

Initial growth of tree species grown on salinized soil with conditioners

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Abstract

The excess of salts and sodium is one of the factors that contribute most to the soil chemical degradation. Recovery of these soils requires the establishment of techniques using soil conditioners and more tolerant species. The present study aimed to evaluate the effect of soil conditioners on the recovery of a saline - sodic soil and on the growth and physiological responses of tree species. Two experiments were carried out in a greenhouse, both using a completely randomized design. In the first experiment, five treatments were evaluated for soil correction: saline soil with no correction, saline soil + calcium sulfate, saline soil+ sulfur, saline soil + O.M. (organic matter) and non saline soil. The second experiment, consisted of a 4x5 factorial arrangement, with four trees species (*Amburana cearensis*, *Caesalpinia ferrea*, *Cnidoscylus philacanthus* and *Moringa oleifera*) and the five treatments described in the first experiment, with three repetitions. Bovine manure, elemental sulfur and calcium sulfate decrease the salinity and sodicity of saline-sodic soils, especially the latter two, which attenuate the negative effects of salinity and sodicity on the photosynthetic rate of *C. philacanthus*, *M. oleifera* and *C. ferrea*, favoring the growth and dry matter production of *C. ferrea* and *M. oleifera*.

Keywords: alkaline soils, Caatinga biome, salinity control, salt stress

Introduction

Soils with excess of salts and sodium are characterized by high values of pH and exchangeable sodium percentage (ESP), low exchangeable calcium and magnesium contents and low availability of cationic micronutrients (Talei et al., 2012). These characteristics, directly or indirectly, lead to physiological and nutritional imbalances in plants, causing a decrease in their growth and development (Sousa et al., 2012; Sá et al., 2015; Araujo et al., 2015). Therefore, to recover the areas productivity it is essential to use techniques that improve these soils fertility (Uddin et al., 2011; Araujo et al., 2015).

In the recovery of these soils, products

such as organic residues, calcium chloride, agricultural gypsum, sulfuric acid and elemental sulfur are considered the most efficient (Fuente et al., 2007; Zia et al., 2007; Leal et al., 2008; Gharaibeh et al., 2009; Gollmack et al., 2011; Sousa et al., 2012, Sá et al., 2013; Ahmad et al., 2013; Souza et al., 2014). However, the use of tree species more tolerant to salts can contribute to the recovery process of these areas (Qadir et al., 2007; Araujo et al., 2015). In general, native species are adapted to the severe climatic conditions of the semi-arid region, and can be an important alternative for the recovery and use of salinized areas or in salinization processes (Qadir, 2007). In addition, these species are of

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multiple use, have deep root systems, increase permeability, soil porosity, assist in the lowering of the water table, and reduce the risks of soil salinization (Gill et al., 2009).

The species *Amburana Cearensis*, *Caesalpinia ferrea* and *Cnidoscylus philacanthus* are native of the Caatinga biome and suffer deforestation, mainly for use as firewood in potteries and bakeries in the semiarid region (Lorenzi, 2000). The *Moringa oleifera* is a tree species probably from India and adapted in the region (Lorenzi, 2000), presenting fast growing and has been used in animal feed. Although they are species with economic potential and adapted to the stressful conditions of the Brazilian semiarid, there is little or no information about the tolerance of these species to salinity and sodicity (Sousa et al., 2012).

Thus, the aim of this study was to evaluate the effect of conditioners on the recovery of a saline-sodium soil of the semiarid region of the Paraíba State and the effect on the growth and

physiological responses of four tree species, occurring in the Caatinga biome.

Material and Methods

Two experiments were conducted in a protected environment of the Campina Grande Federal University, Center for Food, Agricultural Science and Technology (CCTA), Campus of Pombal-PB, Brazil (6°47'3,97 "S, 37°48'6,80"W and 193 m) from December 2012 to May, 2013. Samples of a saline-sodic soil and a non-saline soil, both classified as Fluvic Neossol (Embrapa, 2013), were used. Samples were randomly obtained at depth of 0-40 cm, in an area belonging to the fruit growing sector of the Irrigated Perimeter of São Gonçalo, located 10 km from the municipality of Sousa-PB, Brazil. After dried in air, the samples were sent to the Laboratory of Soils and Plant Nutrition of the CCTA/UFCG for their chemical and physical characterization (Table 1), according to the methodology proposed by Embrapa (2011).

