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Original Article

The effect of fertilization at planting for *Pinus elliottii* and *Pinus caribea* var. hondurensis plantations and top dressing for *Pinus elliottii* plantations, in Guareí, SP, Brazil.

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Abstract
Pine species play important role in Brazilian economy for solid wood and resin production. However, information about the effect of fertilization on wood and resin production is scarce. Thus, to investigate the relationship between different fertilization regimes on wood and resin productivity further, this paper analyzes the effects of fertilization in two experiments, organized in 2 parts. The first part is about the effect of 5 fertilization treatments at planting for *Pinus elliottii* (PEE) and *Pinus caribea* var. *hondurensis* (PCH), analyzed from two to eight years after planting considering volume, diameter at breast height, basal area and total and dominant height. The second part explored the effect of varying top dressing fertilization treatments on resin production of a 17-year-old *Pinus elliottii* production plantation. For the first experiment, fertilization at planting contributed to substantial gains for the parameters evaluated for PCH. For example, volume was 58% higher for trees which received fertilization at planting, compared to the control group. For PEE, fertilization do contributed for gains, but they were not statistically meaningful for all the characteristics evaluated, but for basal area. In the second part, results showed that top dressing fertilization had effect on resin production and the best treatment was 200 kilograms of N-P-K (06-30-06) per hectare at planting (treatment number 2). Thus, we concluded that fertilization management must take into account the factors such as the time, the amount of application and the species being fertilized.
Keywords: Slash pine, Fertilizing, Resin.

Introduction

Pine plantations occupy 1.6 million hectares in Brazil (Iba 2016), and it is mostly used for resin and wood production. Although Brazilian pine plantations are commonly implemented without any fertilization (Brito et al. 1986; Chaves and Correa 2003; Moro et al. 2014), it presents great adaptation and growth in most Brazilian environmental conditions. The Brazilian mean annual average increment is 25 m^3ha^{-1} $year^{-1}$, while the American mean annual average increment is 10 m^3ha^{-1} $year^{-1}$ (Moro et al. 2014). Despite the fact the response to fertilization is positive in most cases (Lee and Jose 2003), it relies on several factors.

Nutrient exportation is huge on wood production regimes; hence, there is a need to investigate further fertilization demand because nutritional status influences environmental sustainability and wood and resin production. Research related to fertilization methods for Pine plantations are limited, especially for Brazilian plantations.

Regarding resin production, in 2001 Brazil was the third producer in the world, responsible for 7% of the total production, which corresponds to 56 million ton $year^{-1}$ (Romanelli and Sebbenn 2004). Since 2012, Brazil is the second world producer, just behind China (Cunnighan et al. 2012). From 2014 to 2015, Brazilian resin production rose 33.1% and São Paulo state production represented 64.3% of the total (IBGE 2015). Although pine wood prices reaches good values, normally, resin production is highly profitable, even considering volume yield losses resulting from the artificial wounding. For example, Baena (2004), studying *Pinus elliottii* plantations in São Paulo and Paraná states, with varying volume losses (5, 15 and 30%), genetic improvement (25, 50 and 75%) and varying interest rates (6, 9 and 12%/year) concluded that resin production is a reasonable way to increase income, based on net present value, internal tax of return, and beneficial cost ratio.

Thus, considering the role pine species play in Brazil, this paper aims to analyse the effect of fertilization for timber production for both species *Pinus elliottii* and *Pinus caribea* var. *hondurensis*, and the effect of top dressing fertilization on *Pinus elliottii* resin production, in order to plan management practices focused on wood and resin production in a sustainable environment.

Material and Methods

Methods are split in experiments 1 and 2 because they are two distinct procedures at different plantations, with its different objectives, both installed by the Resinas Brasil group. Experiment 1 aims to use fertilization to enhance tree growth. Experiment 2 aims to use top dressing fertilization to promote resin production gains.

