was used to compare the differences among treatment means (Steel *et al.*, 1997).

RESULTS

Effect of different inorganic and organic amendments on rice paddy yield (Mg ha^{-1})

Paddy yield is a critical yield attribute in rice production, which was improved considerably by all the treatments (*Table 1*). Average of three seasons (*Table 1*) showed that different amendments had significant effect on rice paddy yield. Treatment using gypsum @ 100% SGR recorded the statistically ($P \leq 0.05$) maximum paddy yield (3.43 Mg ha^{-1}), however it was non-significant with $CaCl_2$ @ 50% SGR + biogas slurry @ 10 t·ha^{-1} (3.32 Mg ha^{-1}). $CaCl_2$ @ 50% SGR produced mean paddy yield of

3.01 Mg ha^{-1}, which was statistically significant with H_2So_4 @ 25% SGR + biogas slurry@ 10 t·ha^{-1} (2.84 Mg ha^{-1}). Whereas minimum paddy yield (2.19 Mg ha^{-1}) was recorded in control where no amendment was used.

Table 1 - Comparative effect of different inorganic and organic amendments on rice paddy yield (Mg ha^{-1})

Treatments	2013	2014	2015	Mean
Control	1.92 D	2.30 D	2.34 D	2.19 E
Gypsum @ 100% SGR	3.08 A	3.58 A	3.63 A	3.43 A
$CaCl_2$ @ 50% SGR	2.60 B	3.30 B	3.13 B	3.01 B
$CaCl_2$ @ 50% SGR + biogas slurry @ 10 t· ha^{-1}	2.96 A	3.48 AB	3.52 A	3.32 A
H_2SO_4 @ 25% SGR	2.40 C	2.77 C	2.83 C	2.66 D
H_2SO_4 @ 25% SGR + biogas slurry@ 10 t·ha^{-1}	2.55 B	2.94 C	3.05 B	2.84 C
LSD	0.1363	0.1800	0.2126	0.1269

Means sharing the same letters are statistically similar at *P*≤ 0.05.

Table 2 - Comparative effect of different inorganic and organic amendments on rice straw yield (Mg ha^{-1})

Treatments	2013	2014	2015	Mean
Control	3.68 D	4.42 D	4.49 D	4.20 E
Gypsum @ 100% SGR	6.90 A	8.03 A	8.13 A	7.69 A
$CaCl_2$ @ 50% SGR	5.98 B	6.82 B	7.01 B	6.60 B
$CaCl_2$ @ 50% SGR + biogas slurry @ 10 t·ha^{-1}	6.80 A	7.89 A	8.12 A	7.60 A
H_2SO_4 @ 25% SGR	5.28 C	6.08 C	6.22 C	5.86 D
H_2SO_4 @25% SGR + biogas slurry @ 10 t·ha^{-1}	5.61 C	6.29 BC	6.70 BC	6.20 C
LSD	0.3597	0.5305	0.6568	0.2125

Means sharing the same letters are statistically similar at *P*≤ 0.05.

Effect of different inorganic and organic amendments on rice straw yield (Mg ha^{-1})

As far as straw yield is concerned mean value of three consecutive seasons showed statistically difference between the applied treatments and maximum straw yield (7.69 Mg ha^{-1}) was with application of gypsum @ 100% SGR, which was at par (*P*≤ 0.05) with $CaCl_2$ @ 50 % SGR + biogas slurry @ 10 t·ha^{-1} with straw yield of (7.60 Mg ha^{-1}) (*Table 2*). While minimum average straw yield (4.20 Mg ha^{-1}) was recorded in control.

Effect of different inorganic and organic amendments on wheat grain yield (Mg ha^{-1})

Concerning the effect of different amendments on wheat grain yield, data showed a noticeable effect of all the treatment used than control (no amendment) (*Table 3*). Overall mean values for grain yield showed that maximum grain yield (3.19 Mg ha^{-1}) was produced in gypsum @ 100% SGR, which was slightly higher in $CaCl_2$ @ 50% SGR + biogas slurry @ 10 t·ha^{-1} (3.06 Mg ha^{-1}) and difference between two treatments was not large enough to reach level of significance ($P \leq 0.05$). T_1 (control) led to minimum grain yield of 2.00 Mg ha^{-1}, in comparison with those of other applied treatments.