Table 1. Chemical and physical attributes of soil samples of the first experiment.

Soils	pH CaCl ₂	CSe dSm ⁻¹	P mg dm ⁻³	K	Na	Ca	Mg	H+Al	ESP %
Saline-sodic	10.7	16.8	5.8	0.20	11.38	0.5	0.6	0.0	89.0
Non-saline	8.0	0.8	8.2	0.98	1.19	4.0	2.9	0.0	12.0
	Sand	Silt	Clay	Moisture at 0.033Mp			DS	Dp	
	-----g kg ⁻¹ -----						---gcm ⁻³ ---		
Saline-sodic	622	140	238	66.9			1.45	2.64	
Non-saline	775	67	158	69.4			1.48	2.61	

ESP- exchangeable sodium percentage; SD- soil density; PD- particle density; CSe- conductivity of the saturation extract.

In the first experiment, a completely randomized design was used with five treatments according to the use of soil conditioners (without correction, calcium sulfate, elemental sulfur, organic matter and non-saline soil) with 12 replicates, totaling 60 pots with 6.0 dm³ of soil each.

The dose of calcium sulfate p.a (11.76 g kg⁻¹) was determined as suggested by Leite et al. (2007) using the formula $NG = 0.86 Na + x$ /calcium sulphate purity, where: NG = need for gypsum in g kg⁻¹ soil, Na + x = exchangeable sodium content in cmol_c dm⁻³. For elemental sulfur, an analytical product (p.a) was used and its dose was calculated based on the recommended dose of gypsum, in order to provide the same amount of sulfur supplied by calcium sulfate.

For the organic matter, the bovine manure was used in the dose corresponding to 15% of the soil volume. The manure used was purchased from growers of the region and exposed to the climatic conditions of the period. This organic material contained 19.0 g kg⁻¹ of N; 7.59 g kg⁻¹ of P; 4.60 g kg⁻¹ of K; 260 g kg⁻¹ C and 0.40 g kg⁻¹ Na. The materials were incorporated and homogenized to the soil volume contained in each pot.

After the application of the conditioners, the soils were maintained for 30 days with humidity corresponding to 70% of the field capacity. Then the soil was washed, applying a volume of water equivalent to twice the total porosity of the soil. The water used for washing had an EC average of 0.28 dS m⁻¹ cm at 25 °C. After washing, from four of the 12 pots of each treatment, 100g of

soil were removed to perform a new chemical characterization of the soil, according to the previously described procedures.

The second experiment was a continuation of the first one and the same 60 pots containing the five treatments of soil correction of the previous experiment were used. The experiment was carried out in a completely randomized design, with treatments consisting of a 4x5 factorial scheme, with four tree species: *Amburana cearensis*, *Caesalpinia ferrea*, *Cnidoscylus philacanthus*, combined with the five treatments tested in the first experiment, with three replicates totaling 60 experimental units. The seeds of the species were germinated in 300 mL tubes filled with non-saline soil and bovine manure in the proportion of 3:1 (v / v). After reaching about 15 cm in height, the seedlings were selected and transferred to the pots with the soils already washed, that is, after the leaching of the salts, with the respective treatments.

After 15 days after transplanting it was evaluated, through a non-destructive method the transpiration rate, photosynthetic rate, stomatal conductance and intercellular CO₂ concentration in the plants by non-destructive method using the infra-red gas analyzer (*Infra-red Gas Analyzer*, portable, open system, Li-Cor LI-6400XT model). The measured of these variables were realized in the leaves of the middle third of each plant of each treatment under full sun, from 8:00 a.m. to 10:00 p.m.. After 75 days of transplanting, the plant diameter and plant height were measured. Then, the aerial parts of the plants were separated from the roots and dried in an oven at 65-70°C to obtain the shoot dry mass (SDM) and root dry mass (RDM). With the values of plant height, stem diameter, MSR and MSPM, were estimated the relative growth in height, relative growth in diameter, relative production of MSPM and MSR, correlating the values of these variables, obtained in the saline soil (with or without correction) with those obtained in the non-saline soil.