Experiment 1

Area

The experiment was established in March of 2008 on 14.73 hectares, in Guareí municipality, São Paulo state, which is classified as Cfb, with short and cold summers (Araujo et al. 2013), according to the Koppen's climatic classification, which is the system most used by geographical and climatological societies across the world (Alvares et al. 2014). Two pine species were used: *Pinus elliiottii* and *Pinus caribea* var. *hondurensis* (hence forward referred as PEE and PCH, respectively). The seedlings were planted in the field 6 months after sowing and were originated from seed orchard aiming wood production improvement. Soil was prepared using a 30-cm-deep subsoiler. Planting was done manually in 3 x 1.5 m spacing. Before establishing the experiments, soil analysis was performed to observe macro and micronutrients content in the soil (Table 1) before setting the treatments. Soil texture was sandy, with 89.2% of sand, 8.8 of clay and 2% of silt.

Table 1. Soil chemical analysis at the surface layer before the experiment establishment, for macro and micronutrients (DTPA method), in Guareí, Sao Paulo, Brazil.

pH	O. M.	P $_{res}$	Al $^{3+}$	H+Al	K	Ca	Mg	Sb	CTC	V%
$CaCl_2$	Gdm^{-3}	Mgdm^{-3}	-----------------mmol$_c$dm^{-3}-----------------							
3.7	11	5	----	42	0.2	2	1	3	46	7
B		Cu		Fe		Mn			Zn	
-----------------------mgdm^{-3}-----------------------										
0.13		0.4		65		0.4			0.3	

Database

Data was collected in 6 occasions (once a year, beginning in the second year), from 540 m² plots (18 repetitions per treatment). Total height (TH) and diameter at breast height (DBH) of all trees was measured using a clinometer and metric tape, respectively. Sectional area (g) was calculated using equation 1 and volume (V) was calculated using a form factor of 0.5 (equation 2), as suggested by Drescher et al. (2001). Basal area (G) is the sum of all sectional area of trees within one hectare. Dominant height (H) is the mean of the 100 thickest trees per hectare (Scolforo 1993).

$$g = \frac{\pi * DBH^2}{40000} \quad (1)$$

$$V = g * H * 0.5 \quad (2)$$

Treatment

The treatments tested are described in Table 2. Limestone and gypsum were broadcast applied. All the fertilizers were applied on the planting row. Top dressing fertilization was applied 1 month after planting. Treatments were compared by Tukey test, with 95% of confidence, using the software R.

Table 2. Treatments with varying nutrition degree for *Pinus elliottii* and *Pinus. caribaea* var. *hondurensis* at planting and top dressing, in Guareí, Sao Paulo, Brazil.

Treatment	NKP (kgha^{-1}) 06-30-06 *(planting)*/20-00-20 *(top dressing)*	Lime (tha^{-1}) *(planting)*	Borax (kgha^{-1}) *(top dressing)*	Zinc sulfate (kgha^{-1}) *(top dressing)*	Copper sulphate (kgha^{-1}) *(top dressing)*	Gypsum (tha^{-1}) *(planting)*
1	-	-	-	-	-	-
2	200/0	-	-	-	-	-
3	100/150	1.5	10	5	4	-
4	200/300	1.5	20	10	8	-
5	200/300	1.5	20	10	8	1

Experiment 2

Area

The planting was at the summer of 1991/1992 in Guareí municipality, São Paulo state, using *Pinus elliottii*s seedlings, on 8.46 hectares. Top dressing fertilizations were made in March of 2008, 17 years after planting. Soil was prepared using a 30 cm deep subsoiler. Planting was made manually in 3 x 3 spacing. Before establishing the experiments, soil analysis were done to observe macro and micronutrients contents (Table 3) to set the treatments. Soil texture was sandy, with 90.3% of sand, 6.8 of clay and 2.9% of silt.

