

CHANGES IN SOIL CHEMICAL ATTRIBUTES AND NUTRITION OF *Anadenanthera colubrina* AND *Eucalyptus* CLONE UNDER NATURAL FERTILIZERS AND BIOCHAR

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Resumo

Mudanças nos atributos químicos do solo e nutrição de Anadenanthera colubrina e clone de Eucalyptus sob fertilizantes naturais e biochar. O estudo teve por objetivo avaliar mudanças nos atributos químicos do solo e a nutrição de *Anadenanthera colubrina* e de um clone de *Eucalyptus* sob diferentes fontes de adubação, utilizando sedimentos de reservatórios (SR), sedimentos de piscicultura (SP) e biocarvão (BC) na região semiárida do Brasil. Após aplicação dos tratamentos, foram amostradas as folhas e solo do clone de *Eucalyptus* e *A. colubrina*. As folhas foram coletadas para análise nutricional e solo para análise mineral e de fertilidade. Os teores de K⁺ e P no solo foram influenciados pelos fertilizantes naturais, e o biocarvão aumentou o teor de C. O plantio de *A. colubrina* reduziu os níveis de K⁺ e P do solo, e o clone de *Eucalyptus*, o teor de Mg²⁺. Os SP foi responsável por aumentar a disponibilidade de P para ambas as espécies, sendo uma boa opção para uso em solos naturalmente pobres em P. A *A. colubrina* apresentou os maiores teores de N, P, K e Ca, sugerindo alta demanda dessa espécie por esses nutrientes. O clone de eucalipto era mais exigente em Mg, sugerindo que seu cultivo fosse realizado em solos ricos em Mg²⁺. O uso de SR e SP é importante para aumentar o crescimento de espécies florestais em regiões semiáridas, e esse manejo é recomendado nas políticas de desmatamento dessas regiões.

Palavras-chave: fertilidade do solo; nutrição florestal; matéria orgânica; ciclagem biogeoquímica

Abstract

This study aimed to evaluate changes in soil chemical attributes and nutrition of *Anadenanthera colubrina* and a *Eucalyptus* clone under fertilization using reservoir sediment (RS), fish farming sediment (FFS) and biochar (BC) in the semi-arid region of Brazil. The *Eucalyptus* clone and *A. colubrina* leaves and soil were sampled after applying treatments. Leaves were collected for nutritional analysis and soil for mineral and fertility analyses. The K⁺ and P concentration in the soil were influenced by the natural fertilizers, and the biochar increased the C content. The *A. colubrina* planting reduced the soil K⁺ and P levels, and the *Eucalyptus* clone cultivation reduced the Mg²⁺ content. The FFS was responsible for increasing P availability in both *A. colubrina* and the *Eucalyptus* clone, being a good option for use in soils which are naturally poor in P. *A. colubrina* presented the highest N, P, K and Ca levels, suggesting high demand of this species for these nutrients. The *Eucalyptus* clone was more demanding for Mg, suggesting that its cultivation should be done in soils rich in Mg²⁺. The use of RS and FFS is important to increase the growth of forest species in semi-arid regions, and this management is recommended in the deforestation policies of these regions.

Keywords: soil fertility; forest nutrition; organic matter; biogeochemical cycling

INTRODUCTION

The elements circulate in nature in a constant and balanced way and the nutrients which compose the vegetal biomass generally return to the abiotic environment by senescent material falling after its fragmentation, decomposition, and mineralization. The search for knowledge on the self-sustainability of ecosystems is constant, indispensable and increasing regarding nutrient cycling, especially in regions where rain scarcity is a limiting factor in the absorption of nutrients (ALBUQUERQUE *et al.*, 2018). Therefore, only a soil fertility evaluation is insufficient to evaluate a plant's nutritional status. Thus, it is crucial to consider the content and type of nutrients, mainly in the plants' leaf component.

