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Remediation of a Highly Calcareous Saline Sodic Soil Using Some Soil Amendments

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Authors' contributions

This work was carried out in collaboration between both authors. Authors ON and AM designed the research work and performed the experiment, analyzed the data and wrote the first draft of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Amelioration of saline and sodic soil by organic and inorganic amendments can be improved the physical, chemical and biological properties of soil. A laboratory experiment using soil columns was conducted to evaluate the effect of different amendments on some physical and chemical properties of a highly calcareous saline sodic soil (pH= 8.3, ECe= 55 dS/m, $CaCO_3$= 26.12% and ESP=27.5%). The studied soil was treated with three amendments, viz pressmud, gypsum by-product and phosphoric acid. Pressmud (PM) was applied at rates of 0, 7.5 and 15% per kg soil whereas, gypsum by- product (G) was mixed with the upper 5 cm of the soil surface and applied to the soils at rates of 0, 2.5 and 5 g/kg. Phosphoric acid 50% (PA) was mixed with irrigation water at 0, 125 and 250 kg/fed application rates. Untreated soil was used as a control (CTRL). All treatments were replicated three times. After incubation period, leaching process was used for six months. At the ending of the experiment, the soil samples were taken from all soil columns and analyzed for some physical and chemical properties. The obtained results showed that, soil pH, ECe and ESP were decreased in all amendments either, single or in combination compared with CTRL. Soluble Na concentration was reduced, while soluble Ca and Mg were increased when addition of all amendments compared with CTRL. Moreover, data revealed that the bulk density and wilting point were decreased, while field capacity and available water were increased in all

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amendments compared to CTRL. Our study suggests that the combination of PM1+G1+PA1 effectively reclaimed a highly calcareous saline-sodic soil than all other treatments.

Keywords: Remediation; amendments; saline; sodic; soil properties.

1. INTRODUCTION

Salt-affected soils are commonly occurring in arid and semi-arid regions under poorly drained conditions. It is covering an area of 62% in more than 100 countries around the world [1,2]. It is characterized by the occurrence and accumulation of salts especially sodium ions (Na^+) at a level which may caused the destabilization of soil structure, reduction in soil infiltration rate and hydraulic conductivity, increasing fertility problems and consequently decreasing yield of crops [3,4]. Reclamation of these soils needs a good quality water flow through soil profile incorporated with soil amendments such as calcium ions (Ca^{2+}) to replace and remove harmful excess Na^+ ions from cation exchange sites which subsequently leached down from the root zone as drainage water [5,6,7,8,9]. There are many procedures that can be used to improve salt affected soils, such as, leaching, chemical remediation including gypsum ($CaSO_4.2H_2O$), calcite ($CaCO_3$), calcium chloride ($CaCl_2$), sulfuric acid (H_2SO_4), phosphoric acid (H_3PO_4) [10,11, 12,13,14].

Gypsum is the most common chemical amendments which is applied for removal the harmful of salinity and sodicity from soils. It is cheap, high solubility, availability and easily handling [15,16]. Several studies suggested that the application of gypsum in saline sodic and sodic soil can ameliorate the physical and chemical soil properties such as bulk density, hydraulic conductivity, water infiltration, soil pH, electrical conductivity, exchangeable sodium percent and sodium adsorption ratio [6,9,17,18].

Recently, various organic amendments such as mulch, farmyard manures and composts, have been effectively used to improve salt affected soils [13]. Pressmud (also called filter cake or filter mud) is a solid waste and produced by the sugar mills. It is an enrichment source of organic matter and other nutrients such as N, P, K, Ca, Mg, Fe, Zn, Cu and Mn and can be applied to soils for improvement of physical, chemical and biological properties [9,19,20,21,22]. It also contains sulfur, which helps to acidify the soil. This acidification makes soluble calcium available and thus improves soil structure and increases the leaching of salts. In addition, pressmud is capable of improvement soil texture, structure, organic matter contents, the water holding capacity and aeration of soil [23,24].

Phosphoric acid (H_3PO_4) used as a reclaimed for saline-sodic soil. Phosphoric acid was more efficient than other chemicals amendments such as phosphogypsum in improving soil hydraulic conductivity, reducing the exchangeable sodium percentage, pH and EC [12]. Moreover, sulphuric and phosphoric acid increase the dissolution of calcite in calcareous saline sodic soils [10,12]. Hence this study was carried out to evaluate the effect of the applications of pressmud (PM), gypsum (G) and phosphoric acid (PA) (either applied alone or in different combination) on some physical and chemical properties of highly calcareous saline-sodic soils.

