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Use of wood ash and poultry litter in the early development of *Eucalyptus benthamii*

Uso de cinza de madeira e cama de aviário no desenvolvimento inicial de Eucalyptus benthamii

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RESUMO

Os solos brasileiros geralmente apresentam baixa fertilidade natural, dentre eles os solos florestais. O estudo tem como objetivo avaliar o crescimento inicial de *Eucalyptus benthamii* no planalto catarinense, com aplicação de fontes de adubação orgânicas e mineral. O estudo foi realizado em casa de vegetação, utilizando um Cambissolo Háplico. Cada unidade experimental foi constituída por um vaso de 2,5 dm³ de solo. O delineamento experimental utilizado foi completo casualizado, com quatro tratamentos e cinco repetições. Os tratamentos foram constituídos das seguintes fontes de adubos: testemunha (sem adubo); adubo mineral (NPK 9-33-12, equivalente a 187 mg dm³); cama de aviário na dose equivalente de 2.200 kg ha^{-1} e cinza vegetal de madeira de eucalipto na dose de 5.500 kg ha^{-1}. A quantidade de cada adubo foi aplicada para fornecer o equivalente a 50 kg de P_2O_5 ha^{-1}. Foram avaliados altura de plantas, número de pares de folhas aos 90 e 180 dias e a massa seca de parte aérea e raízes, índice de qualidade de Dickson e os teores de fósforo (P) e nitrogênio (N) na parte aérea de eucalipto. A adubação com cinza de madeira apresentou altura superior aos 90 dias após a implantação, sendo semelhante ao fertilizante mineral e testemunha aos 90 dias e semelhante à adubação mineral. Já aos 180 dias após a cinza de madeira foi superior as demais fontes de adubação, sendo semelhante a adubação mineral. A massa seca da parte aérea, massa seca de raiz, teor de N e P na parte aérea não apresentaram diferenças entre as fontes de adubação. A adubação via cama de aviário inibiu o crescimento inicial da espécie, contudo a adubação com cinza de madeira pode ser uma alternativa o plantio de *Eucalyptus benthamii.*

PALAVRAS-CHAVE: adubação orgânica; adubo mineral; cama de aviário; resíduo madeirero.

ABSTRACT

The Brazilian soils generally exhibit low natural fertility, including forest soils. The study aims to evaluate the initial growth of Eucalyptus benthamii in the plateau region of Santa Catarina, with the application of organic and mineral fertilization sources. The study was conducted in a greenhouse, using a Haplic Cambisol. Each experimental unit consisted of a 2.5 dm³ soil pot. The experimental design used was completely randomized, with four treatments and five replications. The treatments consisted of the following fertilizer sources: control (without fertilizer); mineral fertilizer (NPK 9-33-12, equivalent to 187 mg dm³); poultry litter at a dose equivalent to 2,200 kg ha^{-1}; and eucalyptus wood ash at a dose of 5,500 kg ha^{-1}. The quantity of each fertilizer was applied to provide the equivalent of 50 kg of P_2O_5 ha^{-1}. Plant height, number of leaf pairs at 90 and 180 days, dry weight of aboveground and root parts, Dickson's quality index, and phosphorus (P) and nitrogen (N) levels in eucalyptus aboveground parts were evaluated. Fertilization with wood ash resulted in greater height at 90 days after establishment, being similar to mineral fertilizer and control at 90 days and similar to mineral fertilization. At 180 days, wood ash was superior to other fertilizer sources, being similar to mineral fertilization. Dry weight of aboveground parts, dry weight of roots, and N and P content in aboveground parts showed no differences among the fertilizer sources. Poultry litter fertilization inhibited the initial growth of the species; however, fertilization with wood ash could be an alternative for planting Eucalyptus benthamii.

KEYWORDS: organic fertilization; mineral fertilizer; poultry litter; wood residue.

INTRODUCTION

Brazil offers favorable soil and climate conditions for cultivated forest production, particularly for *Eucalyptus* species (FLORES et al. 2016). In 2021, Brazil's eucalyptus plantations covered approximately 7.53 million hectares, making it the country's most widely cultivated forest species (IBA 2022). For optimal eucalyptus growth, a robust initial development stage is crucial. High-quality seedlings have better survival rates, growth, and plant development. This reduces the need for frequent cultural practices and ensures a high-quality, cost-effective product. These characteristics are especially desirable in regions with frost and adverse climate conditions for cultivation, such as the Santa Catarina Plateau (FRIGOTTO et al. 2020).