Table 3. Soil chemical analyse at the surface layer before experiment establishment, for macro and micronutrients (DTPA method) in Guarei, Sao Paulo, Brazil.

pH	M.O.	P $_{res}$	Al $^{3+}$	H+Al	K	Ca	Mg	Sb	CTC	V%
$CaCl_2$	Gdm^{-3}	Mgdm^{-3}	-----------------mmol$_c$dm^{-3}-----------------							
3.8	9	5	----	38	0.1	2	1	3	41	7
B		Cu		Fe		Mn			Zn	
-----------------------mgdm^{-3}-----------------------										
0.13		0.2		65		0.1			0.1	

Database

Data was collected in 3 annual resin tapping, measured by weight of resin produced per groove (each one was 18 cm long, in average) times 22, which is the average of total annual grooves is made in a tree, for the trees from all the 5 treatments.

Treatments

The treatments tested are in Table 4. Limestone was broadcast applied. At the moment top dressing fertilization was proceeded, the mean DBH and total height were 20 cm and 18 m, respectively. Results for the growth of the characteristics assessed (*yield*) were analyzed by the linear model below, where *a* means age, *treat* means treatment and β are the coefficient of the model.

$$Yield = \beta_0 + a\beta_1 + treat\beta_2$$

Table 4. Treatments of top dressing fertilization used for *Pinus elliottii* plantation, in Guarei SP, Brazil.

Treatment	NKP (kgha^{1}) 20-00-20	Lime(tha^{1}) (planting)	Copper sulphate (kgha^{-1})(top dressing)
1	-	-	-
2	150	-	4
3	300	-	8
4	150	1.5	4
5	300	1.5	8

Results and discussion

Experiment 1

Any dose of fertilization contributed to substantial gains in volume, basal area, diameter at breast height, total height and dominant height for *Pinus caribea* var. *hondurensis* (Figure 1). For this species, volume, basal area and total height were 58%, 27% and 39% higher in treatment 3 in comparison to the control group at the age of 8 (Table 5). However, as there were no differences between the treatments were fertilization was used, the best treatment was the number 2, because it was the one that used fewer and smaller amount of fertilizers with statically same result of the others, making fertilization cheaper and less invasive for the environment.

For *Pinus elliottii*, the gains were not meaningful for all the dendrometric characters assessed, but for basal area in treatment 5, at the age of 8 as well (Table 5). Still, even the differences between the treatments being not statistically meaningful, the averages on the control group were smaller for all characteristics, but for the heights. Before the age of 8, there was no meaningful difference between the treatments for all characters assessed. However, these differences tend to be accentuated over time, being much bigger beyond, at harvest. The rotation age rely on several factors, such as discount ratio and yield, for example, but it is around 20 for pine species plantations (Wang et al. 2006; Bendtsen and Senft 2007), what enforce the small-interval growth importance for the final product.