2. MATERIALS AND METHODS

2.1 Sampling and Analysis of Soil

The study was carried out during the season 2015-2016 on the Experimental Farm of the Faculty of Agriculture, Sohag University, Egypt. The Farm is pounded between latitude 26 ^{o} 35' and 26 ^{o} 45' N and longitude 31^o 35' and 31^o 45' E. Soil samples were collected from 0-30 cm depth then the collected samples were air dried, crushed to pass through a 2-mm sieve and prepared for analysis. Particle size distribution was determined by the pipette method following the method elaborated by [25]. Bulk density was determined by the core method according to the methodology described by [26]. The moisture retention capacity of the soil at 1/3rd and 15 bars were determined as per procedure described by [27] using pressure plate apparatus. Organic matter (OM) content was estimated by a modified Walkley-Black method given by [28]. Calcium carbonate content was determined volumetrically using the calibrated collin's Calcimeter method [29]. Soil pH was measured in 1:1 soil: water suspension by pH meter (Orion model 410A) according to [29]. Electrical conductivity was determined in soil past extract (ECe) using electrical conductivity meter (Orion model 150) [29]. Soluble cations and anions were analyzed in the saturated soil paste extraction according to [29]. Exchangeable sodium percentage (ESP) was estimated using the equation given by [28]. Cation exchange capacity (CEC) was determined by sodium acetate solution and ammonium acetate as a displacing solution [30]. The main physical and chemical properties of the studied soil are presented in Table 1.

Table 1. Physico-chemical properties of studied soil

Soil parameters	Unit	Value
Sand	%	73
Silt	%	16
Clay	%	11
Bulk density (BD)	g/cm^3	1.66
Field capacity (FC)	%	9.42
Wilting point (WP)	%	5.26
Available water (AW)	%	4.22
OM	%	1.08
$CaCO_3$	%	26.12
pH	-	8.3
ECe	dS /m	55
Ca^{2+}	meq/l	38.34
Mg^{2+}	meq/l	13.02
Na^+	meq/l	309.33
K^+	meq/l	3.42
HCO_3^-	meq/l	60
Cl^-	meq/l	285
SO_4^{2-}	meq/l	40
ESP	%	27.5
CEC	$cmol^+$/ kg	7.62

2.2 Experimental Design and Treatments Amendments

The experimental test was carried out under laboratory conditions using polyvinyl chloride (PVC) with 30 cm height and 10 cm inner diameter. In each soil column, 5 cm layer of sand was placed on the bottom as a filter to facilitate leaching. The soil treatments consisted of the control (CTRL); pressmud (PM) which applied at application rates of 0, 7.5 and 15% per kg soil ; gypsum by product (G) $CaSO_4$-$2H_2O$ that mixed with the upper 2 cm of soil column and applied at 0, 2.5 and 5 g/kg and phosphoric acid 50% (PA) which dissolved in irrigation water at application rates of 0, 125 and 250 kg/fed. Also, the different combinations of these treatments were applied. All treatments were replicated three times and were incubated at field capacity under laboratory conditions for one month before leaching experiments. The chemical properties of the (PM) are shown in Table 2. The details of experimental design are presented in Table 3.

Table 2. Chemical properties of pressmud (PM)

Analysis	Unit	PM
pH	-	7.3
EC	dS/m	4.14
Total N	%	1.1
Total P	%	0.9
Total K	%	0.5
Ca	%	1.7
Mg	%	0.6
OM	%	6.54
Fe	ppm	5368
Zn	ppm	107
Cu	ppm	55
Mn	ppm	236

2.3 Leaching Process

Leaching process was applied every 30 days by adding one pore volume of water (over saturation) to the soil columns. The leachate was collected from each soil column and analyzed according to the methodology described by [31]. After the end of the leaching experiment, the soil

Table 3. Design of the treatments

Treatments	Pressmud (PM) %	Gypsum (G) g/kg	Phosphoric acid (PA) kg/fed
CTRL	0	0	0
PM1	7.5	0	0
PM2	15	0	0
G1	0	2.5	0
G2	0	5	0
PA1	0	0	125
PA2	0	0	250
PM1+G1	7.5	2.5	0
PM1+PA1	7.5	0	125
G1+PA1	0	2.5	125
PM1+G1+PA1	7.5	2.5	125

samples were taken from all soil columns and analyzed for their physical and chemical properties following the above mentioned standard methods.

2.4 Statistical Analysis

The data were statistically analyzed using analysis of variance (ANOVA) following the method given by [32]. The differences between treatments were determined using Duncan's Multiple Range Test. The least significant range at 5% level of probability was computed to detect the difference among the treatments means and their interactions.