Table 3 - Comparative effect of different inorganic and organic amendments on wheat grain yield (Mg ha^{-1})

Treatments	2013	2014	2015	Mean
Control	1.79 E	2.08 D	2.14 D	2.00 D
Gypsum @ 100% SGR	2.92 A	3.21 A	3.44 A	3.19 A
$CaCl_2$ @ 50% SGR	2.46 C	2.78 B	2.84 B	2.69 B
$CaCl_2$ @ 50% SGR + biogas slurry @ 10 t·ha^{-1}	2.68 B	3.11 A	3.39 A	3.06 A
H_2SO_4@ 25% SGR	2.14 D	2.48 C	2.58 C	2.40 C
H_2SO_4 @ 25% SGR + biogas slurry @ 10 t·ha^{-1}	2.41 C	2.53 C	2.73 BC	2.55 B
LSD	0.2195	0.1334	0.2510	0.1486

Means sharing the same letters are statistically similar at $P \leq 0.05$

Table 4 - Comparative effect of different inorganic and organic amendments on wheat straw yield (Mg ha^{-1})

Treatments	2013	2014	2015	Mean
Control	2.02 D	2.54 D	2.52 D	2.36 E
Gypsum @ 100% SGR	3.35 A	3.81 A	3.87 A	3.67 A
$CaCl_2$ @ 50% SGR	2.63 B	3.36 B	3.40 B	3.13 C
$CaCl_2$ @ 50% SGR + biogas slurry@ 10 t·ha^{-1}	3.16 A	3.72 A	3.81 A	3.56 B
H_2SO_4 @ 25% SGR	2.34 C	2.98 C	3.02 C	2.78 D
H_2SO_4 @ 25% SGR + biogas slurry @ 10 t·ha^{-1}	2.74 B	3.31 B	3.33 B	3.12 C
LSD	0.2444	0.2956	0.1803	0.1070

Means sharing the same letters are statistically similar at $P \leq 0.05$.

Effect of different inorganic and organic amendments on wheat straw yield (Mg ha^{-1})

Amendments application had pronounced effect on straw yield characteristic of wheat crop than control (no amendment) (*Table 4*). A progressive increase in case of straw yield (3.67 Mg ha^{-1}) was computed in gypsum @ 100% SGR, followed by $CaCl_2$ @ 50 % SGR + biogas slurry @ 10 t·ha^{-1}, which were, however, statistically significant among themselves. When compare these value with control, lowest straw yield

(2.36 Mg ha^{-1}) was given by control (T_1).

Effect of different inorganic and organic amendments on soil properties

Results from our study revealed that regardless of the amendments used, soil chemical properties were substantially improved by all the treatments after three years of experimentation (*Table 5*). Nearly all salinity indicators, i.e pH_s, EC_e and SAR, were gradually decreased with varying levels of different amendments used. Among all the treatments, gypsum @ 100% SGR was most effective to dropped pH_s value by 8.60, followed by $CaCl_2$ @ 50% SGR + biogas slurry @ 10 t·ha^{-1} lowering pH_s value by 8.68, whereas with control decreased in pH_s was only 8.91 of their respective initial values. Similarly, gypsum @ 100% SGR appreciably lowered the EC_e and SAR by 3.97 and 23.84, respectively, and $CaCl_2$ @ 50 % SGR + biogas slurry @ 10 t·ha^{-1} lowered the EC_e and SAR by 4.06 and 27.82, respectively, at the end of study, and control (untreated) was less efficient in decreasing all these salinity indicators when compared with the amendments.

Table 5 - Comparative effect of different inorganic and organic amendments on chemical properties of soil at end of study

Treatments	pH_s	Ec_e	SAR
Control	8.91 A	4.69 A	37.95 A
Gypsum @ 100% SGR	8.60 C	3.97 D	23.84 D
$CaCl_2$ @ 50% SGR	8.76 B	4.08 C	32.41 B
$CaCl_2$ @ 50% SGR + biogas slurry@ 10 t·ha^{-1}	8.68 C	4.06 C	27.82 CD
H_2SO_4 @ 25% SGR	8.81 B	4.18 B	32.87 B
H_2SO_4 @ 25% SGR + biogas slurry@ 10 t·ha^{-1}	8.78 B	4.08 C	32.01 BC
LSD	0.0795	0.0774	4.3446