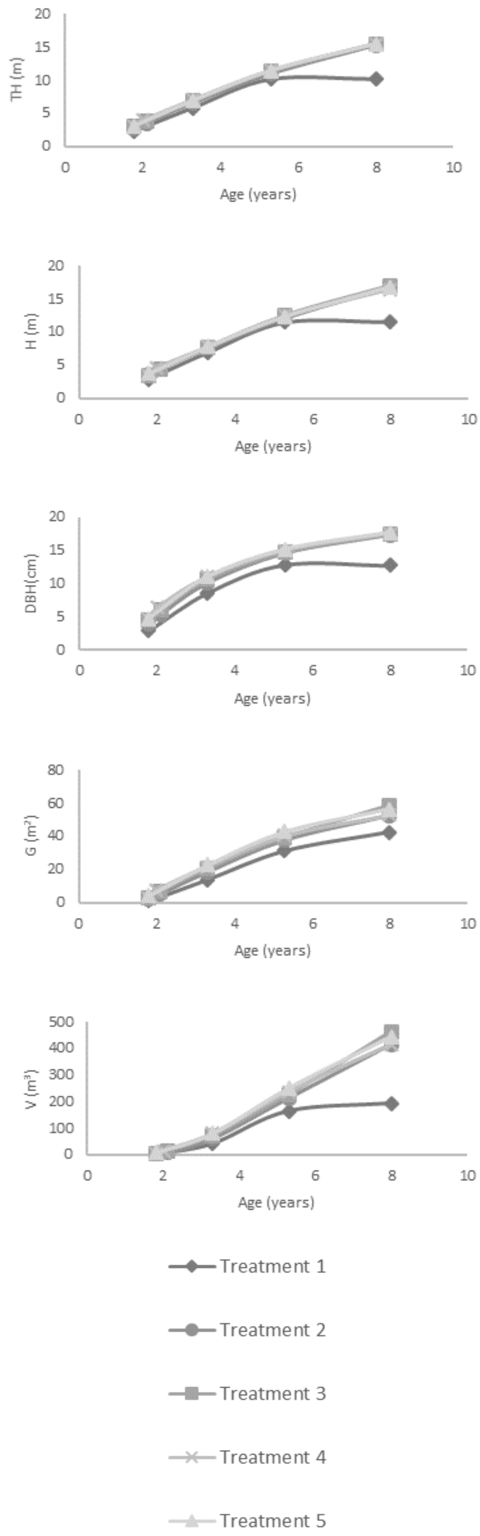


Figure 1. Total height (TH), dominant height (H), diameter at breast height (DBH), basal area (G) and volume (V) for *Pinus caribaea* var. *hondurensis* according to the treatment applied, at Guareí, SP, Brazil.

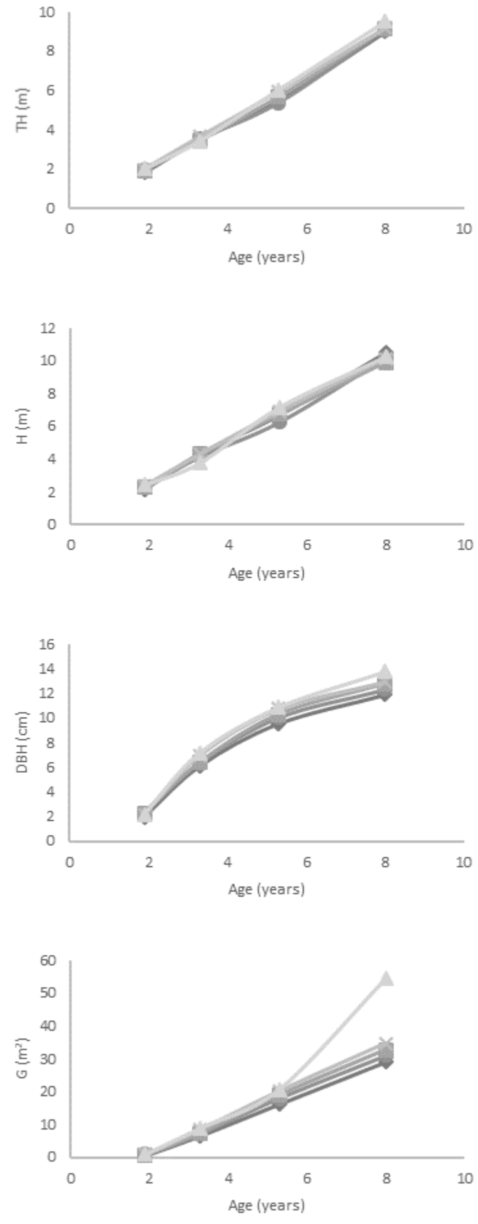
Table 5. Volume (V), basal area (G), diameter at breast height (DBH), total height (TH) dominant height (H), test result (TR) and (standard deviation value) for the Tukey test, with 95% of confidence for trees at 8 years old. Lower case letters compares *Pinus caribea* var. *hondurensis* (PCH) species and capital letters compares *Pinus elliottii* (PEE) treatments.