Knowledge on nutrient content in the phytomass and how this material returns to the soil is not only fundamental for adequate management of the forest production, but also to help reduce costs and environmental impacts as a consequence of reducing the amount of chemical fertilization used. Forest biomass formation contributes to translocating nutrients present in the lower soil layers, being absorbed by the plants' deep roots and returned by senescent plant material, and is essential for the natural maintenance of ecosystems (GAUTAM; MANDAL, 2018). Nutrient exportation from soils is relatively higher in regions with commercial plantations.

Thus, management needs to consider leaving the exploitation residues in the field to improve soil fertility and contribute to maintaining the nutrient cycle (NANDWA; BEKUNDA, 1998).

Measuring and monitoring the nutrient content in the leaves is important, because it can indirectly provide information on soil fertility (SCHROTH; SINCLAIR, 2003). This knowledge can also contribute to increasing the financial return by reducing the costs of chemical fertilizers (TEIXEIRA *et al.*, 2017a). Reforestation with fast-growing species appears as an alternative to mitigate the use of natural vegetation in order to meet the demand for timber and non-timber forest products. However, such species are generally grown on low fertility soils, requiring additional nutrient supplementation to achieve the desired yield. Fast growing species (i.e. *Eucalyptus* sp.) have great importance in the industrial sector, however there is still little knowledge about the influence of forest management and site quality nutrient cycling (GONZÁLEZ-GARCÍA *et al.*, 2016), especially in semi-arid regions. In this context, *Anadenanthera colubrina* has important medicinal properties and economic use for the semi-arid region due to the high content of tannins found in its bark, being used in treating wounds, colds, cough, burns, boils, colic, in addition to leather tannin (ARAÚJO *et al.*, 2008).

Knowing how nutrients are absorbed by each commercial species or their contribution to nutrient cycling can contribute to research on the strategies used by plants to adapt to low rainfall environments, in turn contributing to increased forest productivity, especially with genetic breeding programs. Replacing nutrients in an organic form favors reducing environmental and water pollution, since organic waste which can also generate pollution is reused and chemicals are no longer applied to plantations, in addition to contributing to the increase in productivity levels.

Our hypothesis is that different sources of natural fertilizers and biochar with different C/N ratios can improve the soil chemical attributes and increase the nutrition of the species. Natural fertilizers with lower C/N ratios can nourish plants for a shorter time and biochar can prevent nutrient losses by leaching, providing more gradual and balanced nutrition in the longer-term, and increase the natural fertility. Therefore, this study aimed to evaluate changes in the soil chemical attributes and performance of *Anadenanthera colubrina* and a *Eucalyptus* clone under fertilization using reservoir sediment, fish farming sediment and biochar residues in the semi-arid region of Brazil.

MATERIAL AND METHODS

Study area

The experiment was established in 2014 at the Experimental Station of the Agricultural Research Institute of Pernambuco (*Instituto de Pesquisa Agronômica de Pernambuco - IPA*) in the semi-arid region of Pernambuco (Brazil). The region's climate is semiarid (BSh) according to the Köppen classification, with average annual precipitation of 507 mm and average temperature of 24.7°C (ALVARES *et al.*, 2013). Soils in the region are Entisols (Fluvents) (SOIL SURVEY STAFF, 2014) and chemically characterized up to 90 cm of effective depth (Table 1). The vegetation in the region is composed by Steppe Savannah, or Northeast Brazilian Caatinga (IBGE, 2012).

Table 1. Soil chemical attributes and particle size distribution of the experimental area.

Tabela 1. Atributos químicos do solo e distribuição granulométrica da área experimental.

