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Effect of amendment sources under subsurface drainage system on physical and chemical properties of sodic soil

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Abstract
The present investigation was undertaken to study the effect of amendment sources under subsurface drainage system on physical and chemical properties of sodic soil classified as a fine montmorillonite hyperthermic family of Sodic *Calciustert*. The field experiment was conducted at Post Graduate Institute, Research Farm, Department of Soil Science and Agricultural Chemistry, MPKV, Rahuri, during *Kharif* 2019. Experimental soil showed strongly alkaline reaction, normal electrical conductivity, medium organic carbon content and moderately calcareous.

The experiment was laid out in a randomized block design with three replication and twelve treatments. The treatment comprised of T_1: Absolute control, T_2: Gypsum as per 100% GR, T_3: Elemental sulphur as per 1/5th of GR, T_4: Zeolite @ 600 kg ha^{-1}, T_5: Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1}, T_6: Gypsum as per 50% GR + zeolite @ 600 kg ha^{-1}, T_7: Gypsum as per 100% GR + zeolite @ 300 kg ha^{-1}, T_8: Gypsum as per 50% GR + zeolite @ 300 kg ha^{-1}, T_9: Elemental sulphur as per 1/5th of GR + zeolite @ 600 kg ha^{-1}, T_{10}: Elemental sulphur as per 50% of 1/5th GR + zeolite @ 600 kg ha^{-1}, T_{11}: Elemental sulphur as per 1/5th of GR + zeolite @ 300 kg ha^{-1} and T_{12}: Elemental sulphur as per 50% of 1/5th GR + zeolite @ 300 kg ha^{-1}.

The results of investigation revealed that, the amendments applications in sodic soil under SSD system was influenced the soil physical and chemical characteristics. Significant results were found in reclamation of sodic soil. The physical properties of soil i.e. hydraulic conductivity and bulk density of sodic soil in SSD field was significantly improved by treatment Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1} at harvest of crop. ESP and exchangeable cations i.e. Ca^{2+}, Na^{+}, Mg^{+} and K^{+} content of sodic soils in SSD field after harvest of crop was significantly influenced by treatment Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1} except exchangeable Mg^{2+} which shows nonsignificant effect.

Soil organic carbon, calcium carbonate and cation exchange capacity of sodic soils in SSD field are influenced by the inorganic amendments after harvest of crop. The organic carbon content of sodic soils in SSD field was significantly higher in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1}, applied Elemental sulphur as per 1/5th of GR + zeolite @ 600 kg ha^{-1} was found significantly lower values of $CaCO_3$ and cation exchange capacity was significantly increased by the Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1}.

The SAR in which cations and anions in saturation paste extract of sodic soil in SSD system was significantly influenced by treatment Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1} after harvest of crop. Whereas, sulphate content was non-significant and carbonates was in trace amount.

Keywords: Subsurface drainage, gypsum, elemental sulphur, zeolite, sodic soil

Introduction

In India, salt affected soils currently constitute 6.74 million ha in different agro-ecological regions, the area is likely to increase to 16.2 million ha by Vision 2050 (CSSIR, 2015). Sodic soils cover >50% (3.77 M ha) of the total salt-affected area (6.74 M ha) of India, and in Maharashtra 0.42 M ha of the total salt-affected area (0.60 M ha). According to one estimate (Mandal *et al*., 2010) [1] an area of 6.74 M ha in India suffers from salt accumulation out of which 3.78 M ha (~56 per cent) are sodic while, 2.96 M ha (44 Per cent) are saline soils and in Maharashtra total area under salt affected soil is 0.60 M ha out of which saline soil contain 0.18 M ha and sodic soil having 0.42 M ha. In Maharashtra highest sodicity affected area is in Ahmednagar district (26,500,0 ha) followed by Nashik (40,000 ha), Aurangabad (31,000 ha), Pune (26,000 ha) and Solapur (20,000 ha) Singh *et al.*, (2010) [1].

