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Soil Chemical Attributes, Biometric Characteristics, and Concentrations of N and P in Leaves and Litter Affected by Fertilization and the Number of Sprouts per the *Eucalyptus* L'Hér. Strain in the Brazilian Cerrado

Natasha M. I. Godoi [1], Sabrina N. dos S. Araújo [2], Salatiér Buzetti [2], Rodolfo de N. Gazola [1], Thiago de S. Celestrino [1], Alexandre C. da Silva [3], Thiago A. R. Nogueira [2] and Marcelo C. M. Teixeira Filho [2,*]

[1] Postgraduate Program in Agronomy School of Engineering (FEIS), São Paulo State University (UNESP), Ilha Solteira 15385-000, São Paulo State, Brazil; natashagodoi@bol.com.br (N.M.I.G.); rngazola@gmail.com (R.d.N.G.); thiagocelestrino@yahoo.com.br (T.d.S.C.)

[2] Department of Plant Protection, Rural Engineering and Soils, Ilha Solteira School of Engineering (FEIS), São Paulo State University (UNESP), Ilha Solteira 15385-000, São Paulo State, Brazil; sabrina@agr.feis.unesp.br (S.N.d.S.A.); sbuzetti@agr.feis.unesp.br (S.B.); tarnogueira@agr.feis.unesp.br (T.A.R.N.)

[3] Department of Forestry, Cargill International SA, Três Lagoas 79610-090, Mato Grosso do Sul State, Brazil; Alexandre_C_Silva@cargill.com

* Correspondence: mcmteixeirafilho@agr.feis.unesp.br; Tel.: +55-17-3743-1940

Received: 31 March 2018; Accepted: 20 May 2018; Published: 24 May 2018

Abstract: Given the lack of recommendations for the fertilization of *Eucalyptus* clones in the second production cycle, the effects of fertilizer rates and the number of sprouts per strain in terms of the soil chemical attributes, biometric characteristics, and the concentrations of N and P in the leaves and in the litter of *Eucalyptus* L'Hér. in the Brazilian Cerrado were evaluated. The experimental design was a randomized block with four replicates, arranged in a 2 × 4 factorial scheme: one or two sprouts per strain; four fertilizer rates (0, 50, 100, or 200% of 200 kg ha^{-1} of the formula 06-30-06 + 1.5% Cu + 1% Zn) applied immediately after sprout definition. The option of one sprout per strain yielded higher contents of organic matter (K, S, B, and Mn) in the 0.20–0.40-m layer, the leaf chlorophyll index, the diameter at breast height, and the height of the *Eucalyptus* 44 months after the definition of sprouts. However, N and P leaf concentrations and the wood volume did not differ as a function of the sprout numbers. The fertilizer dosage did not influence the wood volume, even in sandy soil with low fertility. Approximately 86% of the wood volume was obtained from the supply of soil and root nutrient reserves and 14% of this productivity is due to fertilization minerals. The adequate fertilization in the first cycle of the *Eucalyptus* supplies almost the entire nutritional demand of the forest in the second production cycle.

Keywords: *Eucalyptus* sp.; wood volume; second production cycle; annual increment average; soil fertility; nutrient cycling

1. Introduction

Brazil is a country known for its forestry. It is estimated that the area occupied by forests planted in 2016 was 7.74 million hectares, about 0.9% of the national territory and a growth of 0.5% compared to the area in 2015 [1]. *Eucalyptus* L'Hér. planted in 2016 amounted to 5.7 million hectares in the states of Minas Gerais (24%), São Paulo (17%), and Mato Grosso do Sul (15%). There was an increase of 400 thousand hectares of *Eucalyptus* in the period between 2015 and 2016 [1].

Eucalyptus presents a high mobilization of nutrients due to its rapid growth. The harvesting of wood in Brazil is generally carried out when trees are seven years old and in cycles ranging from 7 to 21 years (one to three production cycles during these periods). The removal of biomass results in a large decreases in nutrients, consequently reducing their availability for future plantations. The *Eucalyptus* tree trunk is the largest biomass accumulator among all the parts of the plant, accounting for about 65–80% of the total accumulated biomass [2]. It is, therefore, responsible for the largest removal of nutrients. The total biomass extracted and its compartmentalization determine the degree of the removal of nutrients [2]. Faria et al. [3] found an average decrease of 52% in productivity from the first to the second production cycle of the *Eucalyptus*, which they attributed to the nutrient removal, especially of K, in the previous cycle. Rocha et al. [4] reported that even if forest residues from the first to the second *Eucalyptus* production cycle are maintained, there may be a 6% reduction in the productivity of the wood, and it may take up to 16 years for a site to recover completely when the plant residues are removed.

This situation is made worse by the fact that most plantations in the Brazilian Cerrado region are concentrated in soils with low natural fertility [5,6], where the nutritional deficit is mainly accentuated for N, P, K, Ca, Mg, S, B, and Zn [7]. These generally sandy soils present high levels of aluminum and low water availability, which may compromise the *Eucalyptus*' productivity over time. Therefore, the maintenance of the productivity of the forest requires the replacement of nutrients removed by the harvest and lost by other processes such as leaching. According to Costa et al. [8], fertilization leads to a 30–50% increase in the productivity of *Eucalyptus* forest sites.

Studies have shown that the application of fertilizers to *Eucalyptus* plantations can represent gains ranging from 5% to 90% in the volume of wood (VW). This response to fertilizers, especially N fertilizers, is even more significant in future rotations with more productive genetic materials and the removal of large amounts of nutrients from stands grown in sandy soils [9].

The lack of nutrient fertilization is one of the causes of the reduced productivity of *Eucalyptus* plantations in areas with low fertility soils, such as those in the Brazilian Cerrado. In most of these areas with low soil fertility, the responses to fertilization with N, P, K, S, and B are positive [10]. The application of fertilizer alters the tree's growth, the cycling and nutrient stocks in biomass of the trees, the understory, and the soil [11].

The sprouting of strains is an interesting and common technique in *Eucalyptus* plantations; it can be about 40% more economical than planting seedlings. The management of forests via clear cutting and regeneration through the sprouting of the strains has the advantage of having a high initial growth rate of sprouts compared with plants of the first production cycle, particularly since these first plants have a root system that contains organic and inorganic reserves that can be readily used [12,13]. These roots also facilitate the uptake of water and nutrients. Additionally, because of the high root to shoot ratio, the assimilates are preferably allocated with regard to the shoot formation, thereby increasing the differences in the growth rate compared to plants of the first rotation. This rapid initial growth of shoots may result in maximum wood yields earlier than those of the first rotation. Despite this apparent advantage, it has been recorded that many *Eucalyptus* forests in subsequent cycles have exhibited a decrease in productivity that is not always associated with the reduction in the number of trunks of the original settlement [12].

Given that nutrient cycling and productivity are favored by a greater availability of nutrients, the second production cycle of *Eucalyptus* has a root system that is almost completely formed. However, though the use of root reserves can be the key to the success of the second *Eucalyptus* production cycle, their impact on mature roots and sprouts is uncertain.

Due to the lack of recommendations for the fertilization of *Eucalyptus* clones in the second production cycle in the Brazilian Cerrado, it is necessary to define the best dose of fertilizers for one or two sprouts per *Eucalyptus* strain because the nutritional requirements can vary. The nutrient demand in the management of two sprouts per *Eucalyptus* strain, as well as the response to mineral fertilization, tends to be higher. The objective of this research was to evaluate the effect of mineral fertilizer rates and the number of sprouts per strain on the chemical attributes of the three layers of soil, the biometric characteristics, and the concentrations of the N and P in the leaves and in the litter of *Eucalyptus* during the second production cycle in the Brazilian Cerrado. Additionally, another objective of this research was to better understand what contributes the most in this system to the wood volume productivity and the supply of soil and roots with nutrient reserves or fertilization minerals.

2. Material and Methods

2.1. Location and Climate

The experiment set up in a commercial *Eucalyptus* field, managed by Cargill Agrícola S/A and located in the municipality of Três Lagoas in the state of Mato Grosso do Sul at a latitude of 20°45′ South, a longitude of 51°40′ West (Figure 1), and an altitude of approximately 320 m. It is in this Brazilian Cerrado region that the *Eucalyptus* cultivation proceeds the fastest. The largest paper and pulp industries in the world are located here. Prior to the first cycle production of the *Eucalyptus* in the sample area, there was a degraded brachiaria (*Urochloa brizantha* (Hochst. ex A.Rich.) R.Webster) pasture. The soil of the experimental area is an Arenosols, according to the World Reference Base for Soils (WRB) or an orthosic Quartzarenic Neosol (Entisols) according to the Embrapa classification system [14].

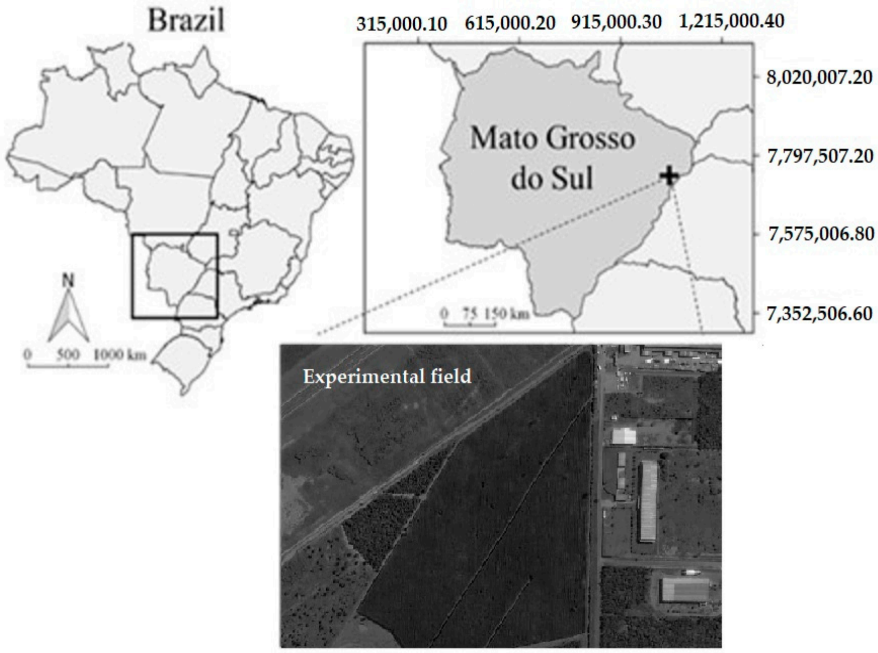

Figure 1. The study area at the Cargill Agrícola S/A (The municipality of Três Lagoas, state of Mato Grosso do Sul, Brazil; 20°45′ S and 51°40′ W, altitude 320 m).