Depth (cm)	pH ⁽¹⁾ (H ₂ O)	Ca ²⁺ (²)	Mg ²⁺ (²)	K ⁺ (³)	Na ⁺ (³)	Al ³⁺ (²)	(H+Al) ⁽⁴⁾	SB ⁽⁵⁾	CEC ⁽⁶⁾	V ⁽⁷⁾	P ⁽³⁾	Sand	Silt	Clay
		—————(cmol _c kg ⁻¹)—————							—————(%)—————			—————(g kg ⁻¹)—————		
0-30	5.8	4.0	0.9	0.5	0.1	0.0	1.5	5.5	7.0	78.6	51.0	616	261	123
30-60	6.0	4.3	0.9	0.2	0.1	0.0	0.9	5.5	6.4	85.9	37.7	603	256	141
60-90	6.3	4.8	1.1	0.2	0.2	0.0	0.8	6.3	7.1	88.7	37.4	620	230	150

⁽¹⁾Soil solution (1:2.5); ⁽²⁾ Ca²⁺, Mg²⁺, and Al³⁺ were extracted using KCl 1.0 mol L⁻¹ and determined through titration; ⁽³⁾K⁺, Na⁺ and P were extracted using Mehlich-1; P dosage was by the KI+H₂O₂ method and determined through UV-VIS spectrophotometry. K⁺, and Na⁺ through flame photometry; ⁽⁴⁾Potential acidity was extracted with a Ca(C₂H₃O₂)₂ solution 0.5 mol L⁻¹ and determined through titration; ⁽⁵⁾Sum of bases; ⁽⁶⁾Cation exchange capacity; ⁽⁷⁾Base saturation; All analyses were performed according to the methodologies described by Teixeira *et al.* (2017b).

Experiment establishment

The plantings were cultivated at 3 m x 2 m spacing with four treatments established in all arrangements: two natural fertilizer sources and one soil conditioner, being: reservoir sediment, fish farming sediment and biochar (produced from the remaining *P. Juliflora*), and control (no fertilization). The experiment had four replicates with plots represented by 28 trees in a completely randomized design. All fertilizers and biochar were applied in the amount of 1.0 kg per plant (1.67 Mg.ha⁻¹), with 500 g being applied at the time of planting and 500 g six months after.

Leaf and soil samples were collected 41 months after planting. Thus, 32 samples were evaluated, 16 of *A. colubrina* and 16 of *Eucalyptus* clones. The natural fertilization sources and biochar were chemically

characterized before application (Table 2). This characterization will serve as a parameter to evaluate the effect of treatments applied 41 months after planting on the chemical properties of the soil, taking the treatment which did not receive fertilization (control) as a parameter.

Table 2. Chemical analysis of the natural fertilizers and biochar used in the experiment.
Tabela 2. Análise química dos fertilizantes naturais e biocarvão utilizados no experimento.

Treatment	pH ⁽³⁾	Ca ²⁺ ⁽⁴⁾	Mg ²⁺ ⁽⁴⁾	K ⁺ ⁽⁵⁾	Na ⁺ ⁽⁵⁾	(H+Al) ⁽⁶⁾	SB ⁽⁷⁾	CEC ⁽⁸⁾	V ⁽⁹⁾	m ⁽¹⁰⁾	P ⁽⁵⁾	C ⁽¹¹⁾	N ⁽¹²⁾	C/N
	(H ₂ O)	(cmol _c kg ⁻¹)					(%)			(mg kg ⁻¹)		(g kg ⁻¹)		
FFS ⁽¹⁾	6.2	7.9	3.1	0.3	0.7	1.0	12.0	13.0	92.3	0.0	373.0	183.0	10.0	18.3
RS ⁽²⁾	5.5	14.8	4.4	0.2	1.6	3.8	21.0	24.8	84.7	0.0	25.0	367.0	28.0	13.1
Biochar	-	-	-	-	-	-	-	-	-	-	-	562.0	4.0	140.5

