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Reclamation of a Saline-Sodic Soil with Organic Amendments and Leaching †

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Abstract: Excessive amounts of Na^+ and soluble salts are characteristics of saline-sodic soils. Loss of soil structure and osmotic stress in plants are negative effects of salinity-sodicity. This study evaluated the effect of cattle manure, biochar and tropical peat at 1 and 2% (*w*/*w*) with leaching, on the exchangeable sodium percentage (ESP), electrical conductivity (EC_e) and pH of a saline-sodic soil from the High Valley of Cochabamba (Bolivia). The soil was placed in simulated soil columns and two lixiviations were applied. The initial values of soil were as follows: ESP of 66.6%, EC_e of 20.5 dS m^{-1}, and pH of 8.55. Results after leaching differed significantly (p = 0.05) among the interactions. Cattle manure at 2% was the most effective in reducing soil ESP to 27.6%, followed by the rest of the treatments. The three amendments at any level were efficient in lowering EC_e below 4 dS m^{-1}. Peat at 2% decreased the soil pH to 7.76. The superiority of cattle manure can be explained by the improvement of soil aggregation and leaching efficiency, through its OM and Ca^{2+} + Mg^{2+} contribution. Overall, cattle manure was superior in reclaiming the soil salinity-sodicity, and only the EC_e threshold value from the US Salinity Lab classification was reached by any amendment, indicating that cattle manure, biochar or tropical peat with leaching, can be used to reclaim some saline-sodic soils.

Keywords: saline-sodic soil; soil remediation; manure; biochar; peat

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1. Introduction

As a category of salt-affected soils, saline-sodic soils are characterized by an excessive amount of soluble salts, and sodium (Na^+) in the soil solution and cation exchange complex. Loss of soil structure and osmotic stress in plants are some of the negative effects of salinity-sodicity. Soil salinity can be measured through electrical conductivity (EC), and sodicity by the exchangeable sodium percentage (ESP) or the sodium adsorption ratio (SAR). Saline-sodic soils can be classified using the threshold values from the US Salinity Lab (USSL) classification [1], as follows: ESP > 15%, EC_e > 4 dS m^{-1} and pH < 8.5. Saline-sodic soils can be reclaimed by leaching with non-saline water and adding chemical/organic amendments.

The addition of organic amendments in sodic soils binds the small soil particles together into large water-stable aggregates, increases porosity and thus improves the soil physical properties [2]. Using organic amendments instead of inorganic amendments can reduce input cost savings as a sustainable and efficient management method to reclaim salt-affected soils [3], besides the beneficial impacts on nutritional and biological soil properties.

A soil-column experiment was carried out to evaluate the reclamation effect of cattle manure, biochar and tropical peat at two rates with leaching, on the ESP, EC_e and pH of a saline-sodic soil.

2. Materials and Methods

The soil (Table 1) was collected from the High Valley of Cochabamba (Bolivia) at a depth of 25 cm. It should be noted that the soil pH is slightly higher than the threshold value of the USSL classification. The organic amendments (Table 2) used to reclaim the soil were: cattle manure (CM) collected locally, tropical peat (PE) as tree fern fiber from the tropical area, and biochar (BI) branded by Greenpoch SA (Belgium).

Table 1. Chemical and physical parameters of the saline-sodic soil, before reclamation.

Property	Value	Property	Value	Property	Value
TOC (%)	0.3	EC_e (dS m^{-1})	20.5	K^+ ($mmol_c$ L^{-1})	1.5
Clay (%)	18.2	ESP (%)	66.6	HCO_3^- ($mmol_c$ L^{-1})	40.3
Silt (%)	52.1	Na^+ ($mmol_c$ L^{-1})	339.2	CO_3^{2-} ($mmol_c$ L^{-1})	20.0
CEC (cmol kg^{-1})	5.0	Ca^{2+} ($mmol_c$ L^{-1})	0.5	Cl^- ($mmol_c$ L^{-1})	185.0
pH	8.55	Mg^{2+} ($mmol_c$ L^{-1})	0.7	SO_4^{2-} ($mmol_c$ L^{-1})	71.1

TOC: total organic carbon, CEC: cation exchange capacity, EC_e: electrical conductivity (paste extract).