3. RESULTS AND DISCUSSION

3.1 Soil Chemical Properties

3.1.1 Soil pH

The results of analysis of variance indicated that the application of all soil amendments alone or the combinations significantly reduced soil pH as compared with CTRL (Table 4). The effect of treatments on soil pH reduction can be arranged as: PM1+G1+PA1 > PM1+PA1 > PA2 > PA1 > G1+PA1 > PM1+G1 > PM2 > PM1 > G2 > G1 > CTRL (Fig. 1). The pH soil decreased from 8.24 to 7.31. The decreased in pH soil is due to the effect of calcium ions that produced from the addition different amendments. The calcium ions replaced Na^+ ions from exchangeable sites and consequently can be leached from the soil. These results are sympathy with the results of works done by [12,17,18,33]. Also, the application of organic matter regardless its is helpful in decreasing soil pH specially in saline-sodic soils due to the effect of organic acids formed during the decomposition process [4,16, 21,34]. The results given by [35] indicated that the application of gypsum improved the soil physico-chemical properties of the root zone and lowering the pH soil. Moreover, the combination of pressmud and gypsum decreased pH soil in saline- sodic soil [9].

3.1.2 Soil ECe

The obtained results indicated that all soil treatments significantly reduced the ECe of the soil as compared with initial ECe value (55 dS/m) (Table 4). The impact of applying different treatments on decreasing ECe values can be layout as: PM1+G1+PA1 > PM1+G1 > PM1+PA1 > G1+PA1 > PM2 > PM1 > G2 > G1 > PA1 > PA2 > CTRL (Fig. 2). The same results were given by [17] who concluded that the addition of gypsum; sulfuric acid and organic manure in soidic soil decreased the ECe. Also, [12] applied phosphoric acid as amendments in calcareous saline sodic soil and found the similar results. Moreover, [6] reported that ECe decreased from 54.4 dS/m to 2.35 dS/m by applying gypsum in saline sodic soil. The organic matter and/or gypsum work as salt-ion chelating agents especially Na^+ which replaced by Ca^{2+} ions in saline sodic soil and hence improved soil properties [8,,9,16,33,36,37]. In addition, organic amendments produce organic acid during decomposition which facilitate the leaching process and consequently decrease ECe [4,38].

