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INFLUENCE OF FERTILIZATION ON GROWTH OF YOUNG CHESTNUT TREES (*Castanea sativa* MILL.) MANAGED FOR WOOD PRODUCTION

RIBEIRO, S. L.; FONSECA, T. F.; PIRES, A. L. Influence of fertilization on growth of young chestnut trees (*Castanea sativa* Mill.) managed for wood production. **CERNE**, v. 25, n. 4, p.357-364, 2019.

HIGHLIGHTS

The growth of chestnut trees managed for timber benefits of adequate fertilization.

The effect of the fertilizers P, PK and NPK was analyzed for young chestnut trees.

The NPK treatment contributed to the tallest plants among the tested treatments.

The trees subject to NPK treatment presented a great regularity of size.

Keywords:
Nitrogen
Phosphorus
Potassium fertilizers
Tree growth

ABSTRACT

In Portugal, chestnut wood demand has increased in the last decades. Since chestnut plantations are usually established in low fertility soils, addition of N, P and K as fertilizers usually have a benefic effect in increasing wood productivity. The study aims to evaluate the effects of fertilization on growth of chestnut tree (*Castanea sativa* Mill.) cultivated for wood purposes. An experimental essay was established in a 3-year old chestnut tree stand with a planting spacing of 3.5 × 3.0 m. Four treatments were applied to randomized blocks with three repetitions: control (C), addition of phosphorus (P), addition of phosphorus and potassium (PK) and addition of nitrogen, phosphorus, and potassium (NPK). The chemical properties of the soil and the concentration of nutrients in the leaves were evaluated after the treatment, and measurements of tree diameter and stem height were made for a monitoring period of 4 years. Treatments did not affect soil properties or leaf nutrient concentrations. On the counterpart, the effect of the fertilizers was noticed for tree dimensions and growth. Gains of NPK in relation to the control were observed for the height variable, over the years. Seven years after application of the treatments, differences were also noticed for the diameter and the volume index variables. The NPK treatment has presented a significant effect on tree growth compared to the control, with noticeable gains in the stem height.

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INTRODUCTION

The chestnut tree (*Castanea sativa Mill*.) is a deciduous tree, from the family *Fagaceae*, of medium-large dimensions, reaching a height of 30-35 m, which may present great longevity (up to 1000 years). It is considered a species of fast growth until the 80 or 90 years, stabilizing the growth at these ages (Serrano, 2009a). Originated in China about 35 million years ago, the chestnut tree is distributed all over the world in several continents: Europe, Asia, America, and Oceania (Azevedo, 2014). The chestnut tree vegetates well in places with average annual temperatures between 8 and 15° C, being the coldest month above 1° C (Laranjo et al., 2007). In relation to precipitation, it requires a minimum rainfall between 600 and 800 mm (Conedera et al., 2016), with average annual precipitations between 800 and 1600 mm (Laranjo et al., 2007).

It is a valuable species with high economic importance as it can be managed for timber production (high forest or coppice) and for fruit (chestnuts) production, being able to generate other positive externalities, namely with regard to the production of mushrooms (Marques, 2007). According to data from the 6th Portuguese forest inventory (ICNF, 2019), the chestnut tree occupies 1% (41 410 ha) of the total forest area in Portugal. In Portugal, traditionally, most chestnut trees are managed for fruit production (traditional orchards). More recently, there has been an increase in the demand for chestnut wood, leading to an increase of plantation of new stands managed for timber production. Wood production at national level accounts for about 167 million m^3, with an average of 8.97 million m^3 of wood harvested per year (DGF, 2001). A significant part of this wood is exported.