Table 2. Some chemical properties and TOC of the organic amendments.

Property	Cattle Manure	Biochar	Tropical Peat
Na^+ (mmol kg^{-1})	1.4	0.1	0.0
Ca^{2+} (mmol kg^{-1})	46.7	5.1	15.5
Mg^{2+} (mmol kg^{-1})	77.4	4.0	30.9
EC (d Sm^{-1})	3.7	0.3	0.7
pH	8.5	9.7	3.6
TOC (%)	23.7	33.0	22.5

Following the protocol of [4], simulated soil columns were assembled with PVC tubes (Ø of 15 cm), and each was filled with 6.7 kg of soil sieved at 4 mm, and then the upper layer was mixed with the respective amendment. The dose of amendments was calculated on a dry weight basis to reach 1 and 2% of organic matter (OM). To simulate the water from the rain, distilled water was used for the leaching process. The volume of water was calculated as a pore volume (PV) using the formula provided by Kahlon et al. [5] and Ahmad et al. [4]. After an initial soil saturation with 3/4 PV, two lixiviations were applied, each with one PV for two to four weeks. Response parameters were soil ESP, EC_e, and pH. The ESP was calculated using Equation 3 in Qadir et al. [6]. The design was completely randomized and the treatments were: CM-1%, CM-2%, BI-1%, BI-2%, PE-1%, PE-2% and control (only leaching). The results were evaluated using LSM-Tukey adjustment.

3. Results and Discussion

The results after leaching showed that soil ESP, EC_e and pH, differed significantly ($p < 0.05$) among the interactions. CM-2% was the best treatment for reducing the initial soil ESP by 39%, followed by CM-1% (by 31.5%), and lastly the rest of the treatments with a similar effect (Figure 1a). CM-1% and CM-2% were as effective as BI-2% and PE-2% for lowering EC_e by over 16 dS m^{-1} concerning the initial soil, while BI-1% and PE-1% showed a lower efficiency but higher than that of the control (Figure 1b). PE-2% decreased the initial pH to 7.76, followed by CM-1%, CM-2% and PE-1% in equal magnitude; in contrast, BI maintained a pH around the initial value (Figure 1c). Although organic amendments were effective in reclaiming this saline-sodic soil, the ESP and pH threshold values from the USSL classification were not reached. It should be pointed out that the percolation time of PE and BI was double that of CM.