The results of the soil chemical analysis of the experimental area at a depth of 0.00–0.20 m were determined prior to the installation of the experiment, according to the methodology proposed by Raij et al. [15]. We noted the following results: P_{resin} = 4 mg dm^{-3}, pH_{CaCl2} = 4.0; organic matter (OM) = 11 g dm^{-3}; K, Ca, Mg, H + Al = 0.4, 1.0, 1.0, and 25.0 $mmol_c$ dm^{-3}, respectively. The contents of $S\text{-}SO_4$, B, Cu, Fe, Mn, and Zn (diethylentriamene pentaacetate—DTPA) were 3.0, 0.23, 0.5, 24.0, 2.6, and 0.6 mg dm^{-3}, respectively, with a base saturation (V%) of 7% and an aluminum saturation (m%) of 83%. We observed that the soil was acidic with a low content of OM. The soil was deficient in the contents of macro and micronutrient (that is, below that which is considered as adequate for the good development of *Eucalyptus*). Fertility levels like those of this soil are commonly found in this region.

The climate in the region is Aw, according to the Köppen's classification system [16], characterized as humid tropical with a rainy season in the summer and a dry season in the winter.

2.2. Treatments and Experimental Design

The experimental design was a randomized block with eight treatments and four replicates arranged in a 2 × 4 factorial scheme. The first number in the scheme being the number (one or two) of sprouts per strain in the second cycle. It has four fertilizer rates (0, 50, 100, or 200% of 200 kg ha^{-1} of the formula 06-30-06 + 1% Ca + 3% S + 1% Mg + 1.5% Cu + 1% Zn, which is commonly used in the region) applied soon after the definition of the sprout, in April 2013. The scheme of the eight treatments are listed below:

- one sprout per *Eucalyptus* strain without fertilization;
- one sprout per *Eucalyptus* strain with 50% fertilization;
- one sprout per *Eucalyptus* strain with 100% fertilization;
- one sprout per *Eucalyptus* strain with 200% fertilization;
- two sprouts per *Eucalyptus* strain without fertilization;
- two sprouts per *Eucalyptus* strain with 50% fertilization;
- two sprouts per *Eucalyptus* strain with 100% fertilization;
- two sprouts per *Eucalyptus* strain with 200% fertilization.

Each plot was composed of 49 plants distributed in seven rows with seven plants in each row, with a line of *Eucalyptus* plants as a border at the ends. In all, the total plot area with a border was 367.5 m^2.

2.3. Management History

The *Eucalyptus urophylla* S.T.Blake clone (*Eucalyptus urophylla* × *Eucalyptus grandis* W. Hill ex Maiden) is the most commonly planted *Eucalyptus* species in the region and in Brazil. It is commonly planted with a spacing of 3.0 × 2.5 m. In the first cycle of *Eucalyptus* production in the entire experimental area, the following operations were performed: (a) sampling and soil analysis in the 0–0.20-m and 0.20–0.40-m depth layers; (b) the control of ants; (c) chemical weeding over the total area; (d) liming with 1.5 t ha^{-1} of limestone (Relative total neutralizing power—RTNP = 88%); (e) the application of 250 kg ha^{-1} of gypsum (with 14% S and 17% Ca) after liming; (f) felling: furrows were opened with a depth of 0.50 m in the planting line (on 13 December 2006); (g) the planting of 200 kg ha^{-1} of formula 06-30-06 fertilizer, enriched with 1.0% Ca + 3.0% S + 1.0% Mg + 1.5% Cu + 1.0% Zn, in the planting groove at a depth of 0.15 m; (h) the first topdressing fertilization using 120 kg ha^{-1} of formula 18-00-18 + 6% S + 0.5% B (300 kg of potassium chloride + 282 kg of ammonium sulfate + 368 kg of ammonium nitrate + 50 kg of Borogran with 10% B) 60 days after planting, applied manually in the form of a crown or semicircle 0.30 m away from the seedling neck on the soil and without incorporation into the soil; (i) the second topdressing fertilization using 270 kg ha^{-1} of formula 18-00-18 + 6% S + 0.5% B (300 kg of potassium chloride + 282 kg of ammonium sulfate + 368 kg of ammonium nitrate + 50 kg of Borogran) 10 months after planting, applied mechanically in a continuous fillet on the ground about 0.60 m away from the stem of the plant; (j) the third topdressing fertilization using 350 kg ha^{-1} of formula 15-00-20 + 10% S + 0.5% B (333 kg of potassium chloride + 417 kg of ammonium sulfate + 368 kg of ammonium nitrate + 50 kg of Borogran) 14 months after planting, applied mechanically in a continuous fillet on the ground about 0.60 m away from the stem of the plant; and (k) the *Eucalyptus* harvest was carried out 6 years after planting. The average productivity was 392 m^3 ha^{-1} of wood.

2.4. Experiment Management

Based on the soil analysis (Section 2.1) and the requirement of the *Eucalyptus* crop, two months before the *Eucalyptus* harvest of the first production cycle or rotation, the application of liming and gypsum were performed again in the experimental area. We applied 2 t ha^{-1} of limestone (RTNP = 88%) in order to increase the saturation of the bases to 60% in the total area and without the incorporation of this correction. After liming, 700 kg ha^{-1} of gypsum (with 14% S and 17% Ca) was applied next to the planting line in a range of 0.7–1.0 m on the soil surface and without incorporation into the soil.

After the harvesting of *Eucalyptus* during the rainy season, the strains that were covered with vegetal residue were cleaned within a 15 cm radius of the border of the strain in order to avoid impairing the emission of the sprouts. The thinning was conducted in April 2013 when the sprouts were, on average, 2.5–3.0 m long (the diameter at breast height was between 6.0 and 9.0 cm).

With respect to the selection of sprouts, regardless of the choice of one or two sprouts (Figure 2), we selected more vigorous sprouts located at the top of the strain (the upper side of the strain). In the plots in which the plants exhibited two sprouts, the sprouts were chosen in opposite positions, if possible, so that the opposition of one sprout to the other was in the direction of the planting line. The purpose here was to avoid or reduce the breakage or tipping of the sprouts when in contact with the machines and equipment that transit between the lines of the plantations during the fertilization operations and the maintenance of the forest.

Figure 2. The two sprouts (**A**) and one sprout (**B**) per *Eucalyptus* strain. Três Lagoas, state of Mato Grosso do Sul, Brazil, 2017.

The mineral fertilizer treatments described above were performed manually and in a semi-circle in April 2013. Weed control and plant pest control were performed when necessary.

2.5. Evaluations

2.5.1. Soil Chemical Analysis

Forty-four months after the definition of sprouts and after mineral fertilization, which corresponds to four years of *Eucalyptus* harvest cultivated in the first cycle, soil samples were obtained at depths of 0–0.20, 0.20–0.40, and 0.40–1.00 m in the *Eucalyptus* planting line. The planting line was fertilized in a semi-circle at eight points per plot to form a composite sample. We evaluated the alteration of the chemical attributes of the soil according to the protocol by Raij et al. [15]. The OM content in the soil was estimated by the Walkley–Black method. The available amounts of P, Ca^{2+}, K^{+}, and Mg^{2+}

in the soil were estimated by an ion-exchange resin procedure with B in hot water and Cu, Fe, Mn, and Zn in DTPA. The concentration of P, Al, and B in the soil extracts was quantified by a colorimetric method. The Ca, Mg, Cu, Fe, Mn, and Zn concentrations were determined by an atomic absorption spectrophotometer (AAS) (VARIAN SpectrAA 220FS) and the K using a flame-photometer (METEOR NAK-II). The available amount of $S\text{-}SO_4$ was estimated using a solution of calcium phosphate (Ca (H_2PO_4) 0.01 mol L^{-1}) and the quantification was determined by turbidimetry. The exchangeable aluminum was extracted with a 1 M KCl solution and determined by titration with 0.025 M of NaOH. The total acidity (H + Al) was extracted with a buffer solution of calcium acetate with a pH of 7.0 and determined by titration with ammonium hydroxide (0.025 M). From these values, the sum of bases (SB) {SB = Ca^{2+} + Mg^{2+} + K^+}, the total cation exchange capacity (CEC) at a pH of 7.0 (CEC = SB + (H + Al)), the saturation of exchangeable cations (V%) {V% = SB $\times$ 100)/CEC}, and the aluminum saturation (m%) {m% = (Al^{3+} $\times$ 100)/(SB + Al^{3+})} were obtained.

2.5.2. Concentrations of N and P in Leaves and Litter

At the same time (that is, 44 months after the definition of the sprouts and the mineral fertilization), samples (150 g each) of the *Eucalyptus* leaves and litter were collected from six representative trees or from near these plants. From the leaflet samples deposited on the soil and the biomass of the leaves of the *Eucalyptus* trees, the N and P concentrations were determined using the methodology described by Malavolta et al. [17].

2.5.3. The Height of the Plants

The height of the plants (H) is an essential piece of information for determining the VW of the trees. At an age of 44 months, the height of the three representative plants, sectioned at the level of the soil per plot, was measured using a scale. In order to better measure the height, 10 plants per plot were measured using a Forestor Vertex apparatus, which is composed of a hypsometer and a transponder [18].

2.5.4. Diameter at Breast Height

We used a graduate student and a forest compass to measure the diameter at a breast height (DBH) of 1.30 m. This evaluation was also performed 44 months after the definition of the sprouts and the mineral fertilization in the three representative plants sectioned at the soil level per plot. In addition, in order to better measure the DBH, 10 plants per plot were measured.

2.5.5. Total Wood Volume with Bark

Based on the plant height and the DBH evaluations noted above, the total VW with the bark (m^3 ha^{-1}) was calculated using the following formulae:

$$VW = \sum \frac{VW_i}{A_i} 1000 \quad (1)$$

$$VW_i = \frac{\pi (DBH_i)^2 \cdot ff \cdot H}{4} \quad (2)$$

where VW_i = the volume of the wood with the bark from each tree i; A = the area of the useful plot (367.5 m^2); VW = the total volume with bark (m^3 ha^{-1}); DBH_i = the DBH from each tree (m); ff = the form factor. In this case, a value of 0.5 was assigned and regionally defined for the clone used. Additionally, H_i = the total height of each tree (m).