Furthermore, in naturally low-fertility soils, such as those found in Southern Brazil, it's essential to supply nutrients through fertilizers or nutrient-rich residues (CQFS-RS/SC 2016). These fertilizers can boost yields, enhance productivity, and potentially shorten the production cycle (DIAS et al. 2015).

Most mineral fertilizers are imported and expensive, making fertilization a significant cost in forest plantations (CUNHA et al. 2021). Furthermore, since soluble fertilizers are agricultural commodities, their prices are set by international markets, potentially leading to significant increases in production costs. Alternatively, organic fertilizer sources like poultry litter and wood ash can be used, which not only increase soil nutrient (AN & PARK 2021) levels but may also enhance cation exchange capacity.

Poultry litter is a readily available waste product in Southern Brazil, containing both macro and micronutrients (ROGERI et al. 2016). Additionally, since calcium oxide (CaO) is added to poultry litter, it can raise soil pH and increase calcium levels in the soil (TOLUWASE et al. 2020). However, the bedding contains varying amounts of sawdust and wood shavings mixed with chicken manure, potentially resulting in a high carbon-to-nitrogen (C/N) (CQFS-RS/SC 2016) ratio. This could immobilize some of the soil's nitrogen, possibly affecting the initial growth of eucalyptus seedlings.

The Santa Catarina Planalto region has areas with pine and eucalyptus production, where harvest residues can be used to generate electricity through biomass combustion (HABITZREITER et al. 2019). Additionally, sawmills often produce sawdust, which is commonly used in boilers for heating and drying lumber. Both processes produce ash that requires proper disposal (SANTOS 2012). However, like poultry litter, these ashes contain nutrients that can be used to fertilize forest species, replenishing the nutrients absorbed by the forest (CQFS-RS/SC 2016).

Sawmills can produce substantial amounts of sawdust, reaching up to 18% of the wood volume (HAMBISA et al. 2023). The use of ash allows for partial or even complete replacement of mineral fertilization in *Eucalyptus* seedling establishment, due to the availability of nutrients present, ensuring high productivity (SCHEEPER & TOIT 2017). In addition to their nutrient content, ash can contain alkaline compounds such as OH^-, which help reduce soil acidity (REID & WATMOUGH 2014).

Using organic waste for soil fertility management is a sustainable practice that reduces industrial waste production while minimizing the environmental impact of mineral extraction and nitrogen fertilizer production (THOMAZINI et al. 2022). However, there is still limited research on the early growth of *Eucalyptus benthamii Maiden & Cambage* using alternative fertilizer sources, such as poultry litter and wood ash.

The hypothesis suggests that using poultry litter and boiler ash will produce *Eucalyptus benthamii* seedlings comparable in size to those grown with mineral fertilizers after 180 days of development. The study aimed to assess how organic and mineral fertilization affects the early growth of potted *Eucalyptus benthamii* Maiden.

MATERIAL AND METHODS

The experiment was carried out in a greenhouse at the Rural Sciences Center of the Federal University of Santa Catarina, located in Curitibanos, Santa Catarina.

Samples were collected from a Haplic Cambisol (SANTOS et al. 2018) clay soil, uncultivated in the top 0-20 cm layer, under native forest vegetation, derived from basalt. The soil was clod-broken, sieved through a 2 mm mesh, and oven-dried with air circulation at 60 °C. A soil subsample was collected and sent to the soil analysis laboratory for chemical property testing (Table 1).

Table 1. Chemical characterization of the Cambissolo Háplico in the 0-20 cm layer before the experiment implemented.