⁽¹⁾Fish farming sediment; ⁽²⁾Reservoir sediment; ⁽³⁾Soil:solution (1:2.5); ⁽⁴⁾Ca²⁺ and Mg²⁺ were extracted using KCl 1.0 mol L⁻¹ and determined through titration; ⁽⁵⁾K⁺, Na⁺ and P were extracted using Mehlich⁻¹; P dosage was by the KI+H₂O₂ method and determined through UV-VIS spectrophotometry. K⁺, and Na⁺ through flame photometry; ⁽⁶⁾Potential acidity was extracted with a Ca(C₂H₃O₂)₂ solution 0.5 mol L⁻¹ and determined through titration; ⁽⁷⁾Sum of bases; ⁽⁸⁾Cation exchange capacity; ⁽⁹⁾Base saturation; ⁽¹⁰⁾Aluminum saturation; ⁽¹¹⁾Total organic carbon was carried out by oxidation by the K dichromate method; ⁽¹²⁾N was determined through titration after steam distillation using the Kjeldahl method, according to Tedesco *et al.* (1995); All the other analyses were performed according to the methodologies described by Teixeira *et al.* (2017a).

Soil chemical attributes

Next, we collected soil samples at 30 cm depth to evaluate soil chemical attributes. Then, six trees from the center of the plot's useful area were chosen among the 10 individuals. The collection was performed opening the soil profile and collecting six simple samples to form a composite sample. Finally, this material was nutritionally analyzed and compared with the results of the 0-30 cm layer as shown in Table 1.

Nutrition assessment

Next, 25 leaves in the middle third of the crown were collected for nutritional analysis, distributed throughout the perimeter of the 10 trees of the plot's useful area. The leaves were packed in paper bags and taken to forced aeration 65 ± 5 °C until reaching constant weight.

The leaf sample digestions were performed using a MarsXpress biodigestor with microwave heating and temperature control with a pressurizing tube. After cooling, the material was taken to a fume hood for dilution in a 25.0 ml volumetric flask with distilled water. After dilution, they were stored in a plastic container and put under refrigeration for future analyzes. Total N content was determined based on the Kjeldahl steam drag method (TEDESCO *et al.*, 1995). In turn, P content was determined from the colorimetric method of molybdo-vanadate, with the absorbance reading in a spectrophotometer at a wavelength of 470 nm. The K was quantified by flame photometry. Ca and Mg readings were performed on an atomic absorption spectrophotometer (SILVA, 2009).

Statistical analysis

Statistical analyzes were performed using a factorial design and the means were compared by the Tukey test at the 5% significance level, assessing whether there was significance in the main effects (separate factors) or in the interaction between them. A completely randomized design with two factors was used in order to compare the nutritional contents (Factor 1: two plant species - *Eucalyptus* clone and *Anandenanthera colubrina*; Factor 2: four soil treatments - reservoir sediment, fish farming sediment, biochar and no treatment). The data were analyzed using the Assistat 7.7 beta software program.

RESULTS

Soil chemical attributes

The Mg⁺², K⁺ and P contents of the soil differed statistically between the plantations evaluated in this study (Table 3). *Eucalyptus* clone cultivation reduced Mg⁺² content and *A. colubrina* cultivation reduced K⁺ and P content of the soil, suggesting that the *Eucalyptus* clone is more demanding for Mg⁺² and *A. colubrina* is more demanding for K⁺ and P.

Table 3. Soil chemical attributes after treatment applications.

Tabela 3. Atributos químicos do solo após aplicação dos tratamentos.