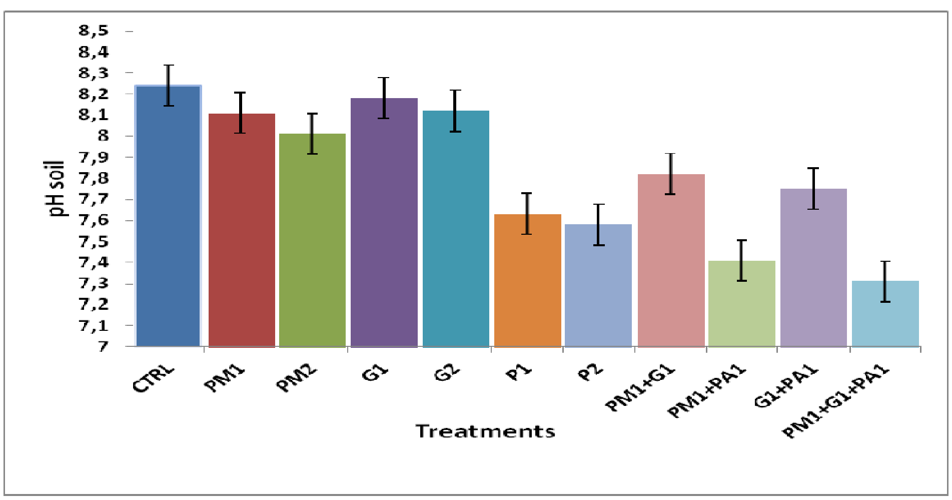

Fig. 1. The effect of the addition of soil amendments on pH soil

Table 4. Mean and standard error values of the pH, ECe, soluble cations and ESP

Treatments / parameters	PM %	G g/kg	PA Kg/fed	pH	ECe dS/m	Ca meq/l	Mg meq/l	Na meq/l	K meq/l	ESP %
CTRL	0	0	0	8.24 a ±0.006	15.23 a ±0.036	30.17 k ±0.028	15.34 k ±0.054	85.53 a ±0.064	3.37 c ±0.008	18.65 a ±0.018
PM1	7.5	0	0	8.11c ±0.003	9.92 f ±0.017	34.73 j ±0.092	16.45 j ±0.077	54.39 e ±0.24	3.41 b ±0.003	11.23 d ±0.014
PM2	15	0	0	8.01 d ±0.006	9.22 g ±0.014	38.51i ±0.108	17.37 h ±0.074	47.38 g ±0.241	3.47 a ±0.003	10.13 f ±0.008
G1	0	2.5	0	8.18 b ±0.005	10.94 d ±0.017	39.28 h ±0.017	17.08 I ±0.014	56.47 d ±0.183	3.22 f ±0.005	11.06 e ±0.030
G2	0	5	0	8.12 c ±0.003	10.1 e ±0.020	42.08 g ±0.017	18.1 g ±0.015	48.67 f ±0.017	3.18 g ±0.003	9.82 g ±0.075
PA1	0	0	125	7.63 g ±0.013	11.35 c ±0.023	44.03 f ±0.013	18.89 f ±0.020	60.67 b ±0.017	3.12 I ±0.005	11.47 b ±0.061
PA2	0	0	250	7. 58 h ±0.005	11.89 b ±0.020	46.8 e ±0.040	20.6 e ±0.057	58.42 c ±0.006	3.05 j ±0.003	11.33 c ±0.006
PM1+G1	7.5	2.5	0	7.82 e ±0.003	8.51 j ±0.027	47.04 d ±0.018	21.43 d ±0.026	32.41 h ±0.018	3.14 h ±0.003	7.23 h ±0.012
PM1+PA2	7.5	0	125	7.41 I ±0.012	8.82 I ±0.020	48.58 b ±0.050	22.69 b ±0.037	28.41 j ±0.092	3.25 e ±0.003	6.14 j ±0.013
G1+PA1	0	2.5	125	7.75 f ±0.017	8.97 h ±0.003	48.06 c ±0.013	21.93 c ±0.068	30.6 I ±0.032	3.23 f ±0.003	7.11 I ±0.014
PM1+G1+PA1	7.5	2.5	125	7.31 j ±0.008	5.71 k ±0.028	50.87 a ±0.034	23.14 a ±0.011	19.17 k ±0.074	3.32 d ±0.003	5.15 k ±0.017

In a column mean values ± standard errors (n=3).
The same letter indicates insignificant differences at P= 0.05.

3.1.3 Soluble cations

Data in Table 4 revealed that the concentrations of Ca and Mg significantly increased with addition of amendments which can be grouped according the following order: PM1+G1+PA1 > PM1+PA1 > G1+PA1 > PM1+G1 > PA2 > PA1 > G2 > G1 > PM2 > PM1 > CTRL (Figs. 3 and 4). This is due to the dissolution of calcite and dolomite as a result of the formation of organic acids that produced during organic matter decomposition [15,38,39]. The same results given by [9,12,40,41]. On the contrary, soluble Na significantly decreased in all treatments compared to CTRL. The treatments can be arranged as: PM1+G1+PA1 > PM1+PA1 > G1+PA1 > PM1+G1 > PM2 > G2 > PM1 > G1 > PA2 > PA1 > CTRL (Fig. 5). The lowest value of soluble Na ions was obtained when the combination of amendments was applied. The reduction of soluble Na due to the effect of leaching process and also the effect of organic acids which produced during the process of decomposition of the amendments which replacement Na by Ca [6,9,16,31]. Soluble K content significantly increased with the application of PM compared to other treatments (Fig. 6). This finding is in consistence with the work conducted by [9] who concluded that the addition of pressmud in saline sodic soil increased the soluble K. In this concern, the application of organic amendments could be raise the amount of soluble K and this may be due to the chemical composition of organic amendments [4,15,40,41]. On the other hand, the reduction in soluble K in other treatments when applied gypsum or phosphoric acid in saline sodic soil may be due to the leaching and replacement of Na and K by Ca on the site exchangeable [7,9,12].