In order to diagnose a significant effect of the treatments by the F's test, the data were submitted to analysis of variance (ANOVA) and the means were compared by the Tukey's test, both tests being performed at 5% probability

using the SISVAR® software (Ferreira, 2011).

Results

All soil chemical attributes were affected by soil correction treatments (Table 2). The application of the conditioners provided to the saline-sodic soils decreases in pH values, in EC_{1:5} (electrical conductivity obtained in the soil: water ratio 1:5), exchangeable Na⁺, ESP levels and elevation in exchangeable Ca and Mg (Table 2). The exchangeable contents of K⁺ were higher in the non-saline soil treatments and in the saline soil treatment treated with organic matter. For non-saline soils, higher values were observed, probably due to their initial values, that is, before the application of the treatments (Table 1). In the case of treatment with organic matter, the highest values of K⁺ may have been due to its fast release by organic matter, since this element is not part of organic compounds. Among the conditioners, the elemental sulfur was the one that reduced the ESP and in the soil sodium contents, although it resulted in lower levels of exchangeable calcium than the calcium sulfate.

The values of CE, pH, K⁺ and Na⁺, obtained from the saturation extract were lower in the saline-sodic soil with the application of the conditioners (Table 3). However, when compared to the non-saline soil, the values remained high. In the decrease of the salinity of the saturation extract (CEes), the treatments with O.M. (Tables 2 and 3) stood out. This fact is probably due to the improvement of the soil physical structure, providing a greater permeability of the water and allowing higher salts leaching (Souza et al., 2014).

Regarding the physiological variables, it is possible to observe that the photosynthetic rate, with the exception of the *Amburana cearensis* species, was higher in the saline soil with sulfur, but did not differ from the non-saline soil (Table 4). According to the same table, the saline soil without correction provided the lowest values for this variable.

The values of transpiration rate and stomatal conductance of the *Cnidoscylus philacanthus* and *Moringa oleifera* species were higher in saline soils treated with calcium sulphate or elemental sulfur and in non-saline soil

Table 2. Chemical attributes of the soil sorption complex used in the first experiment, after application of the treatments and the salt leaching layer.

Treatment	pH _{CaCl₂}	CE _{1.5} dSm ⁻¹	K ⁺	Na ⁺	Ca ²⁺	Mg ²⁺	ESP (%)
			-----cmol _c dm ⁻³ -----				
Saline without corrective	9.4 a	0.83 a	0.60 b	10.2 a	0.67 d	0.56 c	88.15 a
Saline + CaSO ₄	7.5 c	0.58 b	0.42 b	4.27 b	5.20 a	2.52 ab	34.10 b
Saline + sulfur	7.3 c	0.40 b	0.66 b	2.33 c	3.30 b	2.40 ab	26.49 b
Saline + O.M.	8.5 b	0.56 b	0.98 a	6.01 b	2.40 c	0.60 c	43.31 b
Non saline	7.2 c	0.12 c	1.07 a	1.19 c	4.78 ab	2.90 a	12.08 c
CV (%)	1.9	34.8	31.8	29.7	25.34	36.2	35.4

Means followed by the same letter are not different according to Tukey's test at 5% of probability. ESP- exchangeable sodium percentage; EC_{1.5}- electrical conductivity of the soil:water ratio 1:5; O.M.- organic matter; CV- Coefficient of variation.

Table 3. Chemical attributes of the saturation extract of soils of the first experiment after the application of the treatments and the salt leaching layer.

Treatments	CSe dSm ⁻¹	pH _{es}	K ⁺	Na ⁺
			-----cmol _c L ⁻¹ -----	
Saline without corrective	6.68 a	10.05 a	0.16 b	6.11 a
Saline + CaSO ₄ 2H ₂ O	4.63 b	8.22 c	0.09 c	3.60 b
Saline + sulfur	5.04 ab	8.25 c	0.09 c	3.73 b
Saline + O. M.	2.42 c	9.24 ab	0.07 c	2.72 bc
Non saline	0.87 d	7.29 d	0.29 a	2.17 c
CV (%)	16.27	1.29	14.36	16.35

Means followed by the same letter are not different according to Tukey's test at 5% of probability. CSe- electrical conductivity of the saturation extract; O.M.- organic matter; CV- Coefficient of variation.