2.5.6. Average Annual Increment

The average annual increment (AAI) in m^3 ha^{-1} $year^{-1}$ was calculated using the following formula:

$$AAI = \frac{VW}{t} \tag{3}$$

where AAI = the average annual increment (m^3 ha^{-1} $year^{-1}$); VW = the total volume with bark (m^3 ha^{-1}), and t = the time (year).

2.5.7. Leaf Chlorophyll Index

We determined the leaf chlorophyll index (LCI) indirectly at the same time as the other variables by examining the last fresh leaves of the middle third of the plant in 10 leaves per plot, using a portable digital chlorophyllometer (Falker Agricultural Automation, Porto Alegre, Brazil).

2.6. Statistical Analysis

We analyzed the results using a variance analysis (*F* test) and Tukey's test at a 5% probability level to compare the number of sprouts. A polynomial regression was applied to verify the effect of the fertilizer rates. All the statistical analyses including the Pearson correlation ($p < 0.05$) were performed using the SAS system (SAS Institute Inc., Cary, NC, USA).

3. Results

3.1. Soil Chemical Analysis

The chemical attributes of the soil at a depth of 0–0.20 m at 44 months after choosing the *Eucalyptus* sprouts are listed in Table 1. The pH values of the soil under the *Eucalyptus* plants indicated the acid reaction and did not vary as a function of the sprout numbers per strain or the fertilization rates. Such variation was noted for the other parameters studied, with the exception of the K and Mn concentrations. We verified that there were higher contents of K and Mn when we selected one sprout per strain. However, we observed that an increase in the fertilization rate decreased the Mg content, the sum of bases (SB), the CEC, and the V% and that it increased the iron content up to 106.6 kg ha^{-1} at a depth of 0–0.20 m. However, there was an increasing linear response for the P and Cu contents of the soil, as well as an increase in m%.

Table 1. The soil chemical attributes at a depth 0–0.20 m, 44 months after choosing the *Eucalyptus* sprouts as a function of the number of sprouts per strain and the fertilization rates.

	P $_{Resin}$	**O.M.**	**pH $_{CaCl2}$**	**K**	**Ca**	**Mg**	**H + Al**	**SB**	**CEC**
	(mg dm^{-3})	(g dm^{-3})				(mmol$_c$ dm^{-3})			
Sprouts per strain									
1	6.83a	12.92a	4.12a	0.63a	4.92a	4.00a	24.92a	9.55a	34.47a
2	7.67a	12.42a	4.09a	0.42b	3.83a	3.75a	24.83a	8.01a	32.84a
S.M.D. (5%)	1.89	1.34	0.20	0.14	1.79	1.52	2.93	2.83	3.19
Fertilizing (%) $^{+}$									
0	4.00 $^{(1)}$	13.67	4.15	0.58	4.67	4.83 $^{(2)}$	25.33	10.08 $^{(3)}$	35.42 $^{(4)}$
50	5.00	12.33	4.20	0.52	5.33	5.17	23.83	11.02	34.85
100	5.33	12.50	4.07	0.43	4.00	3.17	25.33	7.60	32.93
200	14.67	12.17	4.00	0.58	3.50	2.33	25.00	6.42	31.42
F Test									
Sprout (S)	0.89 ^{ns}	0.64 ^{ns}	0.07 ^{ns}	10.10 **	1.69 ^{ns}	0.12 ^{ns}	0.00 ^{ns}	1.37 ^{ns}	1.19 ^{ns}
Fertilizing (F)	31.84 **	1.19 ^{ns}	0.86 ^{ns}	1.18 ^{ns}	0.92 ^{ns}	3.61 *	0.27 ^{ns}	2.62 *	1.51 ^{ns}
S x F	1.37 ^{ns}	0.12 ^{ns}	0.76 ^{ns}	0.92 ^{ns}	0.30 ^{ns}	0.31 ^{ns}	0.64 ^{ns}	0.41 ^{ns}	0.51 ^{ns}
C.V. (%)	29.80	12.04	5.71	30.34	46.66	44.92	13.46	36.80	10.84
Average overall	7.25	12.67	4.10	0.53	4.38	3.88	24.88	8.78	33.65
Treatment	V	m	S-SO_4	B	Cu	Fe	Mn	Zn	

Table 1. *Cont.*

	P Resin	O.M.	pH CaCl2	K	Ca	Mg	H + Al	SB	CEC
	(%)	(%)	(mg dm^{-3})			(mg dm^{-3})			
Sprouts per strain									
1	27.71a	42.33a	8.08a	0.54	1.06a	25.67a	16.73a	0.53a	
2	24.26a	42.42a	10.17a	0.47	1.10a	24.92a	9.38b	0.61a	
S.M.D. (5%)	7.18	19.29	6.55	0.17	0.23	4.64	5.21	0.32	
Fertilizing (%) $^{+}$									
0	28.64 $^{(5)}$	25.67 $^{(6)}$	9.17	0.46	0.90 $^{(7)}$	29.83 $^{(8)}$	14.10	0.52	
50	31.72	36.83	7.67	0.49	0.95	23.33	11.22	0.57	
100	23.02	54.50	8.17	0.50	1.00	20.67	12.50	0.35	
200	20.57	52.50	11.50	0.57	1.47	27.33	14.42	0.85	
F Test									
Sprout (S)	1.06 ^{ns}	0.00 ^{ns}	0.46 ^{ns}	0.56 ^{ns}	0.15 ^{ns}	0.12 ^{ns}	9.14 **	0.25 ^{ns}	
Fertilizing (F)	2.32 *	2.31 *	0.31 ^{ns}	0.37 ^{ns}	5.98 **	3.56 *	0.37 ^{ns}	1.93 ^{ns}	
S x F	0.54 ^{ns}	0.26 ^{ns}	0.32 ^{ns}	1.37 *	0.83 ^{ns}	0.52 ^{ns}	0.38 ^{ns}	0.42 ^{ns}	
C.V. (%)	31.57	51.98	52.00	39.28	24.28	20.97	45.61	54.21	
Average overall	25.99	42.38	9.12	0.50	1.08	25.29	13.06	0.57	

B: determined in hot water; Cu, Fe Mn, and Zn: determined in DTPA. The chemical analysis was performed at the UNESP/FEIS Soil Fertility Laboratory. $^{+}$ The percentage refer to 200 kg ha^{-1} of formula 06-30-06 + 1.0% Ca + 3.0% S + 1.0% Mg + 1.5% Cu + 1.0% Zn. Means followed by the same letters in the column are not significantly different by the Tukey's test at $p < 0.05$. * Significant at $p < 0.05$. ** Significant at $p < 0.01$. ^{ns} = not significant. $^{(1)}$ Y = 2.5333 + 0.0539x (R^2 = 0.86 **); $^{(2)}$ Y = 5.1333 − 0.0144x (R^2 = 0.83 **); $^{(3)}$ Y = 10.6933 − 0.0219x (R^2 = 0.76 *); $^{(4)}$ Y = 35.4933 − 0.0210x (R^2 = 0.96 *); $^{(5)}$ Y = 30.3600 − 0.0500x (R^2 = 0.70 *); $^{(6)}$ Y = 30.5333 + 0.1353x (R^2 = 0.72 *); $^{(7)}$ Y = 0.8267 + 0.0029x (R^2 = 0.89 **); $^{(8)}$ Y = 29.8470 − 0.1705x + 0.0008x^2 (R^2 = 1.00 ** e PM = 106.6%).

The interaction of the fertilizer dosage for a given number of sprouts per strain for the content of B in the soil at a depth of 0–0.20 m, 44 months after the setting of the sprouts (Table 2) modulated the increasing linear function only when one sprout was chosen per strain.

Table 2. The results of the interaction between the number of sprouts per strain and the fertilization rates for the B content in soil at a depth of 0.00–0.20 m, 44 months after the setting of the *Eucalyptus* shoots.

	B (mg dm^{-3})	
	Sprouts of Strain	
Fertilizing (%) $^{+}$	**1 $^{(1)}$**	**2**
0	0.42a	0.50a
50	0.44a	0.54a
100	0.56a	0.44a
200	0.73a	0.42a

B: determined in hot water; $^{+}$ the percentage refers to 200 kg ha^{-1} of formula 06-30-06 + 1.0% Ca + 3.0% S + 1.0% Mg + 1.5% Cu + 1.0% Zn. Means followed by the same letters in the column are not significantly different by the Tukey's test at $p < 0.05$. $^{(1)}$ Y = 0.3920 + 0.0016x (R^2 = 0.97 *).

At a soil depth of 0.20–0.40 m, 44 months after choosing the *Eucalyptus* sprouts (Table 3), the contents of OM, K, S-SO_4, B, and Mn were higher when there was only one sprout per strain. These findings are consistent with those for the contents of K and Mn in the 0–0.20 m layer. On the other hand, for the management of two sprouts per strain, no higher contents of these nutrients were verified compared to the chemical attributes of the soil at this depth.

The contents of P, S-SO_4, B, Cu, Mn, and Zn, as well as H + Al and CEC, increased linearly at a depth of 0.20–0.40 m in the soil with increasing fertilization rates (200 kg ha^{-1} of formula 06-30-06 + 1.0% Ca + 3.0% S + 1.0% Mg + 1.5% Cu + 1.0% Zn) (Table 3). For the pH, the decreasing linear function was adjusted according to the increment of the fertilizer rates noted above.

Table 3. The soil chemical attributes at a depth of 0.20–0.40 m, 44 months after the choice of *Eucalyptus* sprouts as a function of the number of sprouts per strain and fertilization rates.