The best conditions for the development of the species are deep soils, relatively fertile, coarse texture to medium, well structured, permeable, and well ventilated (Oliveira, 2007; Serrano, 2009b). The most favorable soil reaction is between 5.5 and 6.5, and it is advisable to perform acid correction whenever the pH is less than or equal to 5.0-5.5 (Oliveira, 2007). Chestnut trees managed for wood production are not very demanding with soils, although they do not vegetate well on skeletal or eroded soils (Oliveira, 2007). They can survive in soils with low fertility. However, the growth is slow, and wood production is irregular. When installed in more fertile soils, the species can present high increments and, therefore, high yields (Oliveira, 2007; Serrano, 2009b). A volume yield of 540 $m^3 \cdot ha^{-1}$ at approximately 45 years is referred by Patrício (2006), as an average value in appropriate sites for this species. In poorly fertile soils, a balanced fertilization with the main macronutrients, nitrogen (N), phosphorus (P), and potassium (K), is expected to positively influence tree growth, increasing the ability of young plants to form new roots, which increases competition for water, light, and nutrients, and increases their resistance to pests and diseases (Pires, 1994; Graciano et al., 2006; Viera et al., 2016).

To the best knowledge of the authors, there are no published results about the effects of the fertilization with the main nutrients N, P and K on the chestnut trees forest systems managed for wood production. The objective of this research was, therefore, to evaluate the effects of nitrogen, phosphorus, and potassium fertilizers on the growth of young chestnut trees managed for wood. This information is critical to provide a scientific basis for the fertilization guidelines to apply in these forest systems. The study was carried out in a chestnut tree experimental essay, for a four-year period (7-year old to – 10-year old trees), located in northeast Portugal.

MATERIAL AND METHODS

Area of study

The study area is in São Martinho de Agueira (county of Miranda do Douro), northeast Portugal (Figure 1). It refers to agricultural land that was fallowed for six years and planted with chestnut trees in 1999. The plantation was installed with a regular spacing of 3.5 × 3.0 m (952 trees per ha).

FIGURE 1 Localization of study area.

The climate in this region is subcontinental, with temperatures ranging from 12.3 °C to 38.8 °C, with an average temperature of 12.0 °C, and total precipitation of 554.7 mm (Mendes et al., 1991). The soils are essentially leptosols and cambisols derived from schist (Agroconsultores and Coba, 1991). Usually, these soils have low fertility and limited potential, due not only to the consequences of their agricultural use but also to the low precipitation that occurs in the summer (Agroconsultores and Coba, 1991).

The chemical properties of the soil determined at the beginning of 2002, prior to the establishment of the experimental plots, are presented in Table 1. The results confirm the low fertility indicated for the region (Table 2).

TABLE 1 Chemical properties of the soil determined before the settlement of the experiment.

Deph	pH (H_2O)	OM	P_2O_5	K_2O	Ca^{2+}	Mg^{2+}	K^+	Al^{3+}	CEC
		-%-	-- mg·kg⁻¹ --		-------------cmol⁺·kg⁻¹---------				
0-20 cm	5.2	2.8	4	36	0.80	0.21	0.09	1.02	2.36
20-40 cm	5.2	1.5	1	34	0.74	0.24	0.07	0.94	2.18

CEC - cation exchange capacity

Experimental design

In April 2002, when the trees were three years old, 12 experimental plots were installed in the study area. The treatments were applied in randomized blocks with three replications. The average plot area is 500 m^2 and contained 48 trees. The four treatments applied were: 1. Control, no N, P or K application, (C); 2. Addition of phosphorus (P) – 200 $kg \cdot ha^{-1}$ of P_2O_5 in the form of calcium superphosphate (42% P_2O_5); 3. Addition of phosphorus and potassium (PK) – 200 $kg \cdot ha^{-1}$ of P_2O_5 in the form of calcium superphosphate (42% P_2O_5) and 100 $kg \cdot ha^{-1}$ of K_2O in the form of potassium sulfate (50% K_2O); 4. Addition of nitrogen, phosphorus and potassium (NPK) - 90 $kg \cdot ha^{-1}$ of N in the form of ammonium sulfate (20.5% N); 200 $kg \cdot ha^{-1}$ of P_2O_5 in the form of calcium superphosphate (42% P_2O_5) and 100 $kg \cdot ha^{-1}$ of K_2O in the form of potassium sulphate (50% K_2O). The same amounts of N, P and K fertilizers were also applied six years later, in January 2008.