Sodic soils are those which have an exchangeable sodium percentage (ESP) of more than 15, PHS values will be more than 8.5, and ECe will be less than 4 dSm^{-1}. Excess exchangeable sodium has an adverse effect on the physical and nutritional properties of the soil (Richards, 1968) with consequent reduction in crop growth, significantly or entirely. Contrary to the saline soils having excessive levels of chlorides and sulphates of Na^{+}, Ca^{2+}, and Mg^{2+}, sodic soils contain high amounts of CO_3^{2-} and HCO_3^{-} salts (Sharma *et al.*, 2016) [2]. Soil sodicity is characterized by high pH, high water soluble and exchangeable sodium, low biological activity, poor physical properties and deficiency of many essential nutrients. Exchangeable sodium and pH decrease soil permeability, available water capacity and infiltration rates through swelling and dispersion of clays as well as slaking of soil aggregates (Lauchli and Epstein, 1990) [4].

Basically, reclamation or improvement of sodic soils requires the removal of part or most of the exchangeable sodium and its replacement by the more favourable calcium ions in the root zone (Tanji and Deveral, 1985) [5]. Gypsum promote leaching and create conducive environment for ionic reactions at soil exchange complex. The addition of gypsum in salt affected soil can removes the excess of Na^{+} from soil profile by leaching process and also improvement of chemical soil properties such as electrical conductivity and sodium adsorption ratio (Amezketa *et al*., 2005) [7]. Elemental sulphur which on oxidation in soil forms sulphurus acid (H_2SO_3). These sulphurus acid neutralize the calcium carbonate and release the calcium in soil (Abdelhamid *et al*., 2013) [6]. The zeolite clay mineral has comb like structure in which the cations like Ca^{2+} and NH_4^{+} are catch hold and release in soil slowly. Clinoptilolite adsorbs Na^{+} and Cl^{-} which enter into the cavities and consequently improves the soil properties (Noori *et al.*, 2007) [12]. If sodium is present, amendments like gypsum, Elemental sulphur and zeolite (Ramesh *et al*., 2011) [13] should be used to leach out sodium to desired level from the exchange sites to reclaim the salt affected soils (Kuligod *et al*., 2002) [8].

In improvement of salt affected soils drainage plays an important role. Among the different types of drainages open drains and subsurface drains are important. In open drains nearly 10-12 per cent cultivated land is wasted and in addition maintenance is required for removal of silt quite often, otherwise they will not be effective. Subsurface drainage is considered as a most suitable approach for groundwater balance and land and water management practices containing the groundwater table at a suitable level (Luthin 1978; Gates and Grismer, 1989) [11, 9]. For reasonably quick results cropping must be preceded by the application of soil amendments gypsum, followed by leaching for removal of salts derived from the reaction of the amendment with the sodic soil, that leachate are drain out by installation of subsurface drainage system in soil (Goel and Tiwari, 2015) [10].

Material and Methods

Layout and Experimental design

A field experiment on sodic soil was conducted during *kharif* 2019, at Post Graduate Institute Research Farm of Department of Soil Science and Agricultural Chemistry, MPKV., Rahuri, Dist. Ahmednagar, Maharashtra (India). The experiment was laid out in a randomized block design with 12 treatments and 3 replications. The experimental gross plot size was 4.5 m x 3.0m i.e. 13.5m^2 and net plot size was 3.0m x 2.6m i.e. 7.8m^2. The subsurface drainage system was already installed at field with laterals spacing of 30 m apart and the experiment was laid on the same site. PVC, corrugated perforated pipe is used, perforation size is 20×15 mm, diameter is 80 mm OD and slope given to the drain pipe is 0.2 percent.

Soils Characteristic

Field experiment was conducted on salt affected soils in which sodic soils. The soil of the experimental site is classified as a fine montmorillonite hyperthermic family of Sodic *Calciustert*. The soil sample were collected and analyzed at the start of the experiment and presented in Table 1. Textural class was clayey, slow hydraulic conductivity. The chemical properties showed strongly alkaline reaction, normal electrical conductivity, Medium organic carbon content and moderately calcareous.