	P_{Resin}	O.M.	pH_{CaCl2}	K	Ca	Mg	H + Al	SB	CEC
	(mg dm^{-3})	(g dm^{-3})				(mmol$_c$ dm^{-3})			
Sprouts per strain									
1	3.50a	10.33a	3.90a	0.39a	1.25a	1.50a	24.58a	3.14a	27.72a
2	3.42a	9.67b	3.92a	0.27b	1.83a	1.25a	23.33a	3.35a	26.68a
S.M.D. (5%)	1.62	0.64	0.08	0.10	0.91	0.53	2.40	1.22	2.54
Fertilizing (%) +									
0	2.50 (1)	10.17	3.97 (2)	0.33	1.50	1.83	22.67 (3)	3.67	26.33 (4)
50	2.50	9.67	3.93	0.33	1.00	1.67	22.50	2.50	25.00
100	3.33	10.33	3.90	0.33	1.67	1.33	24.50	3.33	27.83
200	5.50	9.83	3.83	0.32	2.00	1.17	26.17	3.48	29.65
F Test									
Sprout (S)	0.01 ns	4.92 *	0.23 ns	7.68 *	1.91 ns	1.03 ns	1.24 ns	0.13 ns	0.78 ns
Fertilizing (F)	3.53 *	1.03 ns	3.63 *	0.03 ns	0.97 ns	1.64 ns	3.68 *	0.82 ns	3.86 *
S x F	0.24 ns	0.20 ns	1.43 ns	0.22 ns	0.45 ns	0.12 ns	0.93 ns	0.38 ns	0.83 ns
C.V. (%)	53.40	7.36	2.20	33.56	57.14	43.82	11.46	42.96	10.65
Average overall	3.46	10.00	3.91	0.33	1.54	1.38	23.96	3.25	27.20
Treatment	V	m	S-SO_4	B	Cu	Fe	Mn	Zn	
	(%)	(%)	(mg dm^{-3})			(mg dm^{-3})			
Sprouts per strain									
1	11.49a	79.00a	12.17a	0.57a	0.95a	13.83a	5.12a	0.28a	
2	12.42a	78.50a	9.00b	0.43b	0.87a	13.67a	2.88b	0.28a	
S.M.D. (5%)	4.08	5.85	2.88	0.12	0.11	2.67	1.25	0.10	
Fertilizing (%) +									
0	13.73	74.33	7.67 (5)	0.45 (6)	0.87 (7)	13.83	2.55 (8)	0.18 (9)	
50	10.20	80.83	9.17	0.42	0.80	10.67	3.55	0.27	
100	12.04	81.67	13.67	0.52	0.92	14.83	5.15	0.30	
200	11.87	78.17	11.83	0.62	1.05	15.67	4.77	0.37	
F Test									
Sprout (S)	0.24 ns	0.03 ns	5.56 *	6.30 *	2.77 ns	0.02 ns	14.74 *	0.03 ns	
Fertilizing (F)	0.57 ns	1.46 ns	3.99 *	3.54 *	4.46 *	3.10 ns	4.12 *	4.43 *	
S x F	0.54 ns	0.62 ns	0.97 ns	2.74 ns	1.96 ns	0.41 ns	0.68 ns	0.18 ns	
C.V. (%)	38.96	8.48	31.09	27.69	13.51	22.15	35.72	42.90	
Average overall	11.96	78.75	10.58	0.50	0.91	13.75	4.00	0.28	

B: determined in hot water; Cu, Fe, Mn, and Zn: determined in DTPA. The chemical analysis was performed at the UNESP/FEIS Soil Fertility Laboratory. + The percentage refers to 200 kg ha^{-1} of formula 06-30-06 + 1.0% Ca + 3.0% S + 1.0% Mg + 1.5% Cu + 1.0% Zn. Means followed by the same letters in the column are not significantly different by the Tukey's test at $p < 0.05$. * Significant at $p < 0.05$. ** Significant at $p < 0.01$. ns = not significant. (1) Y = 2.0667 + 0.0159x (R^2 = 0.92 **); (2) Y = 3.9667 − 0.0007x (R^2 = 1.00 *); (3) Y = 22.2667 + 0.0193x (R^2 = 0.91 *); (4) Y = 25.4367 + 0.0202x (R^2 = 0.74 *); (5) Y = 8.6333 + 0.0223x (R^2 = 0.50 *); (6) Y = 0.4157 + 0.0010x (R^2 = 0.87 *); (7) Y = 0.8133 + 0.0011x (R^2 = 0.77 **); (8) Y = 3.0267 + 0.0112x (R^2 = 0.65 *); (9) Y = 0.2033 + 0.0009x (R^2 = 0.94 *).

For the chemical attributes of the soil at a depth of 0.40–1.00 m, 44 months after choosing the *Eucalyptus* sprouts listed in Table 4, we verified a higher S-SO_4 content in the one sprout per strain condition. This same finding was noted for the Mn content.

Much like the data recorded at a depth of 0.20–0.40 m, the contents of P, Cu, and Mn increased linearly. For the content of P, the linear equation was adjusted (Table 4). At 200% of the recommended fertilization (200 kg ha^{-1} of formula 06-30-06 + 1.0% Ca + 3.0% S + 1.0% Mg + 1.5% Cu + 1.0% Zn), we observed a higher content of this P. This result indicates that the increase in the dose contributed to the greater leaching of P in the 0.40–1.00 m layer.

The OM content decreased along the soil profile (Table 1, Table 3, and Table 4) and the lowest content was noted in the 0.40–1.00 m layer (Table 4).

Table 4. The soil chemical attributes at a depth of 0.40–1.00 m, 44 months after choosing the *Eucalyptus* sprouts as a function of the number of sprouts per strain and the fertilization rates.

	P_{Resin} #	M. O.	pH_{CaCl2}	K #	Ca#	Mg	H + Al	SB #	CEC
	(mg dm^{-3})	(g dm^{-3})				(mmol$_c$ dm^{-3})			
Sprouts per strain									
1	4.08a	9.42a	3.92a	0.33a	1.25a	1.08	24.75a	2.67a	27.42
2	7.83a	9.33a	3.87a	0.26a	1.83a	1.00	22.25a	3.09a	25.34
S.M.D. (5%)	7.07	0.66	0.06	0.10	0.96	0.18	3.56	1.01	3.63
Fertilizing (%)$^+$									
0	1.33 $^{(1)}$	9.33	3.88	0.27	1.50	1.00	23.50	2.77	26.27
50	2.67	9.17	3.93	0.35	1.00	1.00	21.33	2.35	23.68
100	6.67	9.33	3.88	0.27	1.83	1.00	23.50	3.10	26.60
200	13.16	9.67	3.87	0.30	1.83	1.17	25.67	3.30	28.97
F Test									
Sprout (S)	1.29 ^{ns}	0.07 ^{ns}	2.90 ^{ns}	2.37 ^{ns}	1.68 ^{ns}	1.00 ^{ns}	2.27 ^{ns}	0.82 ^{ns}	1.50 ^{ns}
Fertilizing (F)	3.42 *	0.46 ^{ns}	0.97 ^{ns}	0.65 ^{ns}	0.77 ^{ns}	1.00 ^{ns}	1.14 ^{ns}	0.78 ^{ns}	1.63 ^{ns}
S x F	0.32 ^{ns}	0.46 ^{ns}	0.97 ^{ns}	0.65 ^{ns}	1.04 ^{ns}	1.00 ^{ns}	0.62 ^{ns}	1.19 ^{ns}	0.97 ^{ns}
C.V. (%)	55.47	8.06	1.85	7.30	23.32	19.60	17.31	15.31	15.70
Average overall	5.96	9.38	3.89	0.30	1.54	1.04	23.50	2.88	26.38
Treatment	V #	m	$S\text{-}SO_4$ #	B	Cu	Fe	Mn #	Zn #	
	(%)	(%)	(mg dm^{-3})			(mg dm^{-3})			
Sprouts per strain									
1	9.83a	81.83a	45.25a	0.61	0.72	9.25a	4.35	0.33a	
2	11.92a	77.67a	16.75b	0.46	0.73	10.17a	1.59	0.27a	
S.M.D. (5%)	3.61	6.76	13.80	0.13	0.08	2.02	1.90	0.17	
Fertilizing (%)$^+$									
0	10.17	80.83	35.33	0.53	0.68	9.67	1.52	0.23	
50	10.00	81.67	25.67	0.45	0.67	7.83	2.37	0.40	
100	11.67	78.00	27.33	0.52	0.73	10.17	3.50	0.15	
200	11.67	78.50	35.67	0.64	0.82	11.17	4.50	0.42	
F Test									
Sprout (S)	1.53 ^{ns}	1.74 ^{ns}	19.62 **	6.15 *	0.19 ^{ns}	0.94 ^{ns}	9.72 **	0.73 ^{ns}	
Fertilizing (F)	0.30 ^{ns}	0.32 ^{ns}	0.66 ^{ns}	1.78 ^{ns}	3.09 ^{ns}	2.19 ^{ns}	2.17 ^{ns}	2.78 ^{ns}	
S x F	0.81 ^{ns}	0.60 ^{ns}	0.54 ^{ns}	2.42 ^{ns}	4.86 *	1.46 ^{ns}	1.52 ^{ns}	0.64 ^{ns}	
C.V. (%)	16.71	9.69	22.39	27.78	12.95	23.80	26.60	10.98	
Average overall	10.88	79.75	31.00	0.53	0.72	9.71	2.97	0.30	

B: determined in hot water; Cu, Fe, Mn, and Zn: determined in DTPA. The chemical analysis was performed at the UNESP/FEIS Soil Fertility Laboratory. $^+$ The percentage refers to 200 kg ha^{-1} of formula 06-30-06 + 1.0% Ca + 3.0% S + 1.0% Mg + 1.5% Cu + 1.0% Zn. The means followed by the same letters in the column are not significantly different in Tukey's test at $p < 0.05$. * Significant at $p < 0.05$. ** Significant at $p < 0.01$. ^{ns} = not significant. $^{(1)}$ Y = 0.5667 + 0.0616x (R^2 = 0.98 *); # Data corrected by the equation $(x + 0.5)^{0.5}$.

In terms of the effects of the interaction between fertilizer dosage and the number of sprouts per strain for the content of Mg and B and the CEC of the soil at a depth of 0.40–1.00 m (Table 5), there was an adjustment to the linear function that was increasing. For the Mg content in the soil and the CEC, there was no difference in the number of sprouts per strain. However, the B content in the soil at the highest fertilizer dosage was significantly higher in the one sprout per strain condition.

For the Cu content in the soil at a depth of 0.40–1.00 m, there was an interaction between the number of sprouts and the fertilizer dose. In the control, the highest Cu content in the soil was noted for the two sprouts per strain condition. In the management of the one sprout per strain condition, the increase in the fertilizer rates linearly increased the Cu content in the soil. This situation was not verified with the two sprouts per strain condition due to the higher absorption of this micronutrient.

The interaction between the number of sprouts per strain and the fertilizer dosage on the Mn content in the soil at a depth of 0.40–1.00 m differed for the one or two sprouts conditions at the two highest rates (100 and 200% of the recommended fertilization). The highest soil content was obtained for one sprout and the linear function for one sprout per strain was also adjusted.

Table 5. The interaction of the number of sprouts per strain and the fertilization rates for B, Cu, CEC, Mg, and Mn in the soil at a depth of 0.40–1.00 m, 44 months after choosing the *Eucalyptus* sprouts.