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Clay	MO[(1)]	pH-$CaCl_2$	P[(2)]	K+[(3)]	$Ca^{2+(4)}$	Mg^{2+}	Al^{3+}	$CTC_{pH7,0}$[5]	V [(6)]	m[(7)]
g kg^{-1}	g dm^{-3}	1:1	mg dm^{-3}		---------$cmol_c.dm^{-3}$--------------				%	
58,8	37,6	4,3	6,9	62,5	2,2	0,7	1,8	14,6	21,1	37,4

[1] soil organic matter content; [2] available P content by Mehlich 1; [3] exchangeable K content extracted by Mehlich 1 and determined by flame photometry; 4 Ca, Mg, and Al extracted by 1 mol L^{-1} KCl, with Ca and Mg determined by atomic absorption and Al by titration. [5]CTCpH7.0 - Cation exchange capacity at pH 7.0; [6] V= CEC saturation by bases; [7] m= CEC saturation by Al.

Dolomitic limestone (99% PRNT) was applied at 3.85 g per kg of soil to increase soil base saturation, following the Liming and Fertilization Manual for Rio Grande do Sul and Santa Catarina states (CQFS-RS/SC 2016), aiming to achieve a water pH of 5.5. The soil was left to incubate for about 30 days to allow the limestone to react. The soil was then transferred to 2.5 dm^3.

The experimental design employed was a completely randomized design with four treatments and five replications, where each experimental unit consisted of one plant per pot. The treatments consisted of the following fertilization regimens: T1 = control (no fertilizer); T2 = mineral fertilizer (9-33-12); T3 = organic fertilizer (poultry litter); and T4 = wood ash. The fertilizer application rates met the crop's phosphorus (P) requirements, based on the soil's available P content and the recommendations from the fertilization and liming manual for Rio Grande do Sul and Santa Catarina states (CQFS-RS/SC 2016). Therefore, fertilizers were applied to add 25 mg dm^3 of P_2O_5[1], using 150, 2200, and 5500 kg per hectare of mineral fertilizer, poultry litter, and plant ash, respectively (Table 2).

Table 2. Chemical composition and quantity of nutrients and NPK fertilizer present in the poultry litter and wood ash applied to the soil.

Table 2. Chemical composition and quantity of nutrients and NPK fertilizer present in the poultry litter and wood ash applied to the soil.

Treatments	Nutrient content[2]				Total applied (kg ha^{-1})[3]			Total
	N	P_2O_5	K_2O	MS[4]	N	P_2O_5	K_2O	
	---------------------%-------------------				-----------kg ha^{-1}------------			kg ha^{-1}
NPK	9	33	12	-	13,5	50	18	150
Litter [1]	3,5	3,8	3,0	75	29	50	50	2.200
Grey[5]	0,34	1,17	2,24	78	14,5	50	95	5.500

[1] Litter = Poultry litter; [2] Nutrient content in dry matter; [3] Total nutrients applied equivalent in kg per hectare; [4] DM = Dry matter. [5] N, P_2O_5 and K_2O content carried out in sulphuric digestion according to TEDESCO et al. (1995).

Eucalyptus benthamii seedlings, sourced from a local commercial nursery with origin control, were used. They were approximately 40 cm tall, had six pairs of leaves, and a stem diameter of 1 cm. The seedlings were planted after fertilizers were applied, mixed, and incorporated into the soil in the pots. The seedlings were then placed in the greenhouse on aluminum benches approximately 1,5 m. The pots were kept 30 cm apart. Soil moisture was maintained at 80% field capacity through manual irrigation.

Evaluations were conducted at 90 days and 180 days post-implantation. Height was measured from the base to the plant's apex using a measuring tape graduated in centimeters, stem diameter was measured 3 cm above the soil using a digital caliper, and the number of expanded leaf pairs per plant was counted. After 180 days, the plants were cut at ground level and separated into roots and shoots. The roots were sieved from the soil, then washed and dried in a forced-air oven at 65°C until reaching constant mass. After drying, the roots and shoots were weighed on an analytical balance to determine their dry mass. The Dickson Quality Index was calculated using dry mass and stem diameter measurements (DICKSON et al. 1960) According to the following equation (equation 1):

$$IQD = \frac{\mathrm{MST}}{\frac{\mathrm{AP}}{\mathrm{DC}}+\frac{MSA}{MSR}} \qquad \text{equation 1}$$

Where:

TDM = total dry mass (g); PH = plant height (cm); SD = stem diameter (mm); SDM = shoot dry mass (g); RDM = root dry mass (g).