The P and K fertilizers were broadcast, and the N fertilizer was applied 30 to 50 cm around each plant (95 g of N), in order to minimize the understory growth.

In September 2003 and January 2006, soil samples were collected, at depths of 0-20 cm and 20-40 cm. At the same time, leaves from the upper third of the trees were collected and analysed for determination of N, P, K, Ca, Mg and S concentrations. All determinations were carried out in the Soil and Fertility Laboratory of UTAD.

In each plot of 500 m^2, 24 central trees were selected and identified for measurements of aboveground size. The dendrometric measurements were performed in the 12 plots in January 2006, 2007, 2008, and in February of 2009, when the stand age was seven, eight, nine, and ten years, respectively. The variables measured in the field were diameter at breast height (d, cm) and total stem height (h, m). The diameter at the breast height was measured to the nearest 0.1 cm with a caliper, while the tree height was determined with a Vertex ultrasonic hypsometer to the nearest 0.1 m. An index of stem volume (v_i, dm^3), based on the values d and h, was calculated for each tree assuming a cylinder shape for the stem of the plants.

Statistical analysis

The effects of the fertilization were studied on the soil chemical properties, on macronutrient concentration in the leaves, and on tree growth, using Tukey's multiple averages comparison test. The evaluation of differences on tree growth was done by means of morphological characteristics on the variables d, h and v_i.

To ascertain the validity of the statistical inference, additional analysis about the normality of the data, and of

TABLE 2 Chemical properties of the soil (average values and standard deviation values), determined one year and four years, after the first application of the fertilizers.

Treatment	pH (H_2O)	OM (%)	P_2O_5 (mg·kg⁻¹)	K_2O (mg·kg⁻¹)	Ca^{2+} (cmol⁺·kg⁻¹)	Mg^{2+} (cmol⁺·kg⁻¹)
Depth (0-20 cm) – One year after treatments						
C	4.9a ± 0.2	3.95*a* ± 0.36	6a ± 4	25*b* ± 4	0.28a ± 0.08	0.09*a* ± 0.03
P	5.0a ± 0.1	4.45*a* ± 1.17	44a ± 9	23*b* ± 1	0.55a ± 0.11	0.07*a* ± 0.02
PK	5.1a ± 0.2	4.09*a* ± 0.27	39a ± 24	39*a* ± 3	0.73a ± 0.29	0.14*a* ± 0.07
NPK	4.9a ± 0.3	3.82*a* ± 0.55	25a ± 15	40*a* ± 9	0.46a ± 0.15	0.12*a* ± 0.08
K-W test	n.s	n.s	n.s	*	n.s	n.s
Depth (20-40 cm) – One year after treatments						
C	4.9a ± 0.1	3.02a ± 0.84	5a ± 4	21a ± 3	0.26*a* ± 0.11	0.07*a* ± 0.02
P	4.9*a* ± 0.2	3.69a ± 0.90	20a ± 3	21a ± 4	0.46*a* ± 0.07	0.08*a* ± 0.03
PK	5.0a ± 0.2	3.01a ± 0.44	9a ± 3	29a ± 9	0.53*a* ± 0.23	0.15*a* ± 0.06
NPK	4.9a ± 0.2	3.62a ± 0.04	16a ± 15	35a ± 8	0.50*a* ± 0.06	0.13a ± 0.05
K-W test	n.s	n.s	n.s	n.s	n.s	n.s
Depth (0-20 cm) – Four years after treatments						
C	5.3*a* ± 0.3	4.81a ± 0.37	33a ± 22	67a ± 20	1.80*a* ± 1.04	0.19a ± 0.10
P	5.0a ± 0.3	4.05a ± 0.54	37a ± 25	60*a* ± 14	0.43*a* ±0.28	0.11a ± 0.05
PK	5.1a ± 0.2	4.17a ± 0.57	57a ± 11	81a ± 14	0.98*a* ±0.58	0.20a ± 0.13
NPK	5.1a ± 0.1	4.29a ± 0.29	55a ± 42	97a ± 8	0.61*a* ± 0.18	0.12*a* ± 0.02
K-W test	n.s	n.s	n.s	n.s	n.s	n.s
Depth (20-40 cm) – Four years after treatments						
C	5.0a ± 0.2	2.91a ± 1.31	10a ± 7	40a ± 14	0.65a ± 0.62	0.11a ± 0.07
P	4.9a ± 0.2	2.93a ± 0.82	12a ± 5	41a ± 5	0.55a ± 0.33	0.10*a* ± 0.03
PK	5.0*a* ± 0.2	2.66a ± 0.46	16a ± 2	57a ± 10	0.99a ± 0.77	0.27a ± 0.27
NPK	5.0a ± 0.1	2.86a ± 0.91	14a ± 8	64a ± 11	0.27a ± 0.11	0.11a ± 0.08
K-W test	n.s	n.s	n.s	n.s	n.s	n.s