Species	Treatment	V (m^3ha^{-1})	TR	G (m^2ha^{-1})	TR	DBH (cm)	TR	TH (m)	TR	H (m)	TR
PCH	1	192.27 (1.28)	b	42.33 (0.17)	b	12.7 (13.0)	b	8.9 (2.99)	b	10.3 (0.43)	b
	2	414.35 (0.10)	a	52.32 (0.01)	ab	17.3 (5.5)	a	15.2 (2.30)	a	16.9 (0.39)	a
	3	462.44 (0.52)	a	58.40 (0.06)	a	17.5 (6.8)	a	15.4 (1.79)	a	16.9 (0.4)	a
	4	415.04 (0.09)	a	52.83 (0.01)	ab	17.5 (5.2)	a	15.4 (1.93)	a	16.4 (1.36)	a
	5	443.55 (0.09)	a	56.21 (0.01)	a	17.7 (5.2)	a	15.4 (1.98)	a	16.7 (0.25)	a
PEE	1	135.91 (40.21)	A	29.14 (9.98)	B	11.9 (0.4)	A	9.0 (0.26)	A	10.5 (0.29)	A
	2	144.27 (45.73)	A	30.91 (9.80)	B	12.3 (0.5)	A	9.1 (0.33)	A	10.2 (0.31)	A
	3	152.63 (61.28)	A	32.68 (12.32)	B	12.8 (0.3)	A	9.2 (0.36)	A	9.9 (0.67)	A
	4	163.84 (66.08)	A	34.68 (13.55)	B	13.0 (0.5)	A	9.2 (0.12)	A	10.1 (0.14)	A
	5	270.11 (123.18)	A	54.49 (21.80)	A	13.8 (0.8)	A	9.5 (0.13)	A	10.3 (0.55)	A

Treatment: 1: control group; 2: 200 kgha-1 of NPK (06-30-06) at planting; 3: 100 kgha-1 of NPK (06-30-06) and 1.5 tonne of lime per hectare at planting, 150 kgha-1 of NPK (20-00-20), 10 kgha-1 of borax, 5 kgha-1 of zinc sulphate and 4 kgha-1 of copper sulphate for top dressing; 4: 200 kgha-1 of NPK (06-30-06) and 1.5 tonne of lime per hectare at planting, 300 kgha-1 of NPK (20-00-20), 20 kgha-1 of borax, 10 kgha-1 of zinc sulphate and 8 kgha-1 of copper sulphate for top dressing; 5: 200 kgha-1 of NPK (06-30-06), 1.5 tonne of lime per hectare and 1 tonne per hectare of gypsum at planting, 300 kgha-1 of NPK (20-00-20), 20 kgha-1 of borax, 10 kgha-1 of zinc sulphate and 8 kgha-1 of copper sulphate for top dressing.

According to Ferreira et al. (2001), pine species respond slower to fertilization than Eucalyptus species. The reasons for this lack of response can be the effect nutrients have inside the tree. For example, Teskey et al. (1994) found that fertilization had no effect on photosynthesis for *Pinus elliottii*. Brix and Ebell (1969) noted that fertilization had no effect on net photosynthesis for *Pseudotsuga menziesii*, as well. Being photosynthesis the main cause of growth, if fertilization was not able to affect photosynthesis, it is consistent to accept that growth is the same for all treatments, even for the control group. Similarly, Barlow et al. (2013) studying the effect of fertilization on initial growth of *Pinus elliottii* by analysing seedling height and root-collar diameter during the first year after planting concluded that the control group had increased growth in height and diameter when compared to treated seedlings.

Figures 1 and 2 show the growth of the characters total height (TH), dominant height (H), diameter at breast height (DBH), basal area (G) and volume (V) for PCH and PEE respectively, from 2 to 8 years. There was no difference between treatments until the age of 8. At the age of 8, it is clear that the control group had the smallest mean in comparison to the other treatments for PCH. For PEE, as we can see on Figure 2, all the treatments had similar values for the parameters evaluated, but basal area and volume. Although basal area in treatment 5 was statistically different (higher) from the other treatments, the character volume had high standard deviation (number in brackets next to volume value on Table 5), and despite of its higher value at the treatment 5, it did not meant significant difference between this treatment and the others, including the control group. The high standard deviation can be explained by the fact seedlings were not from clones, but originated from seeds, which, means genetic and environmental variations affecting tree shape and consequently the volume. Colbert et al (1990) studying the effects of annual fertilization and sustained weed control for juvenile loblolly and slash pine and found out fertilization contributed to substantial gains in biomass for both, where in *Pinus elliottii* had smaller gains in biomass in comparison to *Pinus taeda* (gains of 300% for slash pine and 700% for loblolly pine).