The aerial parts were ground in a Willey-type mill and subjected to sulfuric digestion to determine N and P content in leaf tissue, following the methodology described by TEDESCO et al. (1995). P was determined by colorimetry using a molecular absorption spectrophotometer at a wavelength of 882 nm (MURPHY & RILEY 1962). The N was determined by distillation and titrated with sulfuric acid using a boric acid solution with bromocresol green and methyl red as indicators (TEDESCO et al. 1995).

Data analysis began by verifying the assumptions of normality and homoscedasticity using Shapiro-Wilk (p = 5%) and Bartlett (p = 5%) tests. The data were then subjected to analysis of variance, and when significant differences were found, means were compared using Tukey's test at 5% significance level, using the SISVAR software (FERREIRA 2008).

RESULTS AND DISCUSSION

Eucalyptus benthamii's height was affected by the fertilizer source at both 90 and 180 days (Table 3, Figure 1). The other evaluated parameters were not influenced by the fertilization methods used on the eucalyptus seedlings.

Table 3. Results of the analysis of variance for the parameters evaluated in the initial development of *Eucalyptus benthamii*.

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Parameters	F test	DMS	CV
		90 days	
Height	**0,0049***	9,13	6,66
Neck diameter	0,1978	0,70	9,70
No. of leaf pairs	0,1732	3,15	10,92
		180 days	
Height	**0,0003***	18,81	9,73
Neck diameter	0,1658	0,64	6,19
No. of leaf pairs	0,3484	6,78	12,99
Aerial part mass	0,3867	5,99	20,49
Root mass	0,6074	2,31	21,14
N fabric	0,4406	5,06	19,90
Fabric	0,8195	8,87	50,75
IQD²	0,3239	0,41	23,28

*Significant at 1% probability level. MSD = minimum significant difference. CV = coefficient of variation. ² Dickson quality index.

The application of poultry litter resulted in the lowest plant heights at 90 days after planting (DAP), similar to mineral fertilizer. By 180 DAP, plants treated with ash and mineral fertilizer showed greater height, reaching between 109 to 120 cm tall. Mineral fertilizer showed similar results to poultry litter (with slightly lower average height than ash fertilization) at 90 days. However, this pattern reversed at 180 DAP, when ash and mineral fertilizer produced the tallest plants, ranging from 109 to 120 cm, while poultry litter resulted in plants shorter than 80 cm at 180 DAP. Mineral fertilizer showed similar results to poultry litter (with slightly lower average height than ash fertilization) at 90 days. However, this pattern reversed at 180 DAP, when ash and mineral fertilizer produced the tallest plants, ranging from 109 to 120 cm, while poultry litter resulted in plants shorter than 80 cm at 180 DAP. However, stem diameter and leaf pair count showed no differences between fertilizer treatments at both 90 and 180 DAP (Figure 2).