Values in the column followed by the same letter are not significantly different ($p \geq 0.05$); n.s - not significant; *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. Italic letters refer to the cases where the assumptions of normality of the data and/or of the equality of variance between sets of observations for the Tukey test were not fully met.

the equality of variance between sets of observations were performed. The equality of the variances for each variable was analysed with the Levene test. The study of normality was based on the adjustment of the normal distribution to the data, with the goodness-of-fit analysis performed with the Shapiro-Wilk test. As it was found that some series of observations did not follow a normal distribution, the statistical analysis was complemented with the non-parametric Kruskal-Wallis (K-W) test for equality of medians. The statistical analyses were conducted with the JMP® (v. 10.0) software of SAS® Institute Inc.

RESULTS

Effects of the fertilizers on soil chemical properties

In general, the effect of treatments on soil chemical properties was not significant, at either depth level (0-20 cm and 20-40 cm) one year after treatment. The exception was for the amount of K_2O, evaluated at the 0-20 cm depth (Table 2), as shown by the results from the Kruskal-Wallis test. The plots with the PK and NPK fertilizers presented higher values of potassium in the soil (39 and 40 $mg{\cdot}kg^{-1}$, respectively) than the control plots (25 $mg{\cdot}kg^{-1}$) and the plots with the P treatment (23 $mg{\cdot}kg^{-1}$). No significant differences were detected in the soil analysis, for any of the soil properties, four years after treatment (Table 2).

Effects of the fertilizers on nutrient concentration in leaves

In relation to nutrient concentration in leaves (Table 3), the addition of N (NPK treatment) did not significantly increase the N concentration in leaves. The average P concentrations were also not significantly affected by P addition (P and NPK treatments). Differences were noticed for the concentration of potassium (K), one year after the treatment, with at least one treatment presenting a higher concentration of potassium than the other. The test of Tuckey clearly distinguishes differences in the concentration of potassium in the leaves between the NPK (7.9 $g{\cdot}kg^{-1}$) and the P treatment (4.0 $g{\cdot}kg^{-1}$), with an intermediate behavior for PK (6.5 $g{\cdot}kg^{-1}$) and the control (5.6 $g{\cdot}kg^{-1}$). Despite Ca and S amounts in the fertilizers used, the concentrations of these nutrients in leaves were not significantly affected. The same happened with Mg values (Table 3).

Effects of the fertilizers on the size and growth of the trees

The influence of the various treatments over the years for the variables and summarized in Table 4 (average and standard deviation values) and depicted in Figure 2 and 3.

The results (Table 4) indicate the existance of statistically significant differences among treatments for the average (Tuckey test) or medians (Kruskal-Wallis test) of diameter, height, and volume.

TABLE 4 Effects of treatment on dendrometric variables (age range from 7 to 10 years-old).