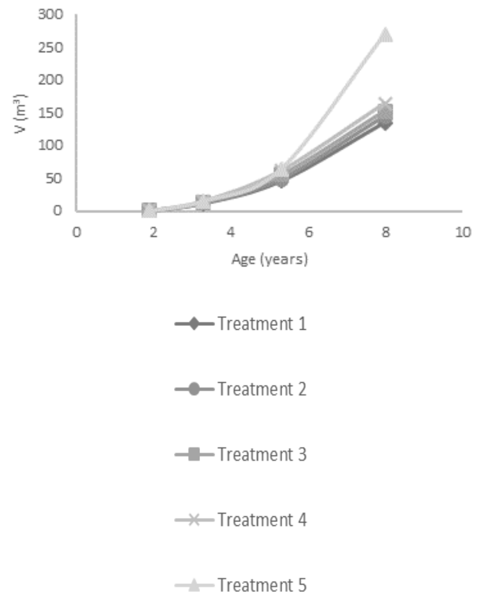


Figure 2. Total height (TH), dominant height (H), diameter at breast height (DBH), basal area (G) and volume (V) for *Pinus elliottii* according to the treatment, at Guareí, SP, Brazil.

Figure 3 represents diameter at breast height (DBH) in centimeter and basal area in m^2/ha for PEE and PCH at 8 years old. Figure 4 represents total height and dominant height for PEE and PCH at 8 years old. Figure 5 shows volume (m^3/ha) for PEE and PCH. Capital letters compares *Pinus elliottii* and small letters compares *Pinus caribea* var. *hondurensis* from each treatment. PCH responded better than PEE to fertilization treatments for all attributes assessed. For all the parameters evaluated, PCH presented higher values, compared to PEE. For all the character evaluated, the smaller value was found on the control group. The other values were statistically equal according to the Tukey test for PCH.

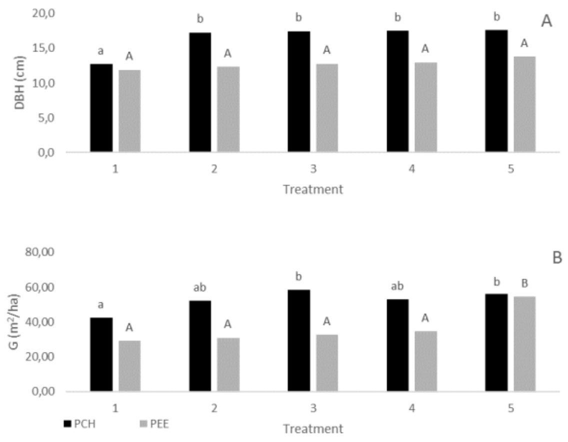


Figure 3: Diameter at breast height (DBH) (A) (cm) and basal area (G) (B) (m^2ha^{-1}) for *Pinus caribea* var. *hondurensis* (PCH) and *Pinus elliottii* (PEE) plantations in Guarei, SP, Brazil at each treatments tested, at 8 years old. Capital letters compares *Pinus elliottii* and lower case letters compares *Pinus caribea* var. *hondurensis* at each treatment.

As shown in Figure 4, total height and dominant height followed similar pattern. For PEE, all the treatments had equal means, according to Tukey test. For PCH, all treatments but the control group had equal means. This indicates that the best tratment was number 2, because it was the least invasive one, which makes planting cheaper and less aggressive for the environment.