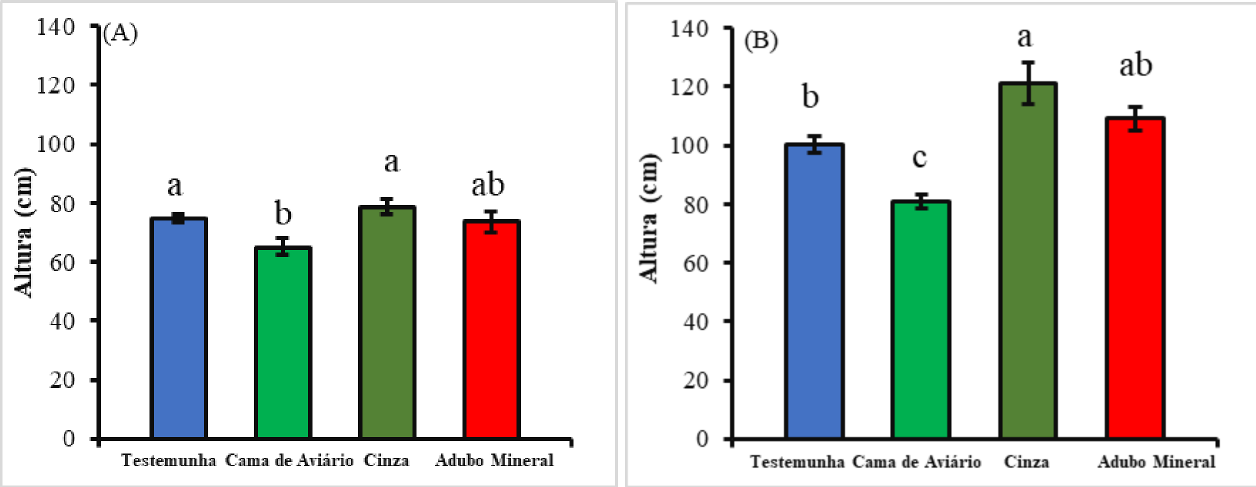

Figure 1. Height of *Eucalyptus benthamii* as a function of different fertilizer sources at 90 days after implantation (DAP) (A) and 180 DAP (B). Means followed by the same letter in the column do not differ from each other at a 5% probability level by Tukey's test. The vertical bar represents the standard error of the sample.

Figure 1. Height of Eucalyptus benthamii as a function of different fertilizer sources at 90 days after implantation (DAI) (A) and 180 DAI (B). Means followed by the same letter in the column do not differ from each other at a 5% probability level by Tukey's test. The vertical bar represents the standard error of the sample.

However, stem diameter and leaf pair count showed no differences between fertilizer treatments at both 90 and 180 DAP (Figure 2). The findings indicate that mineral fertilizer and forest biomass ash led to greater plant heights by the end of the assessment. Plants may respond more strongly to mineral fertilizers due to their higher solubility, with full availability expected shortly after application (MUMBACH et al. 2020). However, soluble fertilizer application only provides N, P, and K nutrients.

Poultry litter is an organic fertilizer where many nutrients are unavailable and require soil microorganisms to mineralize them into plant-accessible forms (NOCE et al. 2014). Therefore, when using litter with higher amounts of wood shavings and sawdust, soil nitrogen immobilization may occur, potentially impacting the initial plant growth. 2020). Thus, we hypothesize that the high C/N ratio and significant amount of recalcitrant compounds in poultry litter led to soil N immobilization, negatively impacting plant performance at both 90 and 180 DAP.

It's worth noting that the nitrogen mineralization from poultry litter is less than 22% of the total nitrogen content within the first 50 days after application (ROGERI et al. 2015) only 50% of the nitrogen from poultry litter will be available in the first year of cultivation (CQFS-RS/SC 2016), due to soil microorganisms' mineralization process. Therefore, in forest plantations using poultry litter as fertilizer, it may be necessary to apply some nitrogen in soluble form to compensate for the slow release rate of nitrogen from the poultry litter.

Ash, in addition to containing N, P, and K levels (Table 2), provides increased Ca and Mg content for plants (SILVA et al. 2013). Additionally, it may contain alkaline compounds that increase soil pH, thereby reducing acidity (BONFIM-SILVA et al. 2019) and increasing the availability of nutrients such as nitrogen and phosphorus (SANTOS et al. 1995). The ash's enhanced nutrient availability boosts forest species' height growth and productivity (BARRETO et al. 2008), outperforming the soluble source (PRADO et al. 2002). Wood ash application could potentially decrease the need for acidity correctors or fertilizers in forested areas with ash availability, such as the Santa Catarina Plateau region.