VARIABLES	SPECIES	TREATMENTS					F-TEST			CV ⁽⁷⁾ (%)
		Control	FFS ⁽³⁾	RS ⁽⁴⁾	Biochar	Average	S ⁽⁵⁾	T ⁽⁶⁾	S x T	
pH (H ₂ O)	<i>Eucalyptus</i> ⁽¹⁾	6.1	6.1	6.0	5.9	6.0	3.37 ^{ns}	1.19 ^{ns}	1.56 ^{ns}	1.90
	<i>A. colubrina</i> ⁽²⁾	6.2	6.1	6.1	6.2	6.1				
	Average	6.1	6.1	6.1	6.0	-				
Ca ²⁺ (cmol _c dm ⁻³)	<i>Eucalyptus</i>	3.3	3.5	3.3	3.0	3.3	0.03 ^{ns}	0.66 ^{ns}	1.13 ^{ns}	13.20
	<i>A. colubrina</i>	3.3	3.1	3.6	3.2	3.3				
	Average	3.3	3.3	3.4	3.1	-				
Mg ²⁺ (cmol _c dm ⁻³)	<i>Eucalyptus</i>	1.3	1.3	1.0	1.2	1.2 b	6.65*	0.09 ^{ns}	0.97 ^{ns}	22.48
	<i>A. colubrina</i>	1.4	1.4	1.6	1.5	1.5 a				
	Average	1.3	1.3	1.3	1.4	-				
K ⁺ (cmol _c dm ⁻³)	<i>Eucalyptus</i>	0.50	0.66	0.67	0.49	0.58 a	28.57**	12.76**	0.83 ^{ns}	12.25
	<i>A. colubrina</i>	0.43	0.54	0.49	0.58	0.46 b				
	Average	0.47 B	0.60 A	0.58 A	0.44 B	-				
CEC (cmol _c dm ⁻³)	<i>Eucalyptus</i>	6.0	6.4	6.7	5.8	6.2	0.06 ^{ns}	0.97 ^{ns}	0.40 ^{ns}	10.97
	<i>A. colubrina</i>	5.9	6.4	6.4	6.2	6.2				
	Average	6.0	6.4	6.5	6.1	-				
V (%)	<i>Eucalyptus</i>	81.7	93.9	81.3	80.6	81.9	0.01 ^{ns}	1.54 ^{ns}	1.15 ^{ns}	18.56
	<i>A. colubrina</i>	85.7	88.4	88.4	63.0	81.4				
	Average	83.7	86.1	84.9	81.8	-				
P (mg dm ⁻³)	<i>Eucalyptus</i>	70.0	90.0	75.0	65.0	75.0 a	51.86**	3.86*	0.43 ^{ns}	8.39
	<i>A. colubrina</i>	55.0	70.0	60.0	55.0	60.0 b				
	Average	62.5 B	80.0 A	67.5 B	60.0 B	-				
C (g kg ⁻¹)	<i>Eucalyptus</i>	8.9	8.9	9.0	11.5	9.6	1.54 ^{ns}	40.69**	1.30 ^{ns}	5.69
	<i>A. colubrina</i>	8.7	9.7	9.4	11.5	9.8				
	Average	8.8 B	9.3 B	9.2 B	11.5 A	-				

⁽¹⁾*Eucalyptus* clone; ⁽²⁾*Anadenanthera colubrina* var. Cebil; ⁽³⁾Fish farming sediment; ⁽⁴⁾Reservoir sediment; ⁽⁵⁾Species; ⁽⁶⁾Treatments; ⁽⁷⁾Coefficient of variation. Similar averages followed by lower case letters in the rows and upper case in the columns do not differ by the Tukey test at 5% significance. * and ** significant at 5.0 and 1.0% significance by the F-test, respectively. ^{ns} not significant.

Nutrition assessment

Although the soil was rich in nutrients (Table 1), it was observed that fertilization sources interfered in the contents of some nutrients, as well as the different forest species. In addition to presenting differences in the P and K content because they are different species, the natural fertilization sources interacted with these different nutritional demands and interfered in the nutrition of the species (Table 4).

Table 4. Nutrient content in the leaves of the species after applying the treatments.

Tabela 4. Teor de nutrientes nas folhas das espécies após aplicação dos tratamentos.