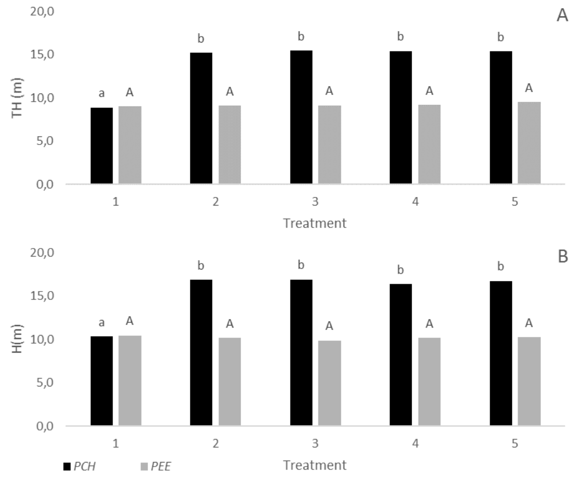


Figure 4. Total height (m) (A) and dominant height (m) (B) for *Pinus caribea* var. *hondurensis* (PCH) and *Pinus elliottii* (PEE) plantations in Guarei, SP, Brazil at each treatments tested, at 8 years old. Capital letters compares *Pinus elliottii*and lower case letters compares *Pinus caribea* var. *hondurensis* at each treatment.

Similarly, for volume, all the treatments had the same effect for PEE. The biological behavior of the PEE in relation to the growth is markedly lower than the PCH, an alternative to stimulate the growth of the PEE would be the accomplishment of the basic fertilization before the planting, and the top fertilization in the following year, before the beginning of the growing season.

For PCH, all the treatments but the control group had the same mean according to Tukey test. Vogel et al. (2005) applied different doses of N, P and K at planting in a *Pinus taeda* plantation and concluded that, based on assessments at 19 months after planting, it is important fertilize plantations to guarantee initial growth.

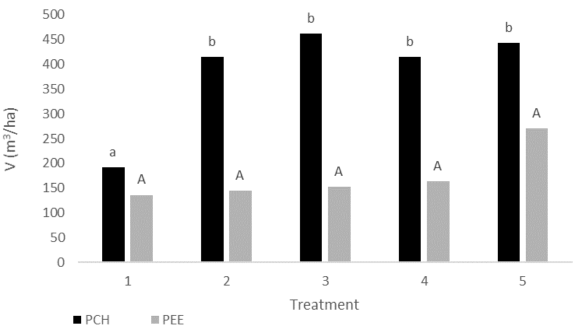


Figure 5. Volume (m^3/ha) for *Pinus caribea* var. *hondurensis* (PCH) and *Pinus elliottii* (PEE) plantations in Guarei, SP, Brazil at each treatments tested, at 8 years old.Capital letters compares *Pinus elliottii* and lowerletters compares *Pinus caribea* var. *hondurensis* at each treatment.

Experiment 2

As mentioned before, it is common to implement pine plantations without any fertilization (Moro et al. 2014) and fertilizing aged stands can mitigate the nutrient shortage. Usually, aged plantations increase growth for both earlywood and latewood due nutrient inputs (Brito 1986). Because the demand for nutrients depends on the stage of stand development, top dressing fertilization would supply the stand's need for nutrition along time. However, the moment of proceeding fertilization along time in stand life is crucial, because if it is made late, the trees would not respond sufficiently, consequently, wasting money and resources.

For the experiment 2 there was meaningful difference between treatments regarding resin production (Table 6) after the second year of harvesting. On the first harvest resin, there were no meaningful differences between treatments. It can be inferred that there was not enough time for the trees to respond in resin production at the first harvest year, since the gap between fertilization treatments and resin tapping was just six months. From the second year, difference starts do appear, being the highest mean represented by the treatment 2, followed by treatment 5. The other treatments were considered equal statistically. On the third year after the dressing fertilizations, the best treatments were the treatment 2 and 4. The fifth treatment is equally good as the third one, and the worst one is the control group. In a general analysis, considering all the harvest years, the best treatment was the number 2, followed by the treatment number 5.