Table 4. Physiological variables of the tree species according to the soil correction treatments of the first experiment.

Soil correction	<i>Amburana cearensis</i>	<i>Cnidoscylus philacanthus</i>	<i>Moringa oleifera</i>	<i>Caesalpinia ferrea</i>
Net photosynthesis (μmol m ⁻² s ⁻¹)				
Saline without correction	2.53 aA	1.43 cB	1.19 cB	2.68 bA
Saline + CaSO ₄ 2H ₂ O	2.88 aC	7.63 bB	12.30 bA	4.40 bC
Saline + sulfur	2.46 aD	11.78 aB	17.83 aA	9.08 aC
Saline + O.M.	1.26 aB	1.83 cB	0.95 cB	3.98 bA
Non-saline	3.91 aD	13.69 aA	11.03 bB	7.15 aC
Stomatal conductance (mol m ⁻² s ⁻¹)				
Saline without correction	0.03 aA	0.03 cA	0.04 cA	0.03 bA
Saline + CaSO ₄ 2H ₂ O	0.03 aB	0.09 bB	0.17 bA	0.05 bB
Saline + sulfur	0.02 aC	0.17 aB	0.42 aA	0.14 aB
Saline + O.M.	0.05 aA	0.03cA	0.03 cA	0.04 bA
Non-saline	0.06 aB	0.19 aA	0.14 bA	0.07 bB
Transpiration (mmol m ⁻² s ⁻¹)				
Saline without correction	0.77 aA	0.96 cA	0.97 dA	0.85 aA
Saline + CaSO ₄ 2H ₂ O	0.78 aB	2.49 bA	3.11 bA	1.31 aB
Saline + sulfur	0.72 aC	3.83 aB	4.32 aA	1.87 aC
Saline + O.M.	1.10 aA	0.97 cA	0.65 dA	1.02 aA
Non-saline	1.10 aC	3.40 aA	2.67 cB	1.30 aC
Intercellular concentration of CO ₂ (mg L ⁻¹)				
Saline without correction	199.6 bB	250.0 aA	247.3 aA	207.3 aB
Saline + CaSO ₄ 2H ₂ O	214.3 bA	190.3 bA	200.0 bA	207.0 aA
Saline + sulfur	213.3 bA	204.3 bA	233.0 aA	225.0 aA
Saline + O.M.	246.6 aA	268.3 aA	248.3 aA	178.3 aB
Non-saline	242.6 aA	186.3 cA	195.3 bA	213.3 aA

Means followed by the same lowercase letters comparing treatments and uppercase comparing vegetal species are not different according to Tukey's test at 5% of probability.

(Table 4). The intercellular concentration of CO₂, in turn, did not follow this same tendency, and for the *Caesalpinia ferrea* species, no difference was observed between the treatments of soil correction. For the *Amburana cearensis* species the soil correction treatments did not affected the physiological variables, except for the intercellular CO₂ concentration, in which the

highest values were obtained in the treatment with O.M., but without differing from the non-saline soil treatment. By the same table, when comparing the species, it was observed that the *Cnidoscylus philacanthus* and *Moringa oleifera* were the ones that presented the highest values for the physiological variables, except for the intercellular CO₂ concentration.

Regarding the plants height (growth), a varied response was observed to the treatments of soil correction according to the vegetal species (Figure 1). For *Amburana cearensis* (Figure 1A), the highest growth in height occurred

in non-saline soil followed by elemental sulfur. With the exception of the cited species (Figure 1), the highest growth of plants was provided by elemental sulfur followed by calcium sulfate. The *Cnidoscylus philacanthus* species (Figure 1D) obtained higher growth in the non-saline soil up to 45 days after transplanting. After this period, elemental sulfur provided better performance of the species. Among the studied species, the highest growth in height was obtained by *Moringa oleifera* and *Caesalpinia ferrea*, especially when grown in saline soil treated with elemental sulfur (Figure 1).