VARIABLES	SPECIES	TREATMENTS					F-TEST			CV ⁽⁷⁾ (%)
		Control	FFS ⁽³⁾	RS ⁽⁴⁾	Biochar	Average	S ⁽⁵⁾	T ⁽⁶⁾	S x T	
N (g kg ⁻¹)	<i>Eucalyptus</i> ⁽¹⁾	16.7	16.5	17.4	16.9	17.6 b	47.4**	1.3 ^{ns}	1.2 ^{ns}	10.2
	<i>A. colubrina</i> ⁽²⁾	23.0	22.9	21.4	22.9	22.6 a				
	Average	19.9	19.7	19.4	22.1	-				
P (g kg ⁻¹)	<i>Eucalyptus</i>	3.9 bBC	4.8 bA	4.6 bAB	3.6 bC	4.2	668.8**	69.7**	28.9**	6.3
	<i>A. colubrina</i>	7.1 aB	10.3 aA	6.8 aB	6.4 aB	7.7				
	Average	5.5	7.5	5.7	5.0	-				
K (g kg ⁻¹)	<i>Eucalyptus</i>	6.1 aA	6.4 aA	6.1 bA	5.1 bB	5.9	23.6**	8.2**	3.9*	5.7
	<i>A. colubrina</i>	6.2 aA	6.8 aA	6.7 aA	6.4 aA	6.5				
	Average	6.2	6.6	6.4	5.7	-				
Ca (g kg ⁻¹)	<i>Eucalyptus</i>	15.0	15.6	15.8	14.9	15.4 b	19.2**	1.4 ^{ns}	2.9 ^{ns}	3.6
	<i>A. colubrina</i>	16.6	15.7	16.4	16.2	16.3 a				
	Average	15.8	15.7	16.1	15.5	-				
Mg (g kg ⁻¹)	<i>Eucalyptus</i>	4.7	4.8	4.5	4.7	4.7 a	465.3**	0.2 ^{ns}	0.5 ^{ns}	8.7
	<i>A. colubrina</i>	2.5	2.4	2.5	2.4	2.5 b				
	Average	3.6	3.5	3.5	3.6	-				

⁽¹⁾*Eucalyptus* clone; ⁽²⁾*Anadenanthera colubrina* var. Cebil; ⁽³⁾Fish farming sediment; ⁽⁴⁾Reservoir sediment; ⁽⁵⁾Species; ⁽⁶⁾Treatments; ⁽⁷⁾Coefficient of variation. Similar averages followed by lower case letters in the rows and upper case in the columns do not differ by the Tukey test at 5% significance. * and ** significant at 5.0 and 1.0% significance by the F-test, respectively. ^{ns} not significant.

The nutrient content found in the pure plantations follows the sequence: N>Ca>K>Mg>P for the *Eucalyptus* clone, and N>Ca>P>K>Mg for *A. colubrina*. The *A. colubrina* species presented higher nutrient

content than the *Eucalyptus* clone, except for Mg. The N content in the leaves showed that there was no interaction between the species and the soil treatment, while *A. colubrina* presented higher content. However, the treatments applied in the soil did not present a difference in the N content of the species when compared to the control (no fertilization).

DISCUSSION

Soil chemical attributes

The application of different sediments in the soils, including the biochar, influenced the concentration of the soils' nutritional contents, especially for K, P and C macronutrients (Table 3). Both reservoir and fish farming sediments increased soil K and P levels, and biochar increased C levels. Although K contents were already high in the topsoil (Table 1), they were increased by 4.5% on average due to sediment application when compared to the initial soil contents before applying the natural fertilizers. Sediments also increased by 44.6% in average P content of the soil (Tables 1 and 3) and differed from each other because the fish farming sediment had much more P than the reservoir sediment (Table 2). Sediment from fish farming tanks commonly has high P and C levels (SALAZAR; SALDANHA, 2007). Thus, the fish farming sediment could have further influenced soil P levels due to the high amounts of P in this sediment. However, it is possible that the P from the fish farming sediment may have been lost from the soil in a number of ways: precipitated due the high levels of Ca already existing in the soil (Table 1) and from the sediment itself (Table 2); complexed by biochar; leached due to the soil being very sandy (Table 1); and/or absorbed by plants.

In using residues from five different fish farming operations, all with nutrient amounts lower than the present study, Silva *et al.* (2017) verified that the use of this material was efficient in yellow passion fruit seedling production, being a good way to reuse the material and reduce the production costs. Theodoro *et al.* (2013) carried out fertility analyzes in the sediments and soils of the Tucuruí-PA reservoir and observed nutrient contents and organic matter with potential use as fertilizer. Even those elements found in quantities considered low were superior to the quantity present in the soil, therefore verifying its feasible use in agronomic production, in addition to the benefit of removing the sediment from the reservoir.