According to Moro et al. (2014), it is harder to predict the effect of fertilization on old plantations because its roots are deeper and spread along soil profile. For example, Barlow et al. (2013) recommends top dressing procedures between the ages of 5 and 10, which would be before canopy closure, for slash pine trees.

Table 6. Treatments applied to the *Pinus elliottii* plantation at Guareí, SP, Brazil, for a mean annual production for a 22-groove tree, in Kilograms. Test result (in bracket) show the difference between treatments in the right for each harvest year.

Treatment	Harvest 2008-2009	Harvest 2009-2010	Harvest 2010-2011
	Resin production (kg)	Resin production (kg)	Resin production (kg)
1	5.06 (a)	3.96 (b)	3.71 (c)
2	5.49 (a)	5.00 (a)	4.37 (ab)
3	4.91 (a)	3.96 (b)	4.10 (b)
4	4.82 (a)	4.08 (b)	4.38 (ab)
5	5.45 (a)	4.26 (ab)	4.03 (b)

Treatment 1: control group; 2: 150 kgha^{-1} of NPK (20-00-20) at planting and 4 kgha^{-1} of copper sulphate as topdressing; 3: 300 kgha^{-1} of NPK (20-00-20) at planting and 8 kgha^{-1} of copper sulphate as topdressing; 4: 150 kgha^{-1} of NPK (20-00-20) at planting, 1.5 tonne of lime per hectare and 4 kgha^{-1} of copper sulphate as topdressing; 5: 300 kgha^{-1} of NPK (20-00-20) at planting, 1.5 tonne of lime per hectare and 8 kgha^{-1} of copper sulphate as topdressing

As resin flow is a defense response in conifers and is controlled by various environmental factors (Rodrigues and Fett-Neto 2009), would be logical that top dressing procedures would not produce a direct effect on resin tapping, because it is not threatening the tree, but creating conditions so the tree can respond. Thus, for resin production, fertilization does not always guarantees greater production. Warren et al. (1997) found out that fertilization decreased resin flow in loblolly pine up to 50% in comparison to control trees. They infer that, because fertilization increased tree growth, resin duct density decreased in cambial tissues of fertilized. Controversially, Knebel et al. (2008) examined the influence of fertilization, artificial wounding and fungal inoculation on resin flow found out that fertilization increased resin flow, but only the younger trees sustained increased resin flow after wounding and inoculation treatments.

Conclusion

In conclusion, fertilizing was effective for growth and resin yield. For experiment 1, the best treatment was the number 2 (200 kgha^{-1} of NPK (06-30-06) at planting) regarding wood production for all characters assessed for *Pinus caribea* var. hondurensis. For *Pinus elliottii*, there was meaningful differences between treatments just for basal area, being the best the treatment 5 (200 kgha^{-1} of NPK (06-30-06), 1.5 tonne of lime per hectare and 1 tonne per hectare of gypsum at planting, 300 $kgha^{-1}$ of NPK (20-00-20), 20 $kgha^{-1}$ of borax, 10 $kgha^{-1}$ of zinc sulphate and 8 $kgha^{-1}$ of copper sulphate for top dressing). For experiment 2, the best treatment was 2 (150 $kgha^{-1}$ of NPK (20-00-20) at planting and 4 $kgha^{-1}$ of copper sulphate as topdressing) and 5 (300 $kgha^{-1}$ of NPK (20-00-20) at planting, 1.5 tonne of lime per hectare and 8 $kgha^{-1}$ of copper sulphate as topdressing) for the second harvest year, and 2 (150 $kgha^{-1}$ of NPK (20-00-20) at planting and 4 $kgha^{-1}$ of copper sulphate as topdressing) and 4 (150 $kgha^{-1}$ of NPK (20-00-20) at planting, 1.5 tonne of lime per hectare and 4 $kgha^{-1}$ of copper sulphate as topdressing) for the third harvest year. Thus, we concluded that for experiment 2, the best treatment was the number 2, because it kept steady being the best for the time observed in this study.

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