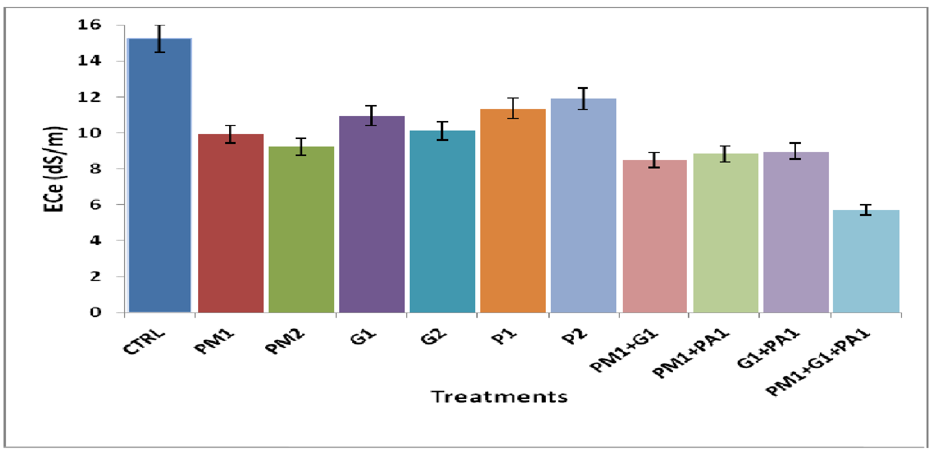

Fig. 2. The effect of the addition of soil amendments on ECe soil

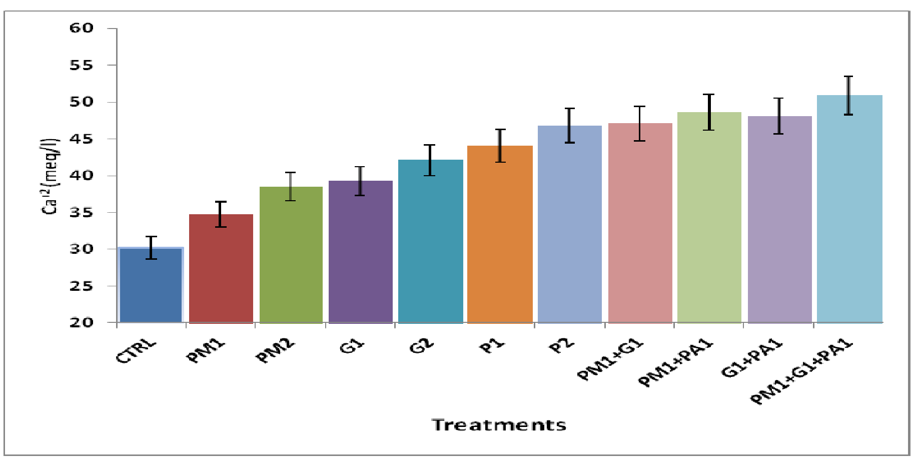

Fig. 3. The effect of the addition of soil amendments on soluble Ca

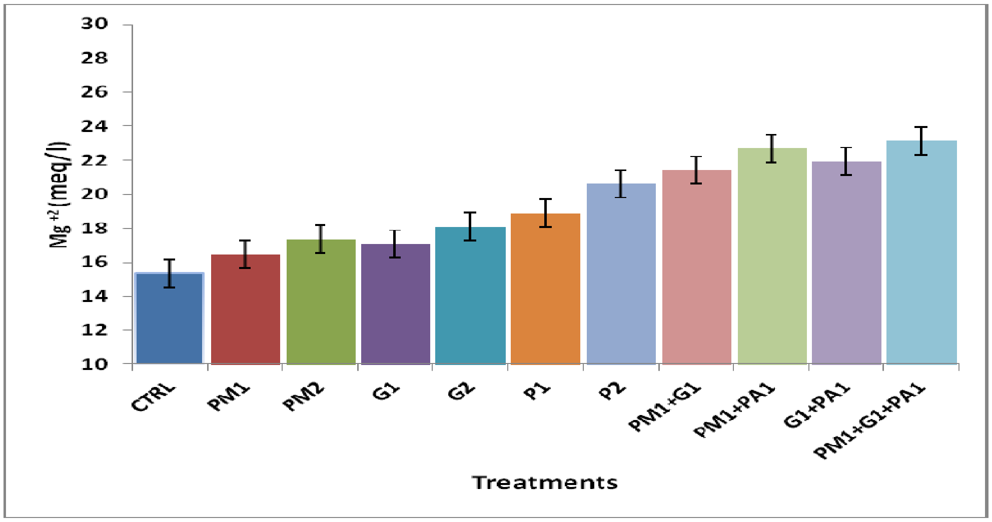

Fig. 4. The effect of the addition of soil amendments on soluble Mg

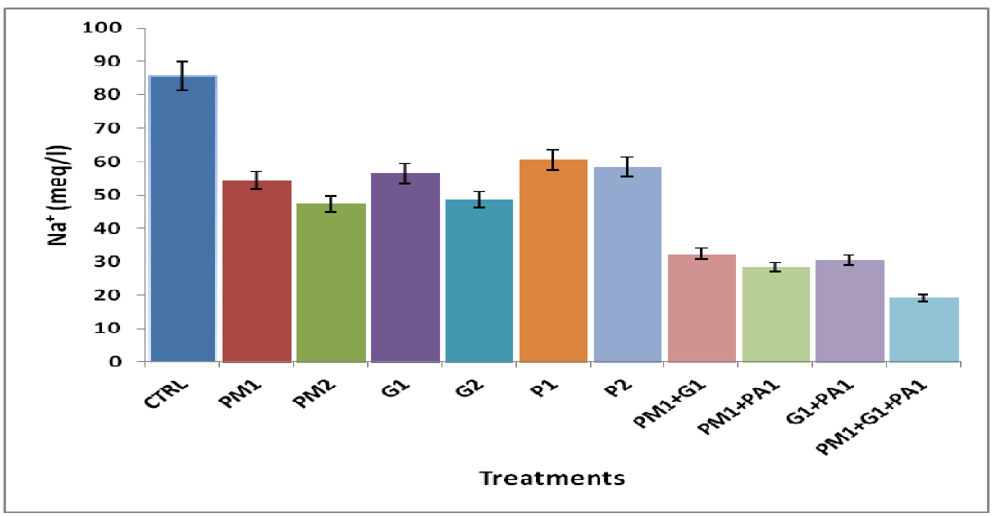

Fig. 5. The effect of the addition of soil amendments on soluble Na

3.1.4 Exchangeable sodium percentage (ESP)

The presented data revealed that the exchangeable sodium percentage (ESP) significantly decreased in the all treatments after leaching compared with the initial ESP value (Table 4). The greatest decrease was found in the PM1+G1+PA1 treatment followed by PM1+PA1 > G1+PA1 > PM1+G1 > G2 > PM2 > G1 > PM1 > PA2 > PA1> CTRL (Fig. 7). The application of organic amendments either singly or in combination in saline sodic soils increased the leaching of Na^+, water infiltration, water holding capacity and the stability of aggregates and thus causing a decreased of ESP [42,43,44,45]. In addition, the decrease in ESP with increasing the application rates of amendments may be attributed to the increase in Ca on soil solution as a result of addition gypsum and organic amendments which promoted Na displacement and removed by leaching process [37,46]. Moreover, the addition of organic matter with gypsum decreased the ESP in saline sodic soil [9,16]. In their study [6] reported that