Treatment	Diameter (cm)	Height (m)	Volume index (dm^3)
	Seven years-old		
C	5.6*a* ± 0.8	4.4*ab* ± 0.2	12.8*a* ± 4.2
P	4.7*b* ± 0.5	4.0*c* ± 0.4	8.4*c* ± 1.7
PK	5.2*ab* ± 0.6	4.3*bc* ± 0.2	9.9*bc* ± 2.6
NPK	5.7a ± 0.7	4.6a ± 0.5	12.8*ab* ± 4.4
K-W test	***	***	***
	Eight years-old		
C	6.7a ± 1.1	5.0*a* ± 0.2	19.7*a* ± 6.7
P	5.7*b* ± 0.5	4.6*b* ± 0.3	13.5*b* ± 2.1
PK	6.2*b* ± 0.4	4.9*a* ± 0.3	15.5*ab* ± 2.9
NPK	6.7a ± 0.8	5.1a ± 0.5	19.3*a* ± 6.0
K-W test	***	***	***
	Nine years-old		
C	8.4*a* ± 0.9	5.7b ± 0.5	35.5*a* ± 11.3
P	7.5*b* ± 0.2	5.3*c* ± 0.4	25.8b ± 1.2
PK	7.7*ab* ± 0.7	5.8*ab* ± 0.6	29.5*ab* ± 7.6
NPK	8.3a ± 0.5	6.2a ± 0.7	34.5*a* ± 8.2
K-W test	***	***	***
	Ten years-old		
C	9.5*ab* ± 1.1	6.4*b* ± 0.4	48.9*ab* ± 14.7
P	8.6*c* ± 0.2	6.1*c* ± 0.2	38.6*c* ± 1.0
PK	8.9bc ± 0.6	6.5ab ± 0.4	43.5*bc* ± 8.7
NPK	9.8a ± 0.6	6.9a ± 0.7	54.1*a* ± 11.6
K-W test	***	***	***

Values in the column followed by the same letter are not significantly different ($p \geq 0.05$); n.s - not significant; *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. Italic letters refer to the cases where the assumptions of normality of the data and/or of the equality of variance between sets of observations for the Tukey test were not fully met.

TABLE 3 Concentration (average values) of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) in the leaves of the trees, one year and four years, after the first application of the fertilizers.

Treatment	N ($g{\cdot}kg^{-1}$)	P ($g{\cdot}kg^{-1}$)	K ($g{\cdot}kg^{-1}$)	Ca ($g{\cdot}kg^{-1}$)	Mg ($g{\cdot}kg^{-1}$)	S ($g{\cdot}kg^{-1}$)
			One year after treatments			
C	9.1a ± 4.6	2.1a ± 0.9	5.6ab ± 1.6	7.9a ± 0.6	2.5*a* ± 0.2	1.3*a* ± 0.2
P	7.5a ± 3.0	1.7a ± 0.2	4.0*b* ± 0.4	8.8a ± 2.1	3.1*a* ± 1.1	1.0*a* ± 0.0
PK	9.5a ± 4.8	2.4a ± 1.3	6.5*ab* ± 1.6	7.4a ± 1.1	2.9*a* ± 0.4	1.0*a* ± 0.2
NPK	7.6a ± 4.2	2.1a ± 0.7	7.9a ± 1.5	7.3a ± 0.6	2.6*a* ± 0.8	1.0*a* ± 0.4
K-W test	n.s	n.s	*	n.s	n.s	n.s
			Four years after treatments			
C	12.8a ± 7.1	1.1a ± 0.7	2.0*a* ± 0.2	12.0a ± 2.9	5.9a ± 3.3	-
P	14.9a ± 2.3	1.4a ± 0.3	3.3a ± 2.4	10.8a ± 0.5	5.0*a* ± 1.0	-
PK	16.9a ± 2.7	1.7a ± 0.6	3.4a ± 1.7	11.2a ± 1.2	4.1*a* ± 0.3	-
NPK	17.2*a* ± 1.8	1.2a ± 0.3	4.6a ± 1.6	10.7a ± 0.4	3.1*a* ± 0.5	-
K-W test	n.s	n.s	n.s	n.s	n.s	-

Values in the column followed by the same letter are not significantly different ($p \geq 0.05$); n.s - not significant; *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. Italic letters refer to the cases where the assumptions of normality of the data and/or of the equality of variance between sets of observations for the Tukey test were not fully met.