In addition to the availability of nutrients, the use of organic fertilization reduces the apparent density of the soil, increasing its porosity and consequently the water and nutrient availability to the plants (KIZITO *et al.*, 2019). The C content was found in higher amount in the parcels that received the biochar treatment due to the material composition. Although not directly contributing to soil fertility, biochar is important for retaining water and nutrients (DUARTE *et al.*, 2019). Biochar application is important to retain nutrients and allow their more efficient use over time in soils of high natural fertility, but very sandy as in this study (Table 1), and especially in forest crops.

Nutrition assessment

A. colubrina showed higher N content than the *Eucalyptus* clone, which is explained by the fact that the species is a legume and associates with bacteria capable of fixing atmospheric N₂ (VEJAN *et al.*, 2016). The different treatments applied to the soil were not enough to present significant differences in the N content of the species, which indicates that the soil already had sufficient nutrient content to meet the requirements of the individuals.

The *Eucalyptus* clone presented an average of 17.6 g kg⁻¹ of N in the leaf fraction, while *A. colubrina* showed an average of 22.6 g kg⁻¹ (Table 4). Studies carried out in the Caatinga environment presented mean values of 6.0 g kg⁻¹ of the N in leaves of *A. colubrina* (ALVES *et al.*, 2017; HOLANDA *et al.*, 2015). This value differs considerably from the present study. However, it is not possible to know the age of the trees of the studies carried out by these authors because it is a natural environment. In addition, the *A. colubrina* individuals in this study are very young, not to mention that competition for water and nutrients is lower because of the homogeneous spacing. This fact led to younger plants having great potential to extract and recycle nutrients, because plants require more nutrients to form biomass during growth (LI *et al.*, 2018).

A. colubrina showed higher P content in all treatments applied to the soil. However, when the treatments within each species were observed, the P content in the *Eucalyptus* clone cultivated with the fish farming and reservoir sediments stood out, as well as the P content in *A. colubrina* cultivated with the fish farming sediment (Table 4). Some factors such as the age of the individuals and the P available in the soil may have contributed to the values found, since the age of the individuals interferes in the nutrient content present in the biomass (Barbosa *et al.*, 2019).

The *Eucalyptus* clone presented an average of 4.2 g kg⁻¹ de P in the leaf fraction, while *A. colubrina* had 7.7 g kg⁻¹ (Table 4). The values found are much higher than those in the literature, which may have occurred due to the large amount of P found in the soil prior to applying the treatments (Table 1), as well as the large amount of

P in the sediments, especially from fish farming (Table 2). The application of the fish farming sediment provided the plants with a higher P value, followed by the reservoir sediment (Table 4).

In a study carried out in *Eucalyptus dunni*, Guimarães *et al.* (2015) found a P value of 1.0 g kg⁻¹ in the leaves, diverging from this study. Although the individuals were close in age in both studies, the amount of nutrients in the soil was very divergent. The P content in the superficial layer was 51 mg dm⁻³ in our study before receiving the treatments (Table 1), while the P content in the study of the authors in the layer up to 20 cm was 2.3 mg dm⁻³.

The application of reservoir sediment and biochar increased the K content in the *Eucalyptus* clone (Table 4). However, the biochar was the only natural fertilizer source which diverged from the others in the *Eucalyptus* clone, reducing nutrient content in the species. The control sample already had a satisfactory K amount because the soil already had a high K⁺ content (Table 1). Moreover, the K⁺ levels in the soil increased even more with the addition of fertilizer sources (Table 3). The nutrient absorption may have been lower for the *Eucalyptus* clone in the biochar treatment, which may have occurred due to the great mobility of this nutrient and the capacity of the biochar to retain the nutrients (LEHMANN, 2007).