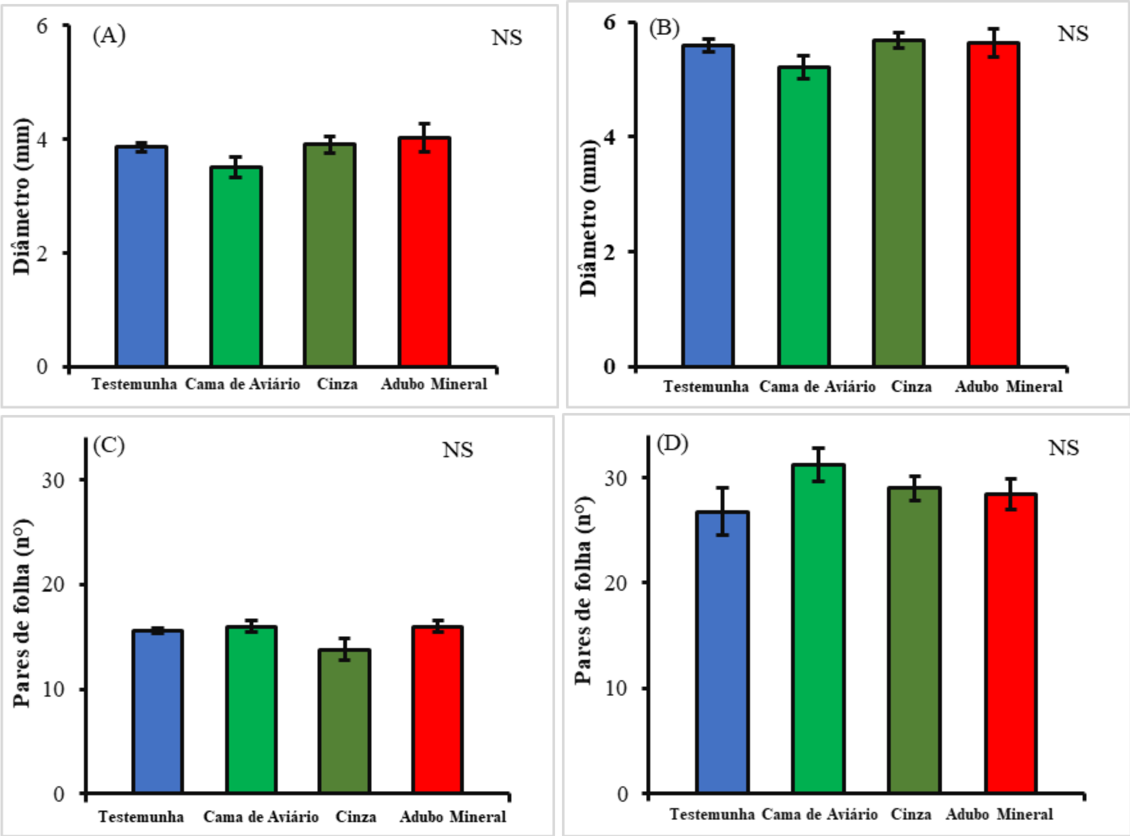

Figure 2. Diameter at 90 (A), 180 DAP (B), number of leaf pairs at 90 (C), and 180 DAP (D) of *Eucalyptus benthamii* as a function of different fertilizer sources. NS = Not significant by ANOVA test. The vertical bar represents the standard error of the sample.

Figure 2. Diameter at 90 (A), 180 DAP (B), number of leaf pairs at 90 (C), and 180 DAP (D) of Eucalyptus benthamii as a function of different fertilizer sources. NS = Not significant by ANOVA test. The vertical bar represents the standard error of the sample.

It's worth noting that prior to cultivation, the soil was treated with limestone, potentially increasing calcium and magnesium levels while reducing soil acidity. This reduction in acidity, combined with soil tillage, may have activated soil microorganisms that ended up mineralizing some of the nutrients present in soil organic matter, such as N, P, and sulfur (S) (DHIMAN et al. 2019). This may have influenced the witness's growth at 90 days, showing similar height values compared to ash and mineral fertilizer. By the 180-day mark, some nutrients may have been taken up by plants, and due to limited carbon input into the soil, microbial activity might have decreased (BARRETO et al. 2008) showing lower values as a result.

There were no differences in diameter or number of leaf pairs between treatments. The diameter observed in this study exceeds the critical threshold (> 2 cm in diameter) for well-formed *Eucalyptus* seedlings (Wedling & Dutra 2010). However, after 90 and 180 days, the average diameter increased to 3.83 and 5.53 cm respectively. This diameter increase across all treatments was 44% from 90 to 180 days of the experiment.

For the dry mass of the aerial part, root dry mass, and N and P content in the aerial part, there was no difference between fertilizer sources (Figure 3). The growth of the aboveground biomass is a crucial factor in seedling quality. The height of the above-ground portion combined with the stem diameter is one of the key morphological indicators for predicting seedling growth after field planting. One possible explanation for this outcome relates to the soil type, which is a clayey Haplic Cambisol with moderate organic matter content, medium natural fertility, and high availability of phosphorus and potassium (Table 1). Additionally, soil liming was performed before cultivation to correct soil acidity and increase pH, while also potentially providing N and P through organic matter mineralization. The hypothesis suggests that soil correction management combined with tillage provided favorable conditions for Eucalyptus growth, diminishing the impact of fertilizer additions on both aboveground biomass and root mass.