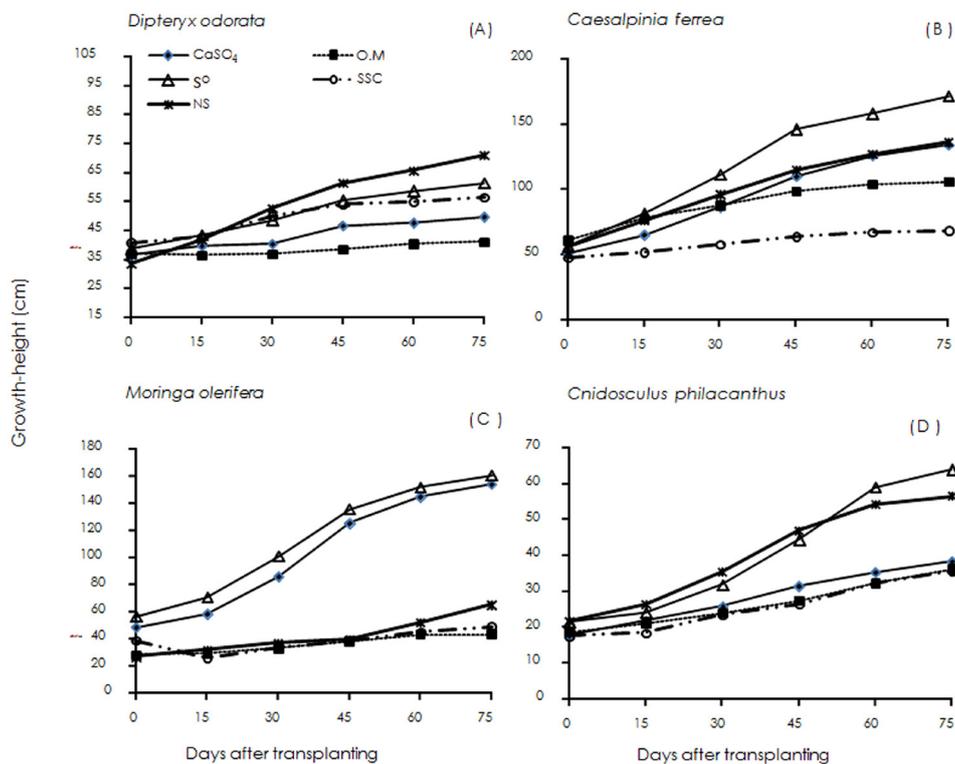


Figure 1. Growth in height of plant species according to the soil treatments. SSC- without correction; CASO₄ – corrected with calcium sulfate; S⁰- corrected with elemental sulfur; O.M- with organic matter; NS- non-saline soil.

The highest values of relative height / growth (Figure 2A) and diameter (Figure 2B) of the plant species were obtained by applying elemental sulfur or calcium sulfate. It was observed that the species *Amburana cearensis* was the most sensitive to salinity in relation to the relative growth in height (Figure 1A), especially in the treatment with organic matter. For both variables the *Moringa oleifera* and the *Caesalpinia ferrea* stood out (Figure 1).

The highest values for relative shoot dry mass (RSDM) (Figure 2C) and relative root dry mass (RRDM) (Figure 2D) were obtained by

applying elemental sulfur or calcium sulfate to the soil. Regardless the species, the application of elemental sulfur provided values for these variables of at least 75%. Comparing the plant species, it was observed that, for RSDM (Figure 2C), the *Moringa oleifera* and *Caesalpinia ferrea* species stood in with the treatments calcium sulfate and elemental sulfur treatments, however, they obtained the smallest responses in the other treatments, both for RSDM (Figure 1C) and for RRDM (Figure 2D).

Discussion

The reduction of the ESP by the application of calcium sulfate or elemental sulfur is mainly due to the sodium displacement of the exchange complex by the calcium released by the conditioners (Sadiq et al., 2007). In this process, the sodium is displaced to the soil solution to react with the sulfate anions, forming sodium sulfate that is removed after the application of a water slide (Leite et al., 2007). As for sulfur, its effect on pH lowering of saline soil is probably due to the biological oxidation of elemental sulfur, which produces acidity and sulfate in the soil (Stamford et al., 2007; Heydarneshad et al., 2012; Sá et al., 2013). The acidity generated by the oxidation of sulfur possibly contributed to increase the minerals solubility such as calcium carbonate and/or magnesium and mainly calcium and potassium feldspar increasing the concentration of exchangeable cations such as calcium, magnesium and potassium, also contributing to the reduction of the soil ESP. Calcium sulfate, despite having no acid reaction, also reduced the pH of the saline-sodic soil. This decrease occurs indirectly, due to the decrease of the exchangeable sodium contents (Miranda et al., 2011; Sousa et al., 2012; Sá et al., 2013).