	B (mg dm^{-3})		Cu (mg dm^{-3})		CEC (mmol$_c$ dm^{-3})		Mg (mmol$_c$ dm^{-3})		Mn (mg dm^{-3})	
	Sprouts per Strain									
Fertilizing (%) $^+$	**1 (1)**	**2**	**1 (2)**	**2**	**1 (3)**	**2**	**1 (4)**	**2**	**1 (5)**	**2**
0	0.59a	0.47a	0.57b	0.80a	25.30a	27.23a	1.00a	1.00a	1.50a	1.53a
50	0.40a	0.49a	0.63a	0.70a	25.00a	22.37a	1.00a	1.00a	3.43a	1.30a
100	0.61a	0.42a	0.80a	0.67a	27.33a	25.87a	1.00a	1.00a	5.57a	1.43b
200	0.83a	0.46b	0.87a	0.77a	32.03a	25.90a	1.33a	1.00a	6.90a	2.10b

$^+$ The percentage refers to 200 kg ha^{-1} of formula 06-30-06 + 1.0% Ca + 3.0% S + 1.0% Mg + 1.5% Cu + 1.0% Zn. The means followed by the same letters in the column are not significantly different in Tukey's test at $p < 0.05$. (1) Y = 0.4740 + 0.0015x (R^2 = 0.57 *); (2) Y = 0.5800 + 0.0016x (R^2 = 0.91 **); (3) Y = 24.2400 + 0.0363x (R^2 = 0.91 *); (4) Y = 0.9333 + 0.0017x (R^2 = 0.77 *); (5) Y = 2.0067 + 0.0268x (R^2 = 0.93 **).

3.2. Concentrations of N and P in the Leaves and Litter

Table 6 lists the results of the N and P concentrations in the leaves and the *Eucalyptus* litter, respectively. For the sprouts per strain, differences were only found in the N concentrations in the leaflet, and the highest content was obtained when there were two sprouts per strain (Table 6). This finding may be due to the higher concentration effect on the leaves with only one sprout per strain. It is important to keep in mind that N is part of the proteins and chlorophyll. However, the N and P concentrations of the *Eucalyptus* leaf at 44 months after choosing the sprouts were not influenced by the increase in fertilization (Table 6).

Table 6. The concentrations of N and P in the leaves and in the litter of the *Eucalyptus* at 44 months after choosing the sprouts, according to the number of sprouts per strain and the fertilization rates.

	N Leaves	P Leaves	N Litter	P Litter
	(g kg^{-1} de D.M.)			
Sprout per strain				
1	18.76a	1.93a	7.32b	0.44a
2	19.67a	1.98a	9.47a	0.51a
S.M.D. (5%)	0.93	0.13	0.67	0.09
Fertilizing (%) $^+$				
0	19.45	1.90	8.16	0.44
50	18.58	2.00	8.00	0.44
100	19.70	1.94	8.80	0.52
200	19.12	1.98	8.62	0.50
F Test				
Sprout (S)	4.51 ^{ns}	0.79 ^{ns}	47.59 **	3.44 ^{ns}
Fertilizing (F)	1.27 ^{ns}	0.48 ^{ns}	1.47 ^{ns}	1.04 ^{ns}
S x F	1.52 ^{ns}	1.14 ^{ns}	0.62 ^{ns}	0.67 ^{ns}
C.V. (%)	5.51	7.63	9.11	20.77
Average overall	19.21	1.95	8.40	0.48

$^+$ The percentage refers to 200 kg ha^{-1} of formula 06-30-06 + 1.0% Ca + 3.0% S + 1.0% Mg + 1.5% Cu + 1.0% Zn. The means followed by the same letters in the column are not significantly different in Tukey's test at $p < 0.05$. ** Significant at $p < 0.01$. ^{ns} = not significant.

3.3. Leaf Chlorophyll Index, Plant Height, Diameter at Breast Height, Total Volume of Wood with Bark, and the Average Annual Increment

The results of the LCI, H, DBH, VW, and AAI of the *Eucalyptus* after 44 months according to the number of sprouts and fertilization rates are listed in Table 7. The LCI of the *Eucalyptus* was not influenced by the fertilization rate. Much like the effect of the number of sprouts per strain, there was a difference between the treatments and the strains, with the one sprout condition yielding higher LCI.

Table 7. The leaf chlorophyll index (LCI), plant height (H), diameter at breast height (DBH), total volume of wood with bark (VW), and the average annual increment (AAI) of *Eucalyptus* at 44 months after choosing the sprouts, according to the number of sprouts per strain and the fertilization rates.

	LCI	H (m)	DBH (cm)	VW (m^3 ha^{-1})	AAI (m^3 ha^{-1} ano^{-1})
Sprout per strain					
1	62.42a	25.28a	17.53a	411.07a	111.28a
2	55.44b	22.21b	13.26b	408.39a	113.32a
S.M.D. (5%)	4.46	0.58			17.47
Fertilizing (%) $^+$					
0	61.07	23.95	14.66	370.52	110.20
50	58.80	23.50	15.66	414.50	112.94
100	56.39	23.58	15.66	429.60	110.45
200	59.47	23.94	15.60	424.30	115.61
F Test					
Sprout (S)	11.27 **	128.78 **	145.06 **	0.019 ^{ns}	0.06 ^{ns}
Fertilizing (F)	0.88 ^{ns}	0.75 ^{ns}	1.46 ^{ns}	1.88 ^{ns}	0.10 ^{ns}
S x F	2.53 ^{ns}	1.35 ^{ns}	1.70 ^{ns}	2.17 ^{ns}	1.30 ^{ns}
C.V. (%)	8.64	2.79	5.95	11.73	17.77
Average overall	58.93	23.74	15.39	409.73	112.3

$^+$ The percentage refers to 200 kg ha^{-1} of formula 06-30-06 + 1.0% Ca + 3.0% S + 1.0% Mg + 1.5% Cu + 1.0% Zn. The means followed by the same letters in the column are not significantly different in Tukey's test at $p < 0.05$. ** Significant at $p < 0.01$. ^{ns} = not significant.

There were larger H and DBH values for the one sprout per strain condition. Regarding the VW, there was no significant difference as a function of the number of sprouts per strain.

Surprisingly, the H, DBH, and VW, 44 months after the sprouts were chosen were not influenced by the amount of mineral fertilizer (Table 7), even in sandy soils with a low fertility content. However, it should be noted that there was an increase of approximately 14% in the VW when the fertilizer dosage (100%) used in the region was applied (200 kg ha^{-1} of formula 06-30-06 + 1.0% Ca + 3.0% S + 1.0% Mg + 1.5% Cu + 1.0% Zn) compared with the control without fertilization.

The AAI of *Eucalyptus* 44 months after the sprouts were chosen averaged 112.3 m^3 ha^{-1} $year^{-1}$. The AAI did not exhibit a significant difference for either the one or two sprouts per strain conditions. For the management of the two sprouts condition, the AAI was only about 2% larger compared to the one sprout per strain condition.

There was no adjustment for the increase in the dosage of the mineral fertilizer for AAI. However, for the 200% recommended fertilization dosage, we observed only a 5% increase compared to the control (without fertilizer).

3.4. Pearson Correlation

The correlations between the chemical attributes of the soil in the 0–0.20-m layer and the other biometric assessments or N and P concentrations in the *Eucalyptus* leaves and litter, as well as the correlation coefficients, are listed in Tables 8 and 9.

Negative correlations were observed between the number of sprouts per strain and the variables K (−0.53 **), Mn (−0.55 **), H (−0.89 **), DBH (−0.90 **), and LCI (−0.52 **). For fertilizer rates, a significant correlation was observed only with m% (0.41 *).

The P content in soil correlated significantly only with B (0.64 **), Cu (0.96 **), and Zn (0.55 **), and inversely with the pH (−0.40 *). The pH, in addition to the content of P, was inversely correlated with the levels of H + Al (−0.62 **), Al (−0.86 **), m% (−0.83 **), Fe (−0.52 **), and Zn (−0.47 *), and positively with OM (0.43 *) and V% (0.60 **). Meanwhile, the organic matter correlated significantly with Ca (0.55 **), Mg (0.48 *), SB (0.52 **), CEC (0.51 **), V% (0.56 **), and Mn (0.43 *) with relatively low coefficients and it correlated inversely with m% (−0.56 **).

The potassium content exhibited a significant correlation with the Fe content (0.42 *), the Mn content (0.51 *), and DBH (0.47 *). The Ca and Mg contents were significantly correlated with SB (0.99 ** and 0.99 **), CEC (0.92 ** and 0.97 **), V% (0.89 ** and 0.82 **), and inversely correlated with m% (−0.70 ** and −0.60 **), respectively.

The cation exchange capacity, as well as the V% and m%, did not correlate with any of the biometric evaluations. Fe was significantly correlated with B (0.46 *), Cu (0.55 **), and Zn (0.43 *) whilst B was correlated with Cu (0.60 **). However, the m% correlated negatively with the P concentration in *Eucalyptus* litter (−0.447 *).

The Mn content exhibited a significant correlation with H (0.61 **) and DBH (0.51 *). The biometric evaluations correlated significantly with one another: H with DBH (0.91 **) and LCI (0.65 **). In turn, the LCI exhibited a significant correlation with DBH (0.60 **) and VW with the AAI (1.00 **).

The N leaf concentration correlated positively with the N in the *Eucalyptus* litter (0.489 *) and with the concentration of P in the leaves (0.448 *). However, there was a negative correlation between the concentration of N in the leaves and the DBH (−0.439 *).

As for the N and P concentrations in the *Eucalyptus* litter, a positive correlation was observed between N and the number of sprouts per strain (0.771 **), and a negative correlation was noted between the concentration of N and the DBH (−0.652 **), H (−0.624 **), and LCI (−0.577 **). For the concentration of P, there was a positive correlation with the N in the *Eucalyptus* litter (0.632 **).

Table 8. The correlation coefficients of Pearson's (r) with significant values ($p < 0.01$ ** and $p < 0.05$ *) highlighted among the chemical attributes of soil, the biometric characteristics and the P and N concentrations in the leaves and in the litter of the *Eucalyptus* cultivated in the Brazilian Cerrado according to the number of sprouts per strain and mineral fertilization at a depth of 0.20 m.