The average K values found in each species were 5.9 g kg⁻¹ for the *Eucalyptus* clone and 6.6 g kg⁻¹ for *A. colubrina*. A study carried out by Vieira and Weber (2017) with eucalyptus seedlings using different substrates showed an average K value of 10.14 g kg⁻¹, well above that found in this study. However, the individuals analyzed were 4 months old. The authors also justified the high value found because the K content in the culture substrate was also high. Similar results to that study were also found by Guimarães *et al.* (2015), finding a K value in the leaves of 48-month-old individuals of 5.9 g kg⁻¹. Alves *et al.* (2017) carried out evaluations in a natural vegetation area and found a K content of 1.38 g kg⁻¹ for *A. colubrina*; this value is lower than the results of this study, most likely because the species is in competition with others and the area has not been subjected to any soil treatment.

Another factor which may have interfered with the K absorption was the high content of Ca found in the leaves (Table 4), since although nutrient absorption especially depends on their concentration in the soil solution, there may be competition between cations in the same site of the root surface, causing the absorption of one of the nutrients to be inhibited by the other (FAGERIA, 2001).

A. colubrina also had the highest Ca content when compared to the *Eucalyptus* clone (Table 4). However, there was no difference between treatments among the fertilization sources. The mean Ca values found in each species were 15.4 g kg⁻¹ for the *Eucalyptus* clone and 16.2 g kg⁻¹ for *A. colubrina* (Table 4). Toledo *et al.* (2013) found Ca values of 16.5 g kg⁻¹ in eucalyptus and recommended reduced fertilization with Ca. This proves that the high Ca levels may have interfered in the K absorption, as previously discussed. In studying 18-month-old individuals, Viera *et al.* (2012) found a Ca content of 10.5 g kg⁻¹, which is lower than this study. The authors recommend that the Ca content should be between 4.40 g kg⁻¹ and 5.90 g kg⁻¹, showing that there may be imbalance in relation to Mg above these values. On the other hand, Alves *et al.* (2017) found 4.1 g kg⁻¹ of Ca in the Caatinga regeneration area. This value is four times lower than the value found in this study for *A. colubrina* (Table 4). This can be explained by the fact that the soil had high Ca levels (Table 1), and *A. colubrina* was fertilized with Ca-rich sediments (Table 2). Additionally, there was no competition between species in *A. colubrina* planting as in the Caatinga regeneration areas.

Mg was the only nutrient which appeared in greater quantity in the *Eucalyptus* clone (Table 4). The mean Mg values found for the species were 4.7 g kg⁻¹ for the *Eucalyptus* clone and 2.5 g kg⁻¹ for *A. colubrina*. Guimarães *et al.* (2015) found lower values for eucalyptus individuals with ages close to this study (2.5 g kg⁻¹), although the soil presented similar levels to those of the control in this research. Viera *et al.* (2012) found 2.7 g kg⁻¹ content in 18-month-old *Eucalyptus* leaves, which is lower than in this study. However, the site's soil presented low Mg content compared to this study. Alves *et al.* (2017) also found smaller amounts for *A. colubrina* (0.50 g kg⁻¹), which can be justified by the age of the individuals and low natural fertility of the soil.

A. colubrina generally presented higher nutrient content, since it is a pioneer species and therefore allocates more nutrients for its growth, creating adequate conditions for ecological succession (HOLANDA *et al.*, 2015).

CONCLUSIONS

- Fertilizer sources and soil conditioner significantly interfere in the *Eucalyptus* clone and *Anadenanthera colubrina* plantations in semi-arid regions, serving as substitutes for chemical compounds;
- The K⁺ and P contents of the soil were influenced by the natural fertilizers and the biochar increased the C content of the soil;
- The fish farming sediment was responsible for increasing P contents in the two species, and is recommended for soils which are naturally poor in P;

- *Anadenanthera colubrina* presented the highest N, P, K and Ca levels, suggesting high demand of this species for these nutrients;
- The *Eucalyptus* clone was more demanding in Mg than *Anadenanthera colubrina*, suggesting that its cultivation in a semi-arid environment should be recommended in soils with high Mg²⁺ content.

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