ESP decreased from 33.4% to 6% by the addition of gypsum followed by leaching in saline sodic soil. The application of sulphur or sulfuric acid decreased the ESP especially in calcareous soils which resulted from dissolving $CaCO_3$ [42,47]. The results presented by [12] suggested that the application of phosphoric acid efficiently reduced the ESP as compared to the addition of gypsum in saline sodic soil.

3.2 Soil Physical Properties

3.2.1 Bulk density

The tabulated Data clearly showed that all soil amendments significantly decreased the values of the soil bulk density, relative to the initial bulk density value (Table 5). The highest observed value was recorded in the treatment combination PM1+G1+PA1 followed by > PM2 > PM1 > PM1+G1 > PM1+PA1 >G1+PA1 > G2 > G1 > PA1 > PA2 > CTRL (Fig. 8). This was in agreement with results found by [17] who investigated that there was a highest decreased in the bulk density with the combination of gypsum, sulfuric acid and farmyard manure compared to other combinations. Also, [48] reported that the application of gypsum and organic wastes in saline sodic soil decreased the value bulk density. In addition, organic amendments were more effective to decreased bulk density compared to inorganic amendments [49,50]. The decreased in bulk density is due to the produced organic acids that speed the dissolving of $CaCO_3$ and consequently increase the total pore space of the saline sodic calcareous soil [42].