	Sprout per Strain	**Fertization Rates**	**P_{resin}**	**O.M.**	**pH**	**K**	**Ca**	**Mg**	**H + Al**	**Al**	**SB**	**$S\text{-}SO_4$**	**CEC**	**V%**	**m%**
Sprout per strain	1.000														
Fertization rates	0.000	1.000													
P_{resin}	−0.154	0.351	1.000												
O.M.	−0.178	−0.321	−0.153	1.000											
pH	−0.050	−0.265	−0.405 *	0.427 *	1.000										
K	−0.535 **	0.011	−0.042	0.203	−0.070	1.000									
Ca	0.172	−0.364	−0.059	0.552 **	0.270	0.071	1.000								
Mg	0.210	−0.404	−0.142	0.480 *	0.175	0.071	0.957 **	1.000							
H + Al	−0.010	0.015	−0.236	0.028	−0.623 **	0.262	−0.121	0.025	1.000						
Al	0.011	0.227	0.324	−0.381	−0.860 **	0.116	−0.312	−0.215	0.544 **	1.000					
SB	0.188	−0.390	−0.106	0.520 **	0.218	0.085	0.987 **	0.991 **	−0.037	−0.259	1.000				
$S\text{-}SO_4$	0.165	0.164	−0.136	−0.164	−0.120	0.356	−0.143	−0.112	0.242	0.158	−0.122	1.000			
CEC	0.179	−0.374	−0.171	0.512 *	0.033	0.158	0.921 **	0.967 **	0.251	−0.095	0.958 **	−0.049	1.000		
V%	0.117	−0.402	−0.109	0.566 **	0.600 **	0.087	0.894 **	0.822 **	−0.443 *	−0.547 **	0.863 **	−0.152	0.709 **	1.000	
m%	0.002	0.414 *	0.258	−0.565 **	−0.827 **	−0.067	−0.696 **	−0.603 **	0.542 **	0.823 **	−0.651 **	0.210	−0.475 *	−0.902 **	1.000
B	−0.142	0.197	0.637 **	0.049	−0.604 **	−0.097	−0.086	−0.114	0.278	0.466 *	−0.104	−0.216	−0.020	−0.320	0.458 *
Cu	−0.185	0.386	0.961 **	−0.111	−0.352	−0.030	−0.081	−0.170	−0.312	0.343	−0.132	−0.176	−0.218	−0.085	0.246
Fe	−0.169	−0.013	0.597 **	0.042	−0.525 **	0.423 *	0.176	0.172	0.170	0.364	0.181	0.064	0.224	0.030	0.143
Mn	−0.551 **	0.063	−0.238	0.430 *	0.308	0.515 *	0.157	0.154	0.147	−0.183	0.164	−0.003	0.201	0.257	−0.317
Zn	0.102	0.366	0.555 **	−0.320	−0.468 *	−0.054	−0.197	−0.170	0.305	0.294	−0.184	0.151	−0.091	−0.359	0.422 *
H	−0.891 **	0.021	0.182	0.279	0.086	0.387	−0.043	−0.070	−0.043	−0.002	−0.053	−0.153	−0.064	0.023	−0.086
DBH	−0.904 **	0.057	0.220	0.181	0.037	0.475 *	−0.187	−0.250	−0.002	0.028	−0.218	−0.140	−0.211	−0.121	0.002
VW	0.058	0.097	0.140	0.090	0.020	−0.100	−0.020	−0.056	−0.043	0.098	−0.042	0.022	−0.053	0.033	−0.022
LCI	−0.525 **	−0.078	0.102	0.315	−0.013	0.084	0.061	0.090	0.110	−0.128	0.079	−0.269	0.108	−0.025	−0.074
AAI	0.058	0.097	0.140	0.090	0.020	−0.100	−0.020	−0.056	−0.043	0.097	−0.042	0.022	−0.053	0.033	−0.022
N Leaves	0.401	−0.005	−0.167	0.006	−0.165	−0.256	0.271	0.319	0.065	0.142	0.297	−0.007	0.307	0.162	0.008
P Leaves	0.194	0.134	−0.303	−0.100	0.088	0.052	0.254	0.236	0.004	−0.216	0.247	−0.014	0.240	0.189	−0.243
N Litter	0.771 **	0.161	−0.086	−0.378	−0.136	−0.386	−0.137	−0.110	−0.077	0.253	−0.128	0.257	−0.146	−0.108	0.213
P Litter	0.377	0.266	−0.127	−0.360	−0.313	−0.359	−0.277	−0.258	0.212	0.392	−0.274	0.108	−0.205	−0.368	0.447 *

Table 9. The correlation coefficients of Pearson's (r) with significant values ($p < 0.01$ ** and $p < 0.05$ *) highlighted among the chemical attributes of soil, the biometric characteristics and the P and N concentrations in the leaves and in the litter of the *Eucalyptus* cultivated in the Brazilian Cerrado according to the number of sprouts per strain and mineral fertilization at a depth of 0.20 m.

	B	**Cu**	**Fe**	**Mn**	**Zn**	**H**	**DBH**	**VW**	**LCI**	**AAI**	**N Leaves**	**P Leaves**	**N Leaflet**	**P Leaflet**
B	1.000													
Cu	0.599 **	1.000												
Fe	0.456 *	0.551 **	1.000											
Mn	−0.241	−0.146	−0.106	1.000										
Zn	0.404	0.368	0.428 *	−0.303	1.000									
H	0.136	0.245	0.220	0.610 **	−0.124	1.000								
DBH	0.213	0.239	0.218	0.515 *	−0.006	0.910 **	1.000							
VW	0.121	0.144	0.118	0.077	0.143	0.271	0.359	1.000						
LCI	0.324	0.093	0.233	0.222	0.024	0.647 **	0.598 **	0.314	1.000					
AAI	0.121	0.144	0.118	0.077	0.143	0.271	0.359	1.000 **	0.314	1.000				
N Leaves	−0.112	−0.088	−0.158	−0.044	−0.360	−0.251	−0.439 *	−0.065	−0.290	−0.065	1.000			
P Leaves	−0.190	−0.313	−0.217	0.049	−0.240	−0.211	−0.132	0.012	−0.115	0.011	0.448 *	1.000		
N Litter	−0.199	−0.021	−0.137	−0.363	−0.045	−0.624 **	−0.652 **	0.199	−0.577 **	0.199	0.489 *	0.106	1.000	
P Litter	0.065	−0.066	−0.190	−0.195	0.038	−0.223	−0.208	0.372	−0.103	0.372	0.295	−0.026	0.632 **	1.000

4. Discussion

4.1. Soil Chemical Analysis

We observed a linear increase in contents of P and Cu in the soil and an increase in the m% with the increase in the fertilizer rates, which can be explained by the uptake of the basic cationic nutrients and the relative acidification, which can be attributed to the mineralization of the deposited OM in the forest area alone. Dick et al. [19], in studies of five-year-old *Eucalyptus dunnii* Maiden, planted seedlings in an area of low natural fertility in the Pampas Gauchos of Brazil and reported a similar situation. These authors verified an increase in the content of P at the end of the *Eucalyptus* production cycle. According to Bazanii et al. [20], the average contents of P_{resin} in the soil for *Eucalyptus* varies from 5 to 7 mg dm^{-3}. In our study, in the superficial layer (0–0.20 m), the average levels of P_{resin} were roughly 7.2 mg dm^{-3}, which is within the average range.

The pH values of the soil under the *Eucalyptus* remained acidic and did not vary as a function of the number of sprouts per strain or the fertilization rate. Santana et al. [21] evaluated the effect of acacia and *Eucalyptus* forest sites on the chemical properties of soil and concluded that the pH values of soil are influenced more by liming and fertilization practices than by forest vegetation in *Eucalyptus* plantations where no liming occurred, in which significant changes in the pH content and the Ca^{2+} and Mg^{2+} levels were observed.

We verified that there were higher contents of K and Mn, when we selected the one sprout per strain condition. This finding indicates that the nutrient uptake of the soil is differentiated according to the number of shoots per *Eucalyptus* strain. We observed that an increase in the fertilizer dosage decreased the Mg content, the SB, CEC, and the V%, indicating that there was a higher uptake of Mg. This situation likely corresponded to maintaining the nutritional balance compared with the larger uptakes of N and K, which were supplied by the mineral fertilizer.

In terms of the relation between the fertilization dosage and the number of sprouts per strain for the B content in the soil at a depth of 0–0.20 m (Table 2), we noted an increasing linear function for the one sprout condition. Therefore, we again observed a lower uptake of this micronutrient in the management of the one sprout condition compared to the two sprouts per *Eucalyptus* strain condition since there was no adjustment for such an evaluation in the latter treatment. The application of B into soil is essential for the development of the *Eucalyptus* species, especially when these plants are managed in sandy soils in the second production cycle. The lack of this micronutrient can lead to a decrease in the growth rate of the height and the DBH [5] and, consequently, reduce the VW produced.

The results presented in Table 3, in relation to the contents of the MO, K, S-SO_4, B, and Mn at a soil depth of 0.20–0.40 m, confirm that the nutrient absorption differed for plants with different numbers of sprouts. This finding highlights the importance of the subsurface layer for *Eucalyptus* nutrition which presents a deep and vigorous root system. According to Kolm [22], roughly 60% of *Eucalyptus* roots are found in the 0–0.30 m layer. However, it is in the first 0.10 m that the largest number of fine roots, responsible for the absorption of the cycled nutrients from litter deposition and mineralization, are found.

The contents of P, S-SO_4, B, Cu, Mn, Zn, H + Al, and CEC at a depth of 0.20–0.40 m and the contents of P, Cu, and Mn at a depth of 0.40–1.00 m increased linearly in the soil with the increasing fertilizer dose. We inferred that the sandy texture of this soil enabled the leaching of these elements to the deeper layers. The increase in the potential acidity is also an indication of the increase in the uptake of cationic nutrients. In soils with forest litter, the dynamics of P can be effected via the leaching of this nutrient to layers below the surface layer. The high rates of the decomposition of litter lead to the production of organic acids with a low molecular weight, which is subject to translocation to the lower layers and can lead to the removal of the P zone via increased uptake by roots [23].

The content of the OM content decreases with the depth in all soils; the lowest OM content of the soil was found in the layer at 0.40–1.00 m. This finding is to be expected, demonstrating the importance of the superficial layer for nutrient cycling. Menegale et al. [24], evaluating the effect of different types of wood harvesting and fertilizer application in a settlement of *Eucalyptus grandis* Hill Ex Maiden, reported that maintaining the forest harvesting residues in the soil contributes to the increasing C and N contents in the soil and is important for the supply of nutrients to the plants. Among the treatments evaluated by the authors, this process is more important in sandy soils, highly productive forests, and successive harvest cycles. In the second production cycle, the treatment in which the forest remains were maintained and there was fertilization and liming, there were higher levels of plant biomass as well.