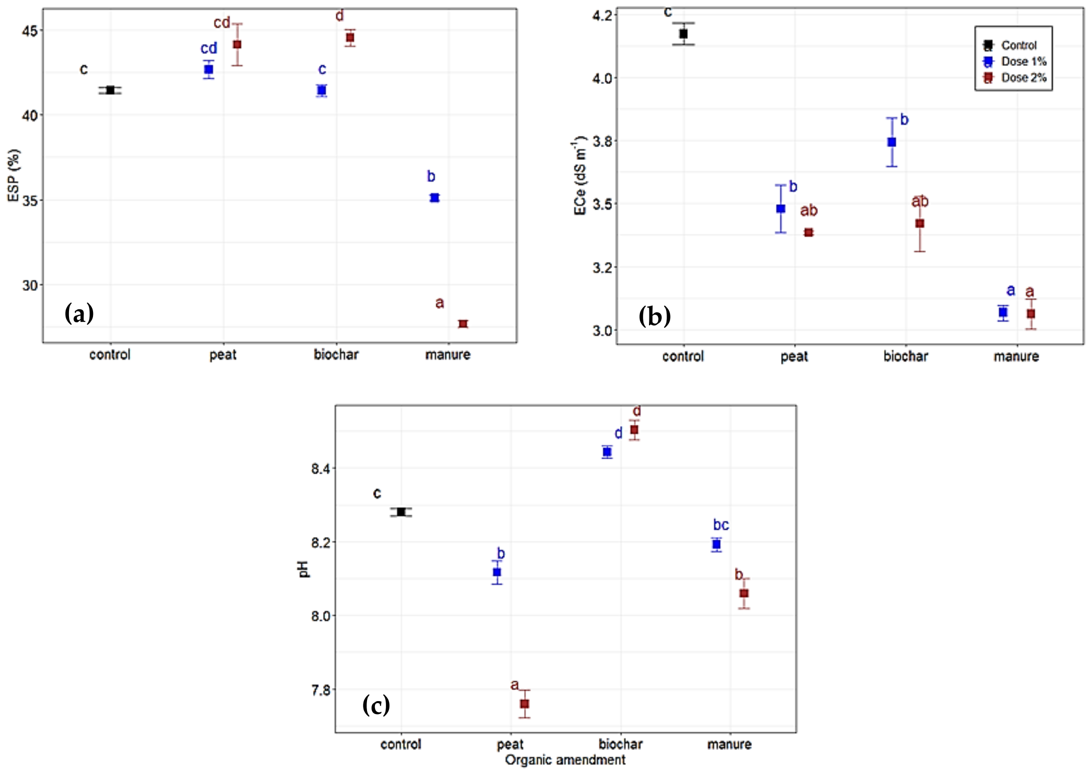

Figure 1. Soil ESP (**a**), EC_e (**b**) and pH (**c**), for the interactions between organic amendments and doses. Means sharing a letter are not significantly different according to pairwise comparisons of LSM with Tukey adjustment ($p < 0.05$). The bars indicate the standard error.

The superiority of CM in decreasing ESP and EC_e can be partly attributed to its initial amounts of TOC, Ca^{2+} and Mg^{2+}, contributing to the improvement of soil structure and infiltration, thus displacing Na^+ from the soil. The lower effectiveness of PE in reducing ESP was likely due to its swelling capacity which interacted with soil dispersion leading to a slowdown of the leaching process. In this regard, [7] reported that reclaimed soil with bentonite showed a lower decrease in salinity and sodicity levels and a higher percolation time due to the swelling capacity. The BI also showed a weak effect on sodicity potentially due to its insufficient ability to influence soil structure, and since, as [8] indicated, the mode of action of BI is physiochemical while composts provide a comprehensive reclamation when biological and physiochemical factors act together. In contrast to BI, the PE significantly reduced the soil pH due to its very low pH, causing an acidic counteracting effect, as [3] found that composts significantly improved soil CEC and pH values but the BI did not.

Water by itself was less effective in decreasing Na^+, but lowered EC_e to 4.2 dS m^{-1}, coinciding with [9], which found that EC decreased significantly even for the unamended soil possibly caused by solute leaching; moreover, [10] stated that flushing water reduced salinity with and without the application of manure.

Overall, the results suggest that CM, BI and PE enhanced the reclamation effect of leaching in remediating soil salinity and/or sodicity, through the positive impact of their OM on soil structure and infiltration, thus improving Na^+ displacement, agreeing with the following findings: organic amendments significantly lowered the level of soil EC_e, ESP and SAR compared to the control soils, improved soil structure, aggregate stability and saturated hydraulic conductivity, even more in compost treated soils [3]. The physical properties of the salinized soil, such as structural stability, infiltration rate, water-holding capacity and washing capacity were considerably improved by OM from the solid waste application [11]. Water hyacinth and rice straw compost singly or combined showed a pronounced decrease in EC, pH, SAR, and ESP compared with control [12].

4. Conclusions

Cattle manure at 2% was the best treatment for decreasing soil ESP to 27.6%, and any treatment was more effective than control in lowering EC_e below 4 dS m^{-1}. Peat at 2% showed a higher reduction in the soil pH (to 7.76). The superiority of cattle manure in reducing ESP and EC_e may be due to the improvement of the soil structure and infiltration through its OM and divalent cations contribution, whereas peat and biochar were less effective possibly due to the swelling capacity and insufficient rate, respectively, which in addition to the soil dispersion led to a slowdown of leaching. Overall, cattle manure with leaching was more efficient in ameliorating soil salinity-sodicity, and any amendment was effective in lowering salts. However, the ESP and pH threshold values from the USSL classification were not reached. This study suggests that some saline-sodic soils can be reclaimed by adding cattle manure, biochar or tropical peat, with leaching.

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