DISCUSSION

Approximately 70% salt degraded soils in Pakistan are subjected to fossil salinity/sodicity and should be reclaimed by chemical amendments or combination of chemical and biological amendments (Muhammed, 1983). Replacement of excessive exchangeable Na^+ from root zone with any Ca-amendment is the most effective and familiar approach for lowering its buildup in salt-affected soils (Ghafoor *et al.,* 2008), as it impair the soil properties to adversely affect the plant growth. Recently, several amendments are being used for reclamation and improvement of saline and alkaline soil, such as $CaCl_2$, elemental sulfur (S), H_2SO_4 and $CaSO_4$ (Hilal and Abd-Elfattah 1987). Gypsum is the most promising and effective amendment for sodic soil reclamation because of its availability, low-priced and ease of handling (Amezketa *et al.,* 2005, Abd El-Hady and Shaaban 2010). Gypsum is relatively insoluble and it has lowest solubility in water below 40ºC (Azimi *et al.,* 2007), whereas $CaCl_2$ is more soluble in water than gypsum (Oster, 1982). Both chemicals are similarly with calcareous soil (Shainberg *et al.,* 1982). Addition of organic matter promotes sustainability of salt-affected soils because of its long-term ameliorative effects on physical, chemical and biological properties of soil (Pang *et al.,* 2010; Ould-Ahmed *et al.,* 2010). Results of our study revealed that different amendments used, significantly increased yield attributes of rice and wheat crop than non amended soil (control). Pooled data showed that among all the treatments, gypsum @ 100% SGR and $CaCl_2$ @ 50% SGR + biogas slurry @ 10 $t{\cdot}ha^{-1}$ proved superior to improve the yield of rice and wheat crops in term of paddy/grain and straw yield over all other treatments. Increased yield of rice and wheat with treatments receiving the gypsum and $CaCl_2$ + biogas slurry than untreated soils can be explained by the ameliorative role of these amendments in alleviating the harmful effects of salinity and sodicity by replacing the Na^+ from exchange site, also after leaching of Na^+ from root zone, crop might also benefited by the improved physical properties of soil leading to more crop growth in these treatments (Hussain *et al.,* 2001, Tzanakakis *et al.,* 2011, Mohamed *et al.,* 2012). Similarly, after decomposition biogas slurry improved the fertility of soil by providing the N, P, and K, total N and P (Moler and Stinner, 2009; Urselmans *et al.,* 2009; Yu *et al.,* 2010), with more microbial activity that results into more root proliferation and water uptake, which in turn had increased yield attributing characters of rice and wheat crop in treatment receiving biogas slurry. Increased crop production with use of gypsum (Hussain *et al.,* 2001; Ghafoor *et al.,* 2001), $CaCl_2$ (Ahmad *et al.,* 2001) and biogas slurry (Ahmad *et al.,* 2014; Ahmad *et al.,* 2015) in salt affected soil has been reported earlier, which reinforced the findings of this study.

Soil qualities

Composite soil sample were taken at end of study and analyzed for pH_s, EC_e, and SAR of soil. Results showed a sharp falling trend in salinity indicators (pH_s, EC_e and SAR) in all treatments receiving amendments than untreated soil (control). Since soil pH_s is a soil feature depicting an overall picture of growth medium, including nutrient availability, fate of added nutrients, and sodicity status, this change is very important. Further release of Ca^{2+} from gypsum and $CaCl_2$, which replaces the exchangeable Na^+ and its leaching from root zone might be the major reason of reduced pH_s, EC_e and SAR. With respect to pH, obtained data showed that gypsum @ 100% SGR recorded the minimum pH value (8.55), followed by $CaCl_2$ + biogas slurry (8.60) at end of study, in comparaison with control having the pH value of 8.82. Decreasing pH by application of gypsum and $CaCl_2$ may be attributed with release of Ca^{2+} from these amendments, which replace the exchange Na^+ and subsequently leach down from root zone (Abdel-Fattah 2012). The removal of Na^+ might be the major reason of reduced SAR within these treatments. With respect to EC_e, data illustrated that gypsum and $CaCl_2$ with biogas slurry efficiently removed the salts from root zone than any other treatments. Decreased ECe in these treatments may be attributed to improve hydraulic conductivity due to which salts were leached down more effectively (Richards, 1954; Oster, 1982).

CONCLUSION

Generally, the soils degraded by salinity and sodicity are reclaimed technically and economically using different chemicals amendments depending upon intensity and type of salinity problem. Therefore, there is dire need to develop efficient reclamation technology since this soil can be used in intensive agriculture after reclamation. Knowledge for the selection of an appropriate amendment and its coordinative application with other amendment may be helpful in determining the effectiveness of reclamation technology.

From the foregoing discussion, it can be concluded that gypsum @ 100% SGR and $CaCl_2$ @ 50% SGR + biogas slurry@ 10 $t \cdot ha^{-1}$ are equally effective strategies for reclaiming sodic soil, which may divert the direction of research to reclaim such soils with conjunctive use organic and inorganic amendments.

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