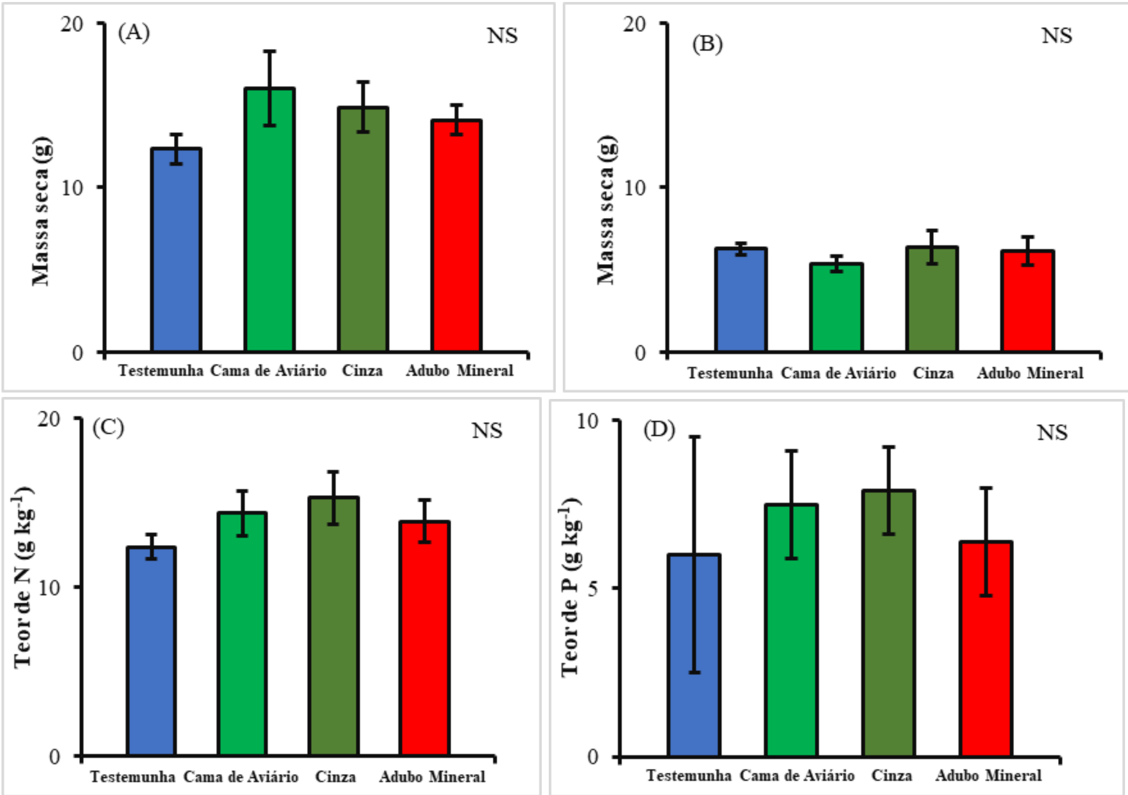

Figure 3. Aboveground mass (A), root mass (B), nitrogen content (C), phosphorus content (D) in *Eucalyptus benthamii* tissue after 180 days of implantation. NS = Not significant by ANOVA test. The vertical bar represents the standard error of the sample.

Figure 3. Aboveground mass (A), root mass (B), nitrogen content (C), phosphorus content (D) in Eucalyptus benthamii tissue after 180 days of implantation. NS = Not significant by ANOVA test. The vertical bar represents the standard error of the sample.

The root mass ranged from 6.14 to 6.36 g, with no difference between fertilizer sources, which is higher compared to other studies, such as *Eucalyptus camaldulensis* ranging from 0.53 to 0.80 g in root biomass when evaluating seedling development in substrates (VIEIRA & WEBER 2017a). Another study found that phosphate fertilizers didn't affect root mass in *Eucalyptus dunni* experiments in Santa Catarina's plateau, only changing fine root quantities (DIAS et al. 2015). The nitrogen content ranged from 12.4 to 15.3 g/kg^{-1}. These values are deemed suitable for plant seedlings around 80 to 100 days (SILVEIRA et al. 2001) and there was no significant difference between the fertilizer sources.