Table 1: Initial soil properties of experimental site

Sr. No.	Parameters	Value
I.	Soil analysis	
1.	Bulk density (Mg m^{-3})	1.58
2.	Hydraulic Conductivity (cmh^{-1})	0.20
3.	pH (1:2.5)	8.56
4.	EC (dSm^{-1})	1.23
5.	Organic carbon (%)	0.49
6.	Calcium carbonate (%)	8.90
7.	Exchangeable Ca^{2+} (cmol (p^{+}) kg^{-1})	35.80
8.	Exchangeable Mg^{2+} (cmol (p^{+}) kg^{-1})	6.08
9.	Exchangeable K^{+} (cmol (p^{+}) kg^{-1})	0.98
10.	Exchangeable Na^{+} (cmol (p^{+}) kg^{-1})	8.75
11.	CEC (cmol (p^{+}) kg^{-1})	52.64
12.	ESP	16.62
13.	SAR	12.54

Application of amendments

Amendments (Gypsum, Elemental sulphur and Zeolite) applied as per treatment with farm yard manure @ 10 t ha^{-1} to all treatment plots except T_1.

The treatment comprised of T_1: Absolute control, T_2: Gypsum as per 100% GR, T_3: Elemental sulphur as per 1/5th of GR, T_4: Zeolite @ 600 kg ha^{-1}, T_5: Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1}, T_6: Gypsum as per 50% GR + zeolite @ 600 kg ha^{-1}, T_7: Gypsum as per 100% GR + zeolite @ 300 kg ha^{-1}, T_8: Gypsum as per 50% GR + zeolite @ 300 kg ha^{-1}, T_9: Elemental sulphur as per 1/5th of GR + zeolite @ 600 kg ha^{-1}, T_{10}: Elemental sulphur as per 50% of 1/5th GR + zeolite @ 600 kg ha^{-1}, T_{11}: Elemental sulphur as per 1/5th of GR + zeolite @ 300 kg ha^{-1} and T_{12}: Elemental sulphur as per 50% of 1/5th GR + zeolite @ 300 kg ha^{-1}.

Soil analysis

In order to study the physical and chemical properties of soil, a representative composite soil sample were collected 0-30 cm depth from experimental field. Surface soil samples were drawn before sowing and after harvest of the crop. The soil samples were collected in cloth bags and then air dried in the shade for processing. The samples were then pounded thoroughly in wooden mortar with pestle and sieved through 2 mm sieve for analysis of physical and chemical properties of the soil and saturation paste extract analysis by using known standard analytical methods. The soil samples were analyzed at initial and at harvest of maize.

Results and Discussion

Effect of amendments on physical properties of sodic soil in subsurface drainage field

Bulk density

The bulk density of sodic soil was significantly less in treatment T_5: Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1} (1.50 Mg m^{-3}) which was at par with treatment T_7: Gypsum as per 100% GR + zeolite @ 300 kg ha^{-1} (1.51 Mg m^{-3}). The decreased bulk density might be because of added calcium replaced the adsorbed sodium from clay complex and leached out through SSD system from soil as soluble form of salt *viz*. sodium sulphate or sodium chloride. The removal of sodium helps to improve the soil physical condition by inhibiting flocculation, dispersion and disintegration of soil particles. As results, increased spore space, aeration and development of capillaries in soil, which in turn decreased the soil bulk density. This might be because of added amendments did provide the calcium in required quantity to replace the sodium from clay complex. This might be due to the removal of sodium which reduced the dispersion of soil particles. Similar results were reported by Bharambe *et al*. (2001) [14].

Hydraulic conductivity

The hydraulic conductivity at harvest of maize was significantly higher in treatment T_5: Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1} (0.34 cm h^{-1}) and was statistically at par with treatments T_2, T_6, T_7 and T_8 containing gypsum alone and in combination with zeolite (0.32, 0.32, 0.33 and 0.31 cm h^{-1}, respectively). The higher hydraulic conductivity after harvest of maize in SSD field might be because of decreased bulk density increased the porosity in soil and reflected in increased hydraulic conductivity of soil (Suarez *et al*., 1984) [15].