At a depth of 0.40–1.00 m (Table 5), the B content in the soil at the highest fertilizer dosage was significantly higher for the one sprout per strain condition. The result was similar for the Mn content in the soil at this depth. The highest soil level was obtained in the course of the one sprout per strain condition. These results indicate that the higher absorption of these micronutrients occurred when the two sprouts per strain condition was selected.

The correlations between all the variables related to the chemical attributes of the soil in the 0–0.20 m layer and the biometric variables were evaluated (Tables 8 and 9). In general, the strong positive correlations between the chemical attributes of the soil were observed.

The pH of the soil is negatively correlated with the contents of P, H + Al, Al, m%, Fe, and Zn and positively correlated with the OM and V%. Brunello [25], studying forest in an Oxisol located in the Amazonas mesoregion, found results similar to those of this investigation: the Al exchangeable soil content was correlated negatively with pH of the soil (−0.617 *), and there was a positive correlation between the pH of the soil and the exchangeable bases contents. This researcher verified that an increase in the pH of the soil when there was an incorporation of the bases in the soil increased the nutrients available to the plants and reduced the toxicity of the elements such as Al and Mn.

The CEC, as well as the V% and m%, did not correlate with any of the biometric evaluations of the *Eucalyptus*. This result can be potentially explained because these evaluations did not change with the same magnitude as the changes in the values of CEC, V%, and m%. That is, they did not present significant correlations. Nutrient cycling in deeper soil layers and the influence of the organic and inorganic reserves in the root system may have influenced the initial growth of the sprouts.

4.2. Concentrations of N and P in the Leaves and in the Litter

According to the appropriate leaf concentrations for the majority of planted *Eucalyptus* species in Brazil cited by Dell et al. [26], the N concentrations were slightly below the range considered to be adequate (18–30 g kg^{-1}); the P concentrations were slightly above the suitable range (1.0–1.3 g kg^{-1}), even for acidic soil with a low P content, which is commonly found in the Brazilian Cerrado. This may be due to the supply of P fertilizer, but what drew our attention was that even in plants that did not receive phosphate fertilization in the second production cycle of the *Eucalyptus*, the contents of this nutrient were above that which was considered adequate, which reinforces the hypothesis of the use of root reserves.

However, the leaf concentrations of N and P in the *Eucalyptus*, 44 months after choosing the sprouts, were not influenced by the fertilizer dose (Table 6). This finding is probably due to the already-established root system of the first reproduction cycle of the *Eucalyptus* and, mainly, because of the nutrient cycling contributing to the supply of these nutrients to the plants.

The leaf concentrations of the N and P in the *Eucalyptus*, 44 months after the sprouts were chosen were not influenced by the fertilizer dose (Table 6), which confirms that the already-established root system of the first *Eucalyptus* cycle and, to a large degree, the nutrient cycling, contributed to the supply of the plant's nutrients.

The concentrations of P and N in both the leaves and the litter exhibited a positive correlation with one another. Santos et al. [27] explained that there was a stoichiometric relationship between the N and the P in leaves and that a high N content in the soil implied a higher demand for P by the *Eucalyptus*. This explanation confirms a synergistic effect among these nutrients for *Eucalyptus* forests.

4.3. Leaf Chlorophyll Index, Plant Height, Diameter at Breast Height, Total Volume of Wood with Bark, and the Average Annual Increment

The LCI was not influenced by the increase in the fertilization, indicating that N was not in short supply for chlorophyll formation and that the importance of the root system was already established for the second cycle of *Eucalyptus* growth. The decreased LCI for the two sprouts per strain can be explained by the dilution effect of N because the accumulation of dry matter in the two sprouts condition is higher than of the one sprout per strain condition. However, the LCI was positively correlated with H and DBH, indicating a larger light uptake when the taller *Eucalyptus* trees were planted and, consequently, s larger stem diameter growth. Reis and Reis [12] found that each sprout left in the *Eucalyptus* strains behaved like an isolated plant and that there was greater pressure on the resources of the environment with an increased number of sprouts per strain, which competed with one another for growth resources.

The *Eucalyptus* with one sprout per strain exhibited higher H and DBH compared with the *Eucalyptus* with two sprouts per strain (Table 7). This finding indicates that the two sprouts per strain condition divides the consumption of nutrients, water, and light, increasing the competition of the sprouts in the same strain and resulting in a reduced plant height. There was a strong negative correlation between the number of sprouts per strain, the H, and the number of sprouts and DBH, confirming that the H and DBH of the sprouts in the same strain decreased as the number of sprouts per strain increased. According to Couto et al. [28], the growth in the stem diameter is influenced by the area available for the shoots. Therefore, the conduction of the strains with two sprouts results in smaller diameters. Depending on the intended purpose of the growth, it may be better to leave only one sprout per strain.

The K and Mn contents in the soil and the H, DBH, and LCI were negatively influenced by the number of sprouts per strain; the larger the number of sprouts per strain, the lower the K and Mn contents in the soil and the lower the plant height, DBH, and LCI. These findings can be explained by the significant requirement of these cationic nutrients associated with the higher uptake by *Eucalyptus*. A moderate Mg deficiency was observed in *Eucalyptus*, which explains this reduction in the LCI and plant growth. Gazola et al. [29], under the same soil and climatic conditions, found that increasing the K dosage resulted in an increase in the K concentrations in the leaves and a decrease in the Ca and Mg concentrations in the *Eucalyptus*.

The VW did not exhibit a significant difference in terms of the number of sprouts per strain. This result is explained by the total sum of the two sprouts, despite them being smaller in the H and DBH. Rezende et al. [30] found that larger numbers of sprouts were correlated with the increased growth in height and VW after both the first and the second cut. On the other hand, Simões and Coto [31], evaluating the effect of the sprout number and the mineral fertilization on the growth of *Eucalyptus saligna* sprouts in the second cycle, verified that the final volume of the cut and stacked wood positively correlated with the number of sprouts and the amount of mineral fertilization.

The H, DBH, and VW were not influenced by the mineral fertilization; the primary explanation for these results may be the nutrient cycling from the litter coming from both the first *Eucalyptus* production cycle and from the second production cycle. In addition, another explanation may be the consumption of the root reserves for the growth of the *Eucalyptus* sprouts. However, Silva [32], studying a five-year-old *Eucalyptus* forest managed by the coppice system with one or two sprouts per strain, verified that fertilization interferes with these variables when the soil and the residues from the previous cycle are not enough to fulfill the plant's needs. This author cited that there was a positive effect of fertilization on the DBH, H, and VW in this situation, finding that the trees that were fertilized exhibited a diameter 22.5% larger than the trees that received treatments without fertilization. Adequate fertilization carried out in the first cycle of *Eucalyptus* in the present research yielded a litter and roots with higher concentrations of nutrients, culminating in an increased nutrient cycling for *Eucalyptus* trees in the second cycle.

Under the same soil and climatic conditions, in the first cycle of *Eucalyptus*, Gazola et al. [29] verified that the maximum yield of *Eucalyptus* was obtained at 21 months of age with the application of 71 kg ha^{-1} of N, 100 kg ha^{-1} of P_2O_5, and 125 kg ha^{-1} of K_2O. Celestrino [33] observed positive results for plant height, DBH, and VW with a dose of 1 kg ha^{-1} of B applied to the *Eucalyptus*.

The AAI was not influenced by the number of sprouts per strain or the mineral fertilizer dose. However, for 200% of the recommended fertilization dose, there was an increase of 5% in the AAI compared with the control (without fertilizer). It is worth noting the high values of the AAI obtained for the cultivation of *Eucalyptus* even in the sandy textured soil with low fertility (on average 112.3 m^3 ha^{-1} $year^{-1}$). Melo et al. (2016) obtained 48-month-old AAI values of 54 m^3 ha^{-1} $year^{-1}$ in the first cycle of the *Eucalyptus* forest; Faria et al. [34] also verified an AAI of 64.3 m^3 ha^{-1} $year^{-1}$ in the first cycle of *Eucalyptus* production (clone I-144) at 57 months of age.

Significant correlations between the chemical attributes of the soil and the biometric variables were rare (Tables 8 and 9), which reinforced the hypothesis of the use of root reserves. Therefore, nourishing the *Eucalyptus* well in the first production cycle can be a more sustainable way to obtain satisfactory wood productivities in the second production cycle.

5. Conclusions

The chemical attributes of the soil at the evaluated depths varied according to the number of sprouts per strain. Forty-four months after choosing the sprouts, in sandy soils with low fertility, there was a larger difference between the numbers of sprouts per strain in the 0.20–0.40 m layer compared with the others soil layers. There were also higher contents of OM, K, S, B, and Mn when one sprout per strain was selected.

The mineral fertilization affects the chemical attributes of the soils at depths of 0–1.00 m and largely provides higher P and B contents, which may increase the potential acidity.

The one *Eucalyptus* sprout condition yielded higher LCI, DBH, and H, being more interesting for the commercialization of the *Eucalyptus* stem; with the two sprouts per strain condition, the N leaflet concentration was higher. However, the N and P leaf concentrations, as well as the total VW with bark, were similar for both the one or two sprouts per strain conditions, regardless of the mineral fertilizer dose.

The LCI, H, DBH, and total VW with the bark of the *Eucalyptus* were not influenced by an increase in the fertilizer dose, even in sandy soil with low fertility. The AAI of the *Eucalyptus* forest was high and similar for both the one or two sprouts per strain conditions. It was not influenced by increases in the mineral fertilization.

The adequate fertilization during the first cycle of *Eucalyptus* growth can supply almost the entire nutritional demand of the forest during the second production cycle. Comparing the control (without fertilization) with the dose of fertilizer commonly used in the region, approximately 86% of the total VW was obtained as a function of the supply of soil and the nutrient reserves of roots, and 14% of this productivity was due to the fertilization minerals.

Author Contributions: M.C.M.T.F. and S.B. conceived and designed the study; N.M.I.G., R.d.N.G., A.C.d.S. and T.d.S.C. prepared the data sets; M.C.M.T.F., N.M.I.G. and S.N.d.S.A. performed the statistical analyses; M.C.M.T.F. and N.M.I.G. interpreted the results; M.C.M.T.F., S.N.d.S.A. and N.M.I.G. wrote the paper with contributions from T.A.R.N. and S.B.