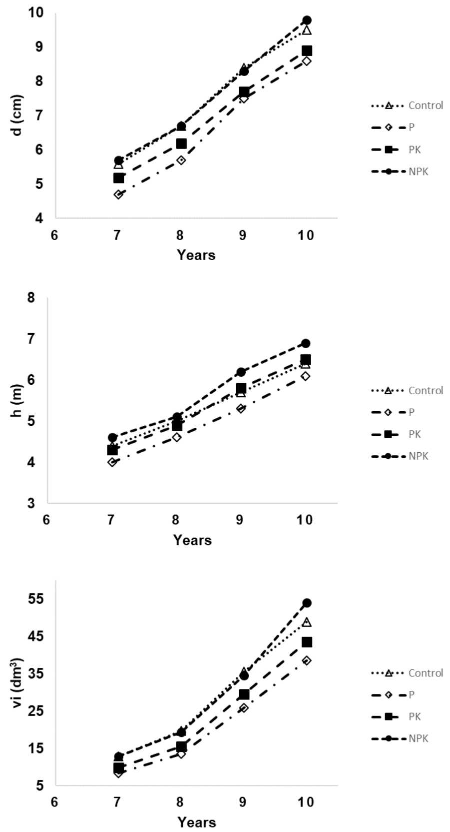

FIGURE 2 Graphical representation of the influence of the various treatments over the years for the variables *d*, *h*, v_i.

Regarding the diameter at breast height variable, the most obvious differences are associated with the lower average values presented by the plants subject to the P and PK treatments in comparison to the values observed for the control and for the NPK treatment. The average diameter determined at the 10 years, for the trees of the control plots (Table 4) is 9.5 cm. This is an expected standard average for tree diameter at that age and in the study area in the absence of fertilizers. Contrasting this value with the tested treatments, it is shown that the trees in the plots treated to PK and P fertilizers present lower average diameters than the standard, with the relative differences being of the order of –6.3% and –9.5% respectively.

Major differences among treatments are noticed for the total stem height variable. When the chestnut trees reach 10 years-old, the trees in the NPK treatment present the highest average stem height (6.9 m), followed by the PK treatment (6.5 m) and control (6.4 m). The addition of phosphorus alone (treatment P) does not beneficiate the development of stem height (6.1 m). Using the average height of the trees in control as a standard, there is a gain of 7.8% in height with the NPK treatment and a 4.7% decrease in the P treatment.

For the variable volume index, used as a proxy of the stem volume, applies, in general, what was