Effect of amendments on chemical properties of sodic soil in subsurface drainage field

Organic carbon

The organic carbon content of sodic soils in SSD field was significantly higher in treatment T_5: Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1} (0.56) and was at par with all the treatments except T_1 (Absolute Control). The increases organic carbon content in SSD field due to normal growth of the crop, thus crop residues have been contributed to the organic carbon content of SSD field. It may also be due to decomposition and degradation of organic matter, addition of FYM and increased in root biomass which contributed to the organic carbon content of soil. The lower values of organic carbon in sodic soils in SSD plots by ameliorating with amendments might be because of exchanged sodium degrade the organic matter and leached down from soil during reclamation process.

Calcium carbonate

The calcium carbonate content of sodic soil after harvest of maize was significantly influenced by the inorganic amendments. The application of T_8: Elemental sulphur as per 1/5th of GR + zeolite @ 600 kg ha^{-1} was found to record the significantly lower values of $CaCO_3$ (7.17%) and was statistically at par with treatments T_3, T_{10}, T_{11} and T_{12} elemental sulphur applied alone and in combination with zeolite (7.40, 7.54, 7.25 and 7.72%, respectively). The decrease in $CaCO_3$ in sodic soils in SSD field at sulphur treatments was due to the solubilization of $CaCO_3$ by the release of acid (H_2CO_3). The sulphur application produced the sulphurus acid on their oxidation, which solubilize the $CaCO_3$ in sodic soil (Abdelhamid *et al*., 2013) [6].

Cation exchange capacity

The cation exchange capacity of sodic soil in SSD field was significantly increased by the treatment Gypsum as per T_5: 100% GR + zeolite @ 600 kg ha^{-1} after harvest of maize (65.47 cmol (p+) kg^{-1} soil) and was statistically at par with other gypsum containing treatments alone and in combination with zeolite i.e. T_2, T_6, T_7, and T_8 (59.86, 62.11, 64.83 and 61.48 cmol (p+) kg^{-1} soil, respectively). The gypsum provides mainly the calcium which can exchange the cations from exchange site of clay complex. The increases in CEC might be due to more removal of soluble salts through leaching. Similar results were recorded by Bharambe *et al.* (1990) [16].

Table 2: Effect of Amendments on Physical and Chemical Properties of sodic soil in SSD Field

Treatments	Physical properties		Chemical properties		
	Bulk density	Hydraulic conductivity	Organic Carbon (%)	Calcium Carbonate (%)	CEC (cmol (p^+) kg^{-1} soil)
T1: control	1.58	0.23	0.49	8.86	53.31
T2: 100% GR	1.54	0.32	0.53	8.51	59.86
T3: 100% ES	1.56	0.29	0.52	7.40	54.98
T4: 100% Zeolite	1.57	0.26	0.51	8.72	54.11
T5: 100% GR + 100% zeolite	1.50	0.34	0.56	7.95	65.47
T6: 50% GR + 100% zeolite	1.53	0.32	0.54	8.26	62.11
T7: 100% GR + 50%	1.51	0.33	0.55	8.12	64.83
T8: 50% GR + 50% zeolite	1.54	0.31	0.54	8.45	61.48
T9: 100% ES + 100% zeolite	1.55	0.30	0.53	7.17	60.10
T10: 50% ES + 100% zeolite	1.56	0.29	0.52	7.54	55.57
T1: 100% ES + 50% zeolite	1.55	0.30	0.53	7.25	57.71
T12: 50% ES + 50% zeolite	1.56	0.28	0.52	7.72	55.16
S.Em(±)	0.009	0.008	0.02	0.24	1.74
CD at 5%	0.027	0.024	0.06	0.75	5.26
100% GR: Gypsum as per 100% GR	100% ES: Elemental sulphur 1/5th of GR		100% Zeolite: Zeolite @ 600 kg ha^{-1}		

Effect of amendments on exchangeable cations of sodic soil in subsurface drainage field