In turn, the addition of organic matter, although in some cases had a positive effect on the growth and production of plants dry mass, produces a less pronounced effect than the other conditioners. The organic residues can physically improve the soil, providing a greater aggregation and increasing its macroporosity, facilitating the removal of the soluble salts (Gill et al., 2009; Makoi & Verplancke, 2010). However, these materials did not contribute to the removal of exchangeable sodium as much as calcium sulfate and elemental sulfur, since the amounts of exchangeable cations released from their mineralization are insufficient for the displacement of exchangeable sodium from the exchange complex (Gill et al., 2009; Miranda et al., 2011).

The reductions in the photosynthetic rate, transpiration rate and stomatal conductance with elevated salinity and sodic levels are attributed to water stress (Tejada et al., 2006; Alves et al., 2009), which causes closure of the

stomata and reduces de CO₂ flow into the cell, as well as the toxic effect of the sodium excess (Munns, 2002; Velinni et al., 2008; Fernandes et al., 2010; Uddin et al., 2011; Souza et al., 2012).

It should be pointed out that in the case of the species *Amburana cearensis*, the absence of a difference between the soil conditioners, for the photosynthetic rate (Table 4), could indicate a greater tolerance of this species to the salt stress. However, this effect was not necessarily reflected in the production of relative dry mass, mainly of aerial part. It is possible that for the cited species, these physiological variables are not good indicators of tolerance to the salinity or can mean that due to the growth in a saline environment, the plant has adjusted to the stressful conditions. Sousa et al. (2012) observed that the reduction of the photosynthetic rate was correlated with the increase of the sodium content and reduction of the potassium/sodium ratio in the aerial part of native Caatinga tree species. Similarly, Uddin et al. (2011) observed a reduction in chlorophyll content in several grass species under salt stress. Thus, the application of these conditioners to the soil could reduce the stressing effects to these species provided by the excess of salts and sodium in the soil.

The decrease of the relative growth of plants and the relative production of dry mass in the saline-sodic soils without corrective occurred probably due to the higher concentration of sodium in the soil, causing toxicity to the plants and due to the higher saline concentration and resulting in a lower osmotic potential of the soil solution, causing water stress in the plants (Mendonça et al., 2007, Fernandes et al., 2010). In addition, it is likely that the excess of sodium in the soil without a corrective may have caused competitive inhibition with potassium and calcium, thus contributing to decrease of plant growth, as observed by Uddin et al. (2011).

Regarding the shoot production, *Caesalpinia ferrea* and *Moringa oleifera* species seem to be the ones with the highest potential use in soils with salt excess and sodium when associated with the use of elemental sulfur or calcium sulfate conditioners. The other species presented fast growth (Sousa et al., 2012). Regarding the dry mass relative to the

photosynthetic rate, the *Moringa oleifera* and *Cnidoscopus philacanthus* species stood out in soils without correction. However, *Cnidoscopus philacanthus* produced less than half of the dry mass when compared to the non-saline soil, with a limited potential without the use of soil conditioners.

Therefore, the beneficial effect of the treatments on the growth of the studied species can be explained by the better soil chemical conditions when treated with elemental sulfur or calcium sulphate (Tables 2 and 3).

Conclusions

Bovine manure, elemental sulfur or calcium sulfate decreases the salinity and the sodicity of saline-sodic soils, with calcium sulfate and elemental sulfur showing better results.

Calcium sulfate and elemental sulfur decrease the negative effects of salinity and sodicity on the photosynthetic rate of the *Caesalpinia ferrea*, *Cnidoscopus philacanthus* and *Moringa oleifera* species, favoring the initial growth, mainly for *Caesalpinia ferrea* and *Moringa oleifera* species.

It should be emphasized that the results of the present study were obtained in a protected environment, requiring studies in the field for validation. It is suggested that future studies evaluate other management situations and/or other soil conditioning products, as well as an evaluation of the soil physical attributes.

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