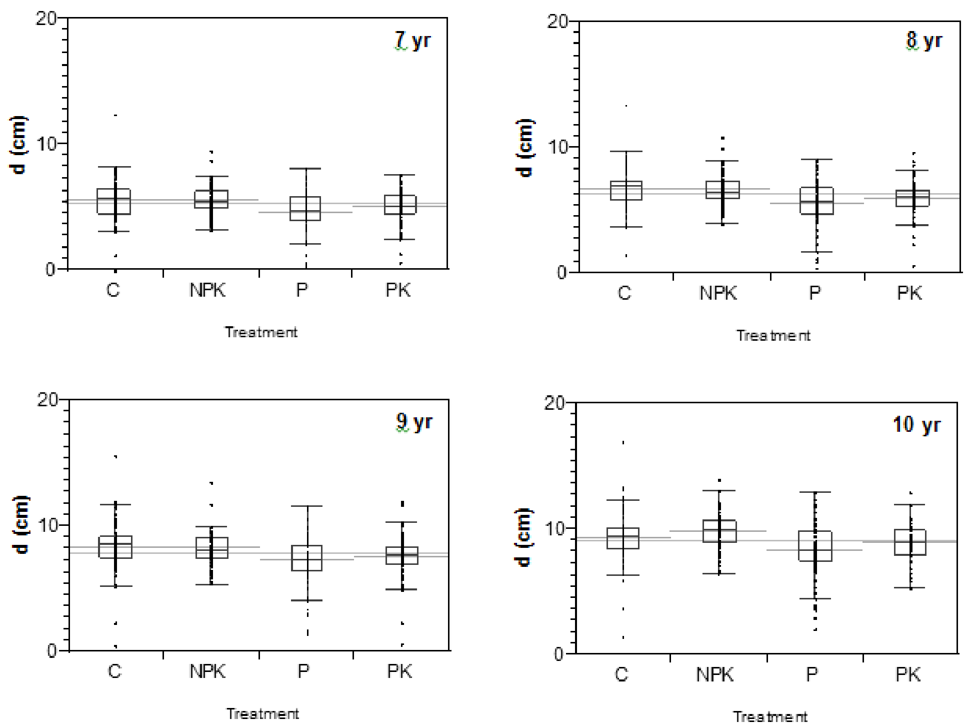

FIGURE 3 Quantile chart for variable h (age range from 7 to 10 years-old). Lines in gray, short lines - treatment average values; long lines – average for the total number of sampled trees.

mentioned for the diameter at breast height. At 10 year-old, the trees that were subject to the NPK treatment reach the highest average value of (54.1 dm^3), while the lowest average values are associated with the P (38.6 dm^3) and PK (43.5 dm^3) fertilizers. In comparison with control (with a of 48.9 dm^3), the trees subject to the PK and to the P treatments demonstrated, respectively, a reduction in the potential volume of –11.0% and –21,1% respectively, and the trees from the NPK treatment showed an increase of 10.6%.

The results of the essay (see Table 4, Figure 2 and 3) evidence three features. One refers to the higher averages (and medians) values achieved with the NPK treatment comparatively to the other fertilizers tested (PK and P), independently of the variable considered (tree diameter, stem height or volume index). Another feature is a great regularity of the diameters of the trees subjected to the NPK treatment comparatively to the variation observed for the control plots. This fact, noticed in general for all the variables (Figure A1 to A3), is the second positive feature associated with the NPK treatment. The third aspect that is worthwhile to mention is the accentuated positive effect of NPK on tree height development (Figure 2 and Table 4).

DISCUSSION

Effects of the fertilizers on nutrient concentration in leaves

Nutrient addition in the soil of N, PK and NPK had no effect on leaf nutrient concentration of N, P, Ca, Mg, and S. The absence of effect of P fertilizer in the leaves is in accordance with the results found by Brio et al. (1998), for stands of 25-year old chestnut trees for timber production. The authors indicated that P concentration in leaves of 25-year old chestnut trees for timber production did not increase after the addition of 100 kg·ha^{-1} of P.

In the current study, both NPK and P fertilizers affected the concentration of K in the leaves. The fertilization with NPK increased the K concentration on leaves, whereas the addition of P fertilizer had a depressive effect on the K concentration in that tissue (7.9 versus 4.0 g·kg^{-1}, respectively; Table 3). Azevedo (2014) reported a similar result of an increasing concentration of K in the leaves, with NPK fertilizers, for the same species. On the other hand, for young plants of *Eucalyptus grandis*, Graciano et al. (2006) indicate that fertilization with N or P altered leaf N and P concentration in the leaves. Fertilization with P additionally increased the S concentration in leaves. For all soil types and doses tested, fertilization with N or P did not alter K concentrations in the leaves. Four years after treatment, no significant differences were found in the leaf nutrient concentration (Table 3). It is known that the effect of fertilization in the nutrient concentration in leaves depends on environmental factors, such as climate and vegetation control, and is affected by the doses applied, hampering comparison among studies.

Comparing the concentration of N, P and K nutrients following fertilization with the nutritional standards (20 to 25 g/kg , with a threshold between 15 and 20 g/kg for N; 1.5 to 1.8 g/kg for P, and 8 to 1.3 g/kg for K; after Bonneau, 1995) it was observed that foliar nutrient levels of N and P remained in the low range of the appropriate levels. Only the K concentration in the NPK treatment, one year after the fertilization, approaches the reference values for optimal growth. In the sampling years, all Ca, Mg, and S concentrations are considered adequate for good growth (Bonneau, 1995).