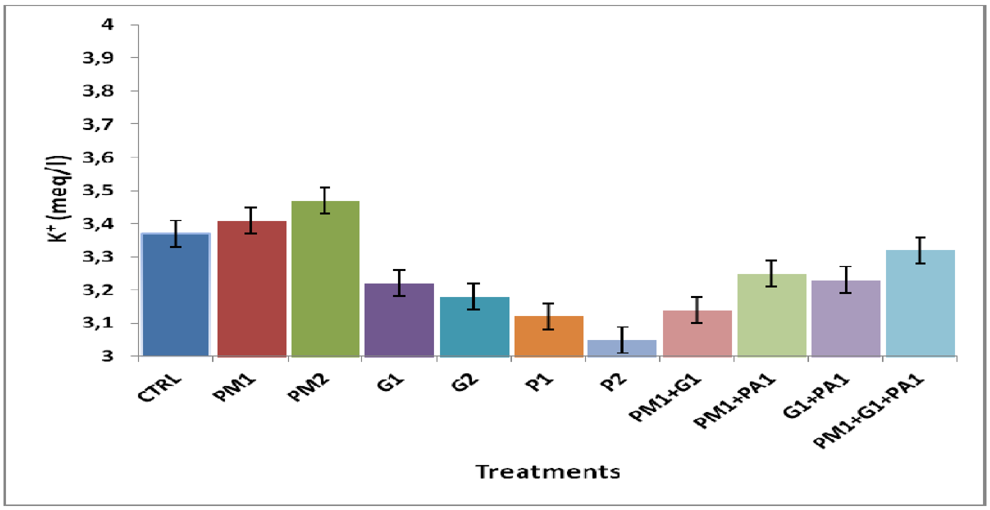

Fig. 6. The effect of the addition of soil amendments on soluble K

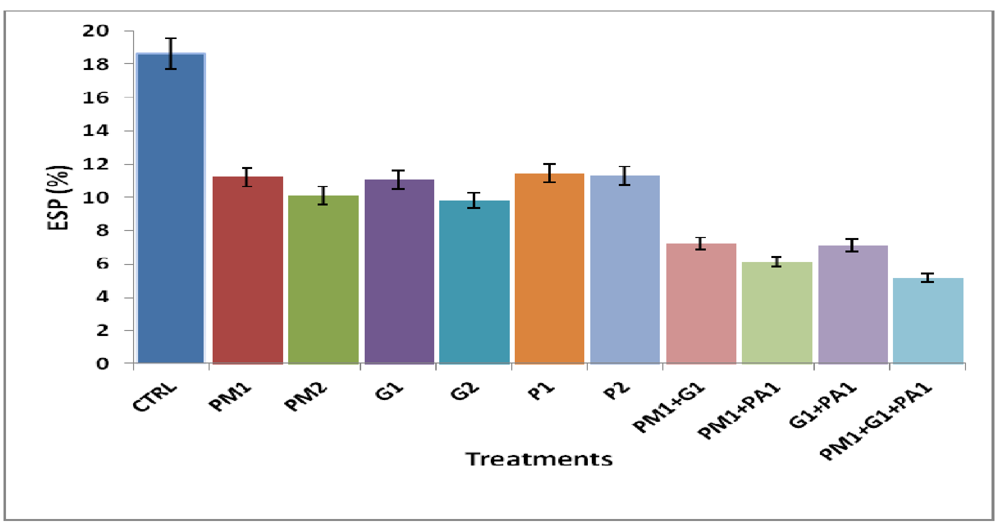

Fig. 7. The effect of the addition of soil amendments on ESP

3.2.2 Soil moisture retention

Data in Table 5 revealed that the application of different soil amendments either alone or combined with each other increased the soil moisture retention. The available water ranged between 4.23% and 9.63%. The maximum available water was recorded in the treatment combination PM1+G1+PA1 followed by > PM2 > PM1 > PM1+G1 > PM1+PA1 >G1+PA1 > G2 > G1 > PA1 > PA2 > CTRL (Fig. 9). The improved in soil moisture content is due to the increase in the exchangeable Ca ions and decreases the exchangeable Na ions. Also, Phosphoric acid dissolved the $CaCO_3$ and releases Ca ions, and improves soil structure [12]. The effect of organic acids, which formed either during decomposition of organic amendments, may be helpful development of soil physical properties [4,16]. The application of organic and/or inorganic amendments can be increased available water content and improved physical properties of saline-sodic soils [50]. [35] reported that the application of gypsum in soil may be improved soil physico- chemical environment in the root zone. In addition, the application of organic and inorganic amendments in saline sodic soil were improve water holding capacity, field capacity and soil water content at wilting point as well as improving soil physical properties [48,51,52,53].