The P content in the aerial parts ranged from 6.0 to 7.9 g kg^{-1}, which is comparable to values reported for *Eucalyptus camaldulensis* (6.5 to 11.79 g kg^{-1}) in a study evaluating wood ash (VIEIRA & WEBER 2017b). This indicates that soil P levels were adequate, providing sufficient phosphorus for the initial growth of eucalyptus. Even in the control without phosphorus addition, the levels were adequate, supporting the hypothesis that soil disturbance combined with improved soil chemical conditions due to lime application may have activated soil microorganisms to mineralize some organic phosphorus.

Similar to the root and shoot dry mass data, there was no difference in the Dickson Quality Index (DQI) (Figure 4). Therefore, the addition of wood ash did not impact the seedling quality as measured by the Dickson Quality Index.

The application of organic waste, such as forest biomass ash, in areas cultivating tree species like eucalyptus can enhance early growth. However, the chemical makeup of both ash and poultry litter varies, which can impact forest growth. Therefore, it's advisable to conduct a chemical analysis of the organic waste and, when necessary, supplement it with soluble fertilizers to prevent nutrient accumulation or deficiency.

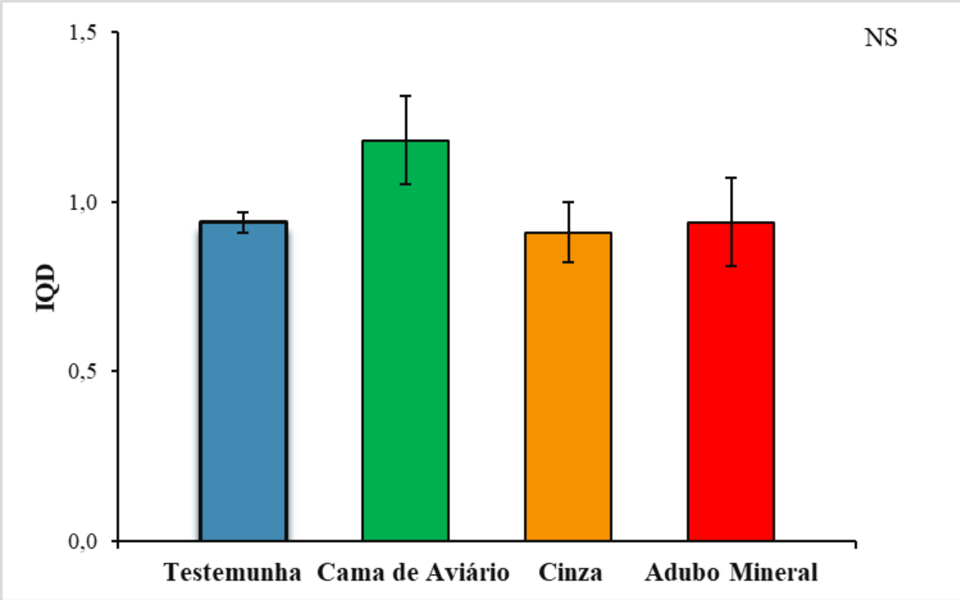

Figure 4. Dickson Quality Index (DQI) of *Eucalyptus benthamii* seedlings after 180 days of planting. NS = Not significant by ANOVA test. The vertical bar represents the standard error of the sample.

Figure 4. Dickson Quality Index (DQI) of Eucalyptus benthamii seedlings after 180 days of planting. NS = Not significant by the ANOVA test. The vertical bar represents the standard error of the sample.

CONCLUSION

Wood ash fertilization can be used in *Eucalyptus benthamii* plantations at a rate of 5000 kg per hectare, as it provides essential nutrients and can reduce the need for expensive soluble fertilizers.

The use of poultry litter in this study hindered the initial growth of *Eucalyptus benthamii* seedlings. This may be linked to the bedding composition and the low nitrogen mineralization rate in the litter. Therefore, it's advisable to analyze poultry litter and supplement nitrogen with soluble sources during early growth stages.

Based on the results obtained, wood ash fertilization may be a viable alternative for fertilizing *Eucalyptus benthamii* seedlings, particularly in the Planalto region of Santa Catarina.

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