Effects of the fertilizers on the size and growth of the trees

Several studies have shown that the addition of N, P, and K, together or individually, increases the wood production of species such as eucalyptus or maritime pine in less fertile soils (Bonneau, 1995; Sette Júnior, 2010; Pires and Xavier, 2010; Camargo, 2013). The influence of adding nutrients is considered more effective at juvenile stages than at maturity. In younger stands, before canopy closure, growth is highly dependent on the availability of soil nutrients. It is during this period that fertilization can be used with high efficiency both to increase the rapid installation of the plant on the ground and thus overcome the youth stage, where the plant is more sensitive to competition and all types of damage (Álvarez et al. 2000), and increase tree growth (Savill et al., 1997). After this juvenile period, the level of dependency of the nutrients on tree growth reduces. In the case of chestnut managed for wood production, Brio et al. (1998) reported that the addition of 100 kg·ha^{-1} of P to chestnut trees aged 25 had no influence on tree growth or on the phosphorus concentration in the leaves.

The results of the current essay for young plants showed, in general, a null or depressive effect on plant growth of P and PK fertilizers, whereas the addition of NPK fertilizer showed a beneficial effect in stem height when plants aged 9 and 10 years.

The absence of effect of the addition of P fertilizer on tree growth has been attributed to the fact that P requirements are low, and trees can get what they need through mycorrhizae and rapid nutrient recycling. The results obtained in this study also point for a negative impact of fertilization with phosphorus (alone) in the growth of young chestnut trees. Different results were reported in the literature for the black-watlle in Brazil (Schumacher et al. 2013), with this macronutrient being identified as the most important for the growth of the species. Differences in the soil characteristics justify, at least partially, the opposite effects reported for P in both studies. Schumacher et al. (2013) attribute the positive effect of fertilization with P to the fact that the soil, in the experimental site, had a lower amount of that nutrient. Graciano et al. (2006) also refer to a beneficial effect of P in young plants of eucalyptus. The P fertilizer promoted growth and improved N and S absorption.

In what concerns the effects of P and PK, in the current study, the lower growth in P and PK treatments may be related to several factors, namely due to the fact that the addition of one or two nutrients may alter the absorption of other nutrients. It has been indicated that the addition of P alone may decrease the absorption of several trace elements, namely Fe, Cu, and Zn, and the addition of K may decrease B absorption (Touzet, 1987).

According to Ballard (1984), there are advantages in applying P together with N and K, because sometimes synergistic phenomena can occur due to the application of these nutrients. This situation is probably explained due to the activity of the roots, which increases the cation exchange capacity and reduce losses. Balance nutrition appears to be important for minimizing advanced nutrient imbalances. Nitrogen is usually the nutrient that limits the most forest growth, mainly due to the low fertility of soils where the forest is established. However, N deficiencies in most cases are not so severe that prevent the development of forest stands but only to slow them (Ballard, 1984). The research confirms the improvement of tree growth in stem height with the addition of nitrogen. Although it is a slight improvement in average height, compared with the control, the trees in the NPK treatment did not present the irregular growth of the trees in control, suggesting a positive effect of adding the three nutrients for an improved homogeneity of tree dimensions. Further research should be developed to sustain this hypothesis.

CONCLUSIONS

The objective of this article was to study the influence of fertilization with nitrogen, phosphorus, and potassium on the growth of chestnut for wood production. The best results were obtained with the NPK treatment, contributing to the tallest and largest plants among the treatments tested. Although the NPK treatment compared favorably, to the control, namely for plants aged 9 and 10 years, the absence of fertilization might be also considered as a viable decision. The decision needs to take into account the investment with nutrition *versus* the effective gains in stem height in volume and in the uniformity of stem size. The dispersion of values of diameter and total height were generally lower for plants subjected to NPK treatment, attesting to a consistent effect of this treatment, compared to the heterogeneity of dimensions manifested in the control plants. The treatments without nitrogen did not perform so well. In fact, both the PK and the P fertilizer behave poorly in comparison to the NPK fertilizer and even with the control, which may be related to nutrient imbalances. The results show the importance of adequate nutrition on the development of young chestnut trees managed for timber production. As forests are usually installed in soils with low fertility, the application of NPK is expected to increase chestnut tree height and positively influences tree productivity.

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