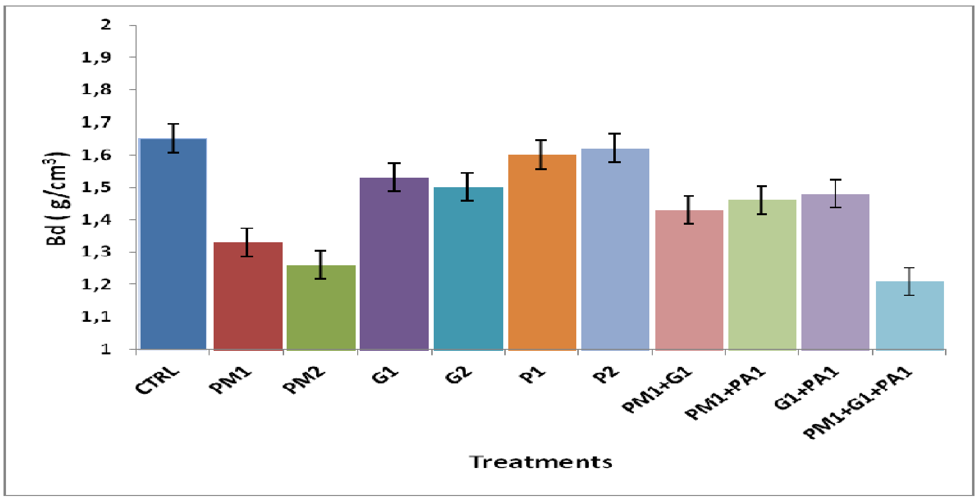

Fig. 8. The effect of the addition of soil amendments on BD

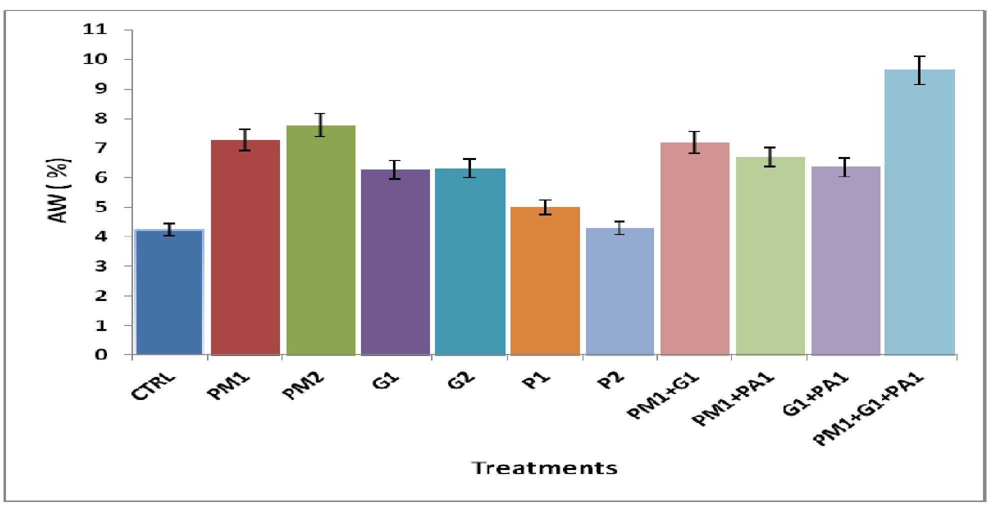

Fig. 9. The effect of the addition of soil amendments on AW

Table 5. Mean and standard error values of the bulk density (BD), Field capacity (FC), permanent wilting point (PWP) and available water (AW)

Treatments / parameters	**PM** %	**G** kg/g	**PA** fed/kg	**BD** **g/cm³**	% **FC**	**WP** %	**AW** %
CTRL	0	0	0	1.65 a ±0.003	9.44 k ±0.021	5.21 j ±0.020	4.23 j ±0.024
PM1	7.5	0	0	1.33 l ±0.008	17.41 c ±0.011	10.12 c ±0.006	7.28 c ±0.006
PM2	15	0	0	1.26 j ±0.003	18.11 b ±0.041	10.33 b ±0.006	7.77 b ±0.040
G1	0	2.5	0	1.53 d ±0.003	13.14 h ±0.017	6.87 g ±0.010	6.27 g ±0.013
G2	0	5	0	1.50 e ±0.006	13.45 f ±0.015	7.12 f ±0.026	6.32 f ±0.013
PA1	0	0	125	1.61 c ±0.003	11.54 l ±0.012	6.54 h ±0.012	5.00 h ±0.012
PA2	0	0	250	1.62 b ±0.003	10.06 j ±0.008	5.74 l ±0.008	4.31 j ±0.008
PM1+G1	7.5	2.5	0	1.43 h ±0.003	15.73 d ±0.036	8.54 d ±0.005	7.19 d ±0.030
PM1+PA1	7.5	0	250	1.46 j ±0.003	15.06 e ±0.011	8.35 e ±0.014	6.70 e ±0.021
G1+PA1	0	2.5	125	1.48 f ±0.003	13.21 g ±0.003	6.85 g ±0.006	6.35 f ±0.003
PM1+G1+PA1	7.5	2.5	125	1.21 k ±0.006	20.17 a ±0.020	10.54 a ±0.006	9.63 a ±0.014

In a column mean values ± standard errors (n=3).
The same letter indicates insignificant differences at P= 0.05.

4. CONCLUSION

It can be concluded that, soil pH, ECe, and ESP were decreased with addition of soil amendments compared with CTRL. The soil pH value reduced from 8.24 to 7.31. Soil salinity was reduced from 55 to 5.71 dS/m. The ESP ranged from 5.15 to 18.65% compared with the initial value of 27.5%. Soluble cations like Ca and Mg concentrations have significant increase in all soil amendments compared with CTRL, while Na reduced in all treatments compared with the initial soil. Soluble K concentration had not significantly increased with the application of amendments, while the effect of addition PM was only significant increased K concentration compared to CTRL. Regarding to physical soil properties, the effects of different soil amendments alone or in combination were positive affected in the bulk density and soil moisture content (field capacity, FC, wilting point, WP, and available water, AW). It could be recommended from the research that the PM1+G1+PA1 in combinations are the best influence treatments than the others to remediate saline sodic soil.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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