Exchangeable calcium

The exchangeable calcium content after harvest of maize was significantly highest in the treatment T_5: Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1} (49.67 cmol (p^+) kg^{-1} soil) and was statistically at par with treatment T_6: Gypsum as per 100% GR + zeolite @ 300 kg ha^{-1} (48.53 cmol (p^+) kg^{-1} soil). The adsorbed sodium on clay surface was easily replaced by the calcium, as calcium is divalent cation and sodium is monovalent cation. The replaced sodium by the calcium of gypsum ($CaSO_4.5H_2O$) was immediately combined with sulphate (SO_4^{2-}) of gypsum and forms sodium sulphate (Na_2SO_4). The sodium sulphate is soluble salts which can be easily leached out from sodic soil through SSD system and calcium remains adsorbed on surface of clay mycelli. This might be the reason for more amount of exchangeable calcium in gypsum amended sodic soils in field.

Exchangeable magnesium

The exchangeable magnesium content in sodic soil was found nonsignificant by various amendments under SSD system. Numerically, it was the highest in treatment T_5: Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1} (9.03 cmol (p^+) kg^{-1} soil) followed by elemental sulphur and zeolite. The nonsignificant results of exchangeable magnesium might be due to the magnesium in sodic soil in the form of insoluble salts like magnesium carbonate and magnesium biocarbonate.

Exchangeable sodium

The exchangeable sodium content in sodic soils in SSD field was found significantly lower in treatment T_5: Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1} (6.82 cmol (p^+) kg^{-1} soil) was statistically at par with treatment T_7: Gypsum as per 100% GR + zeolite @ 300 kg ha^{-1} (6.98 cmol (p^+) kg^{-1} soil). High calcium releases from the gypsum amendments preferentially replace the sodium from clay particles and facilitated it to leached out through SSD system.

Exchangeable potassium

The exchangeable potassium content in sodic soils in SSD field was found significantly highest in treatment T_5: Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1} (1.18 cmol (p^+) kg^{-1} soil) and was statistically at par with all the treatments except T_1 (Absolute control). Numerically the values are more or less similar. This might be associated with the potassium is always remain in soil in an equilibrium condition as exchangeable, nonexchangeable, water soluble and total potassium. Similarly, drying and wetting cycle of soil governs the potassium content in soil.

Effect of Amendments on Derived Parameters of sodic soil in Subsurface Drainage Field

Exchangeable sodium percentage

The exchangeable sodium percentage was significantly less in treatment T_5: Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1} (10.42) and was statistically at par with treatment T_7: Gypsum as per 100% GR + zeolite @ 300 kg ha^{-1} (10.77). This might be associated with addition of calcium through gypsum, replaced the other adsorbed cations from clay particles, as sodium, magnesium, potassium and ammonium etc. This phenomenon decreased the exchangeable sodium percentage in sodic soils. The decrease in soil ESP with increasing rates of amendments may be attributed to increase Ca in soil solution as a result of addition amendments which promoted Na displacement and removed by leaching process (Gharaibeh *et al*., 2009) [18].

Sodium adsorption ratio

The sodium adsorption ratio was significantly influenced by the amelioration of sodic soils with inorganic amendments in SSD field. Significantly the lowest sodium adsorption ratio was recorded in treatment T_5: Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1} (6.62) and was statistically at par with treatment T_7: Gypsum as per 100% GR + zeolite @ 300 kg ha^{-1} (7.15). The decreased SAR by amendments in sodic soil might be associated with improvement in soil physical conditions subjected to replacement of exchangeable sodium from clay complex and leached out from soil and decreased the concentration of sodium in sodic soils (Sagare *et al*. 2001) [17].