Funding: This research was funded by the São Paulo Research Foundation (FAPESP) grant number (2016/11613-1) and the Foundation for the Development of São Paulo State University (UNESP) grant number (0271/001/14).

Acknowledgments: Authors would like to thank the Cargill Agricola S/A, the São Paulo State University (UNESP) and the São Paulo Research Foundation (FAPESP) for supporting our research.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. IBÁ. INDÚSTRIA BRASILEIRA DE ÁRVORES. Report IBÁ-2017. Indicators of Performance of the National Sector of Planted Trees for the Year 2016. Available online: http://iba.org/images/shared/Biblioteca/IBA_RelatorioAnual2017.pdf (accessed on 8 September 2017).
2. Foelkel, C. Minerals and Nutrients of Eucalyptus Trees: Environmental, Physiological, Silvicultural and Industrial Aspects about the Inorganic Elements Present in the Trees. In *Eucalyptus Online Book Newsletter*, 2nd ed.; 2005. Available online: http://atividaderural.com.br/artigos/538773282706a.pdf (accessed on 22 April 2016).
3. Faria, G.E.; Barros, N.F.; Novais, R.F.; Lima, J.C.; Teixeira, J.L. Production and nutritional status of *Eucalyptus grandis* stands in second rotation in response to potassium fertilization. *Rev. Árvore* **2002**, *26*, 577–584. [CrossRef]
4. Rocha, J.H.T.; Goncalves, J.L.M.; Gava, J.L.; Godinho, T.O.; Melo, E.S.A.C.; Bazani, J.H.; Hubner, A.; Arthur Junior, J.C.; Wichert, M.P. Forest residue maintenance increased the wood productivity of a Eucalyptus plantation over two short rotations. *For. Ecol. Manag.* **2016**, *379*, 1–10. [CrossRef]
5. Silveira, R.L.V.A.; Takahashi, E.N.; Sgarbi, F.; Camargo, M.A.F.; Moreira, A. Growth and nutritional status of *Eucalyptus citriodora* sprouts under boron rates in nutrient solution. *Sci. For.* **2000**, *57*, 53–67.
6. Silveira, R.L.V.A.; Gava, J.L. Nutrition and phosphate fertilization in Eucalyptus. In Proceedings of the Lecture presented at the Symposium on Phosphorus in Brazilian Agriculture, 2003, POTAFOS realization, São Pedro, State of São Paulo, Brazil, 14–16 May 2003.
7. Sgarbi, F. *Eucalyptus* sp. Productivity as a Function of Nutritional Status and Soil Fertility in Different Regions of the São Paulo State. Master's Thesis, Superior School of Agriculture "Luiz de Queiroz", University of São Paulo, Piracicaba, Brazil, 2002.
8. Costa, M.G.; Gama-Rodrigues, A.C.; Gonçalves, J.L.M.; Gama-Rodrigues, E.F.; Sales, M.V.S.; Aleixo, S. Labile and Non-Labile Fractions of Phosphorus and Its Transformations in Soil under Eucalyptus Plantations, Brazil. *Forest* **2016**, *7*, 15. [CrossRef]
9. Melo, E.A.S.C.; Gonçalves, J.L.M.; Rocha, J.H.T.; Hakamada, E.R.; Bazani, J.S.; Wenzel, A.V.A.; Arthur Junior, J.C.; Borges, J.S.; Malheiros, R.; Lemos, C.C.Z.; et al. Responses of Clonal Eucalypt Plantations to N, P and K Fertilizer Application in Different Edaphoclimatic Conditions. *Forest* **2016**, *7*, 2. [CrossRef]
10. Barros, N.F.; Novais, R.F. Eucalypt nutrition and fertilizer regimes in Brazil. In *Nutrition of the Eucalypts*; Attiwill, P.M., Adams, M.A., Eds.; CSIRO Publishing: Clayton, Australia, 1996; pp. 335–356.
11. Guedes, M.C.; Poggiani, F. Variation of leaf nutrient contents in eucalyptus fertilized with biosolids. *Sci. For.* **2003**, *63*, 188–201.
12. Reis, G.G.; Reis, M.G.F. Physiology of eucalyptus sprouting with emphasis on its water relations. *Ser. Tecnica IPEF* **1997**, *11*, 9–22.
13. Cacau, F.V.; Reis, G.G.; Reis, M.G.F.; Leite, H.G.; Alves, F.F.; Souza, F.C. Deceptive of young eucalyptus plants and management of sprouts in an agroforestry system. *Pesq. Agropecu. Bras.* **2018**, *43*, 1457–1465. [CrossRef]
14. Embrapa; Empresa Brasileira de Pesquisa Agropecuária—EMBRAPA. *Centro Nacional de Pesquisa de Solos. Brazilian System of Soil Classification*, 3rd ed.; EMBRAPA: Brasília, Brazil, 2013; 353p.
15. Van Raij, B.; Andrade, J.C.; Cantarella, H.; Quaggio, J.A. *Chemical Analysis for Fertility Evaluation of Tropical Soils*; IAC: Campinas, Brazil, 2001; 285p.
16. "Koppen Climate Classification Climatology". Encyclopedia Britannica. Available online: https://howlingpixel.com/wiki/K%C3%B6ppen_climate_classification (accessed on 4 August 2017).
17. Malavolta, E.; Vitti, G.C.; Oliveira, S.A. *Evaluation of the Nutritional Status of Plants: Principles and Applications*, 2nd ed.; Brazilian Association for the Research of Potash and Phosphate: Piracicaba, Brazil, 1997; 319p.
18. Campos, J.C.C.; Leite, H.G. *Forest Measurement Questions and Answers*; UFV: Viçosa, Brazil, 2002; 407p.
19. Dick, G.; Schumacher, M.V.; Momolli, D.R. Characterization of soil fertility in a settlement of *Eucalyptus dunnii* Maiden in the Pampa biome of Rio Grande do Sul. *Ecol. Nutrição Florest.* **2016**, *4*, 68–77. [CrossRef]
20. Bazanii, J.H.; Gonçalves, J.L.M.; Rocha, J.H.T.; Melo, E.S.A.C.; Prieto, M. Phosphate nutrition in *Eucalyptus* plantation. *Int. Plant Nutr. Inst.* **2014**, 148.
21. Santana, G.S.; Knicker, H.; González-Vila, F.J.; González-Pérez, J.A.; Dick, D.P. The impact of exotic forest plantations on the chemical composition of soil organic matter in Southern Brazil as assessed by Py–GC/MS and lipid extracts study. *Geoderma Reg.* **2015**, *4*, 11–19. [CrossRef]

22. Kolm, L. Nutrient Cycling and Microclimate Variations in Eucalyptus grandis Hill ex Maiden Plantations Managed through Progressive Thinning. Master's Thesis, Superior School of Agriculture "Luiz de Queiroz", University of São Paulo, Piracicaba, Brazil, 2001.
23. Chaer, G.M.; Tótola, M.R. Impact of organic waste management during the reform of eucalyptus plantations on soil quality indicators. *Rev. Bras. de Ciência do Solo* **2007**, *31*, 1381–1396. [CrossRef]
24. Menegale, M.L.C.; Rocha, J.H.T.; Harrison, R.; Goncalves, J.L.M.; Almeida, R.F.; Piccolo, M.C.; Hubner, A.; Arthur Junior, J.C.; Ferraz, A.V.; James, J.N.; et al. Effect of Timber Harvest Intensities and Fertilizer Application on Stocks of Soil C, N, P, and S. *Forests* **2016**, *7*, 319. [CrossRef]
25. Brunello, A.T. Availability and efficiency in the use of nutrients in secondary forests under different levels of change in the region of Santarém and Belterra, eastern Amazonia. Master's Thesis, Intituto Nacional de Pesquisa da Amazônia (INPA), Manaus, Brazil, 2016.
26. Dell, B.; Malajczuk, D.; Xu, D.; Grove, T.S. *Nutrient Disorders in Plantation Eucalypts*; ACIAR: Camberra, Australia, 2001; 188p.
27. Santos, F.M.; Chaer, G.M.; Diniz, A.R.; Balieiro, F.C. Nutrient cycling over five years of mixed-species plantations of Eucalyptus and Acacia on a sandy tropical soil. *For. Ecol. Manag.* **2017**, *384*, 110–121. [CrossRef]
28. Couto, H.T.Z.; Mello, H.A.; Simões, J.W.; Vencovsky, R. *Eucalyptus saligna* Smith sprout management. *IPEF* **1973**, *7*, 115–123. Available online: http://ipef.br/publicacoes/scientia/nr07/cap05.pdf (accessed on 4 February 2017).
29. Gazola, R.N.; Buzetti, S.; Teixeira Filho, M.C.M.; Dinalli, R.; Moraes, M.L.T.; Celestrino, T.S.; Silva, P.H.M.; Dupas, E. Rates of N, P and K in the cultivation of eucalyptus in soil originally under Cerrado vegetation. *Semina Ciências Agrárias* **2015**, *36*, 1895–1912. [CrossRef]
30. Rezende, G.C.; Suiter Filho, W.S.; Mendes, C.J. Regeneration of the forest masses of the Agricultural and Forestry Company Santa Bárbara. *Boletim Técnico SIF* **1980**, *1*, 1–24.
31. Simões, J.W.; Coto, N.A.S. Effect of sprout number and mineral fertilization on growth of *Eucalyptus saligna* Smith on second rotation. *IPEF* **1985**, *31*, 23–32.
32. Silva, N.F. Productivity, Demand and Nutritional Efficiency of Eucalyptus Clones in High Stem and Coppice Regime. Master's Thesis, Federal University of Viçosa, Viçosa, Brazil, 2013.
33. Celestrino, T.S.; Buzetti, S.; Teixeira Filho, M.C.M.; Gazola, R.N.; Dinalli, R.P.; Silva, P.H.M.; Carvalho, A.C.; Sarto, G.D. Sources and application methods of boron in Eucalyptus crop. *Semina Ciênc. Agrár.* **2015**, *36*, 3579–3594. [CrossRef]
34. Faria, G.E.; Barros, N.F.; Cunha, V.L.P.; Martins, I.S.; Martins, R.C.C. Evaluation of productivity, content and efficiency of nutrient utilization in genotypes of *Eucalyptus* spp. in the Jequitinhonha valley, MG. *Ciênc. Florest.* **2008**, *18*, 363–373. [CrossRef]