Table 3: Effect of Amendments on Derived Parameters of sodic soil in Subsurface Drainage Field

Treatments	Exchangeable Cations [cmol (p^+) kg^{-1}]				Exchangeable Sodium Percentage (ESP)	Sodium Adsorption Ratio (SAR)
	Ca^{2+}	Mg^{2+}	Na^+	K^+		
T1: control	35.63	7.90	8.21	1.04	15.40	11.41
T2: 100% GR	47.80	8.57	7.23	1.16	12.08	8.31
T3: 100% ES	38.00	8.57	7.70	1.13	14.01	10.14
T4: 100% Zeolite	35.70	8.07	8.03	1.12	14.84	11.02
T5: 100% GR + 100% zeolite	49.67	9.03	6.82	1.18	10.42	6.62
T6: 50% GR + 100% zeolite	47.57	8.67	7.16	1.17	11.53	7.65
T7: 100% GR + 50%	48.53	8.90	6.98	1.17	10.77	7.15
T8: 50% GR + 50% zeolite	46.77	8.43	7.33	1.16	11.92	8.17
T9: 100% ES + 100% zeolite	39.63	8.37	7.36	1.16	12.25	9.05
T10: 50% ES + 100% zeolite	37.06	8.63	7.56	1.14	13.60	9.91
T1: 100% ES + 50% zeolite	39.87	8.60	7.42	1.15	12.86	9.72
T12: 50% ES + 50% zeolite	35.57	8.33	7.66	1.13	13.89	10.27
S.Em(±)	0.405	0.501	0.067	0.009	0.23	0.23
CD at 5%	1.187	NS	0.198	0.065	0.701	0.680
100% GR: Gypsum as per 100% GR	100% ES: Elemental sulphur 1/5th of GR			100% Zeolite: Zeolite @ 600 kg ha^{-1}		

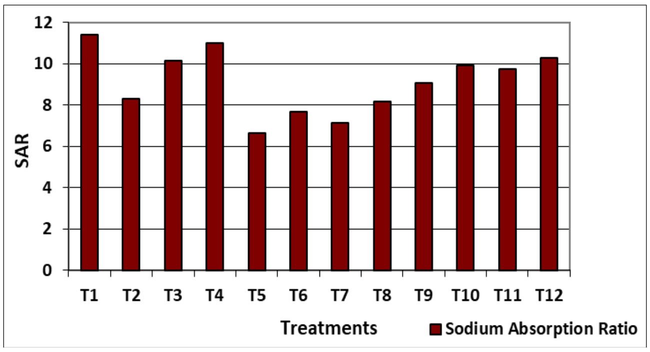

Fig 1: Effect of amendments on SAR in subsurface drainage field at harvest of maize

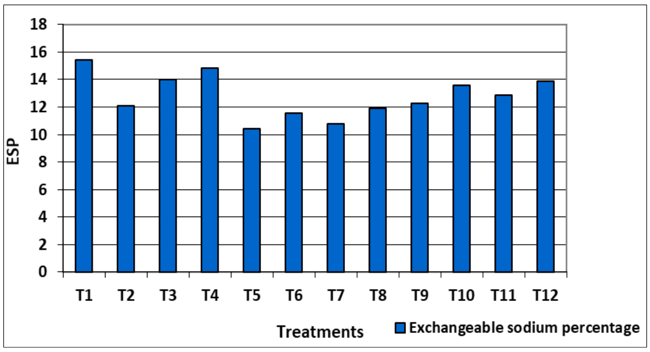

Fig 2: Effect of amendments on ESP of soil in subsurface drainage field at harvest of maize

Conclusion

The results obtained from present investigation clearly indicates the beneficial effect of combine application of gypsum with zeolite under subsurface drainage system in enhancing the improvement of soil health *viz.* physical condition (bulk density and hydraulic conductivity), chemical properties (Exchangeable cations, soluble ions, organic carbon, calcium carbonate and cation exchange capacity) and maximum soluble salt leached out through sub surface drainage system, when compared to either sole application of amendments sources and combine application of elemental sulphur with zeolite. The results discussed in earlier chapter on the basis it can be concluded that application of Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1} found beneficial for reclamation of sodic soil under subsurface drainage system. The present investigation was based on one season experimentation it needs to be verified by applying the inorganic amendments in combinations along with proper drainage system (sub surface drainage system) for better results.

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