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Influence of the Nutritional Aspects on Initial Growth of African Mahogany (*Khaya ivorensis* A. Chev.)

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Abstract

Khaya ivorensis A. Chev. (African mahogany) is one of the most economically important forest species, since it is used in the international furniture market. However, little is known about its culture and nutritional requirements. This study aimed to assess the development of K. ivorensis plants subjected to different base saturations, as well as to different N, P and K levels. An 8-ha area was used, wherein 4 ha had base saturation increased to 55% and the remaining 4 ha to 75%. The experimental design adopted was randomized blocks with eight repetitions in a factorial scheme (4 × 4 × 4), being four N doses, four P doses and four K doses. The base saturation was assessed through the block effect. The root collar diameter and the plant height were measured 12 months after planting. Each experimental plot comprised six plants. The root collar diameter showed statistical differences between blocks and N doses. Only the NPK association showed statistical variation in plant height. However, a growth decreasing trend resulting from increased N doses was observed, as well as a growth increasing trend resulting from increased P and K doses. All treatments favored African mahogany growth. The most indicated base saturation was 55%, since there was no plant growth improvement when V% was increased to 75%. The excess of N impaired the growth of the species. The best treatment comprised 60 g urea, 240 g triple superphosphate, and 168 g potassium chloride.

Keywords: plants' mineral nutrition, forest species, plant growth, hardwood

1. Introduction

Meliaceae is an important hardwood family, which comprises the most valuable tropical timbers in the world (Ravindran, 2018). Genera such as *Swietenia* sp., *Cedrella* sp., *Toona* sp., *Khaya* sp., among others, belong to this family. The restriction on the cutting and trade of timber derived from native trees resulted in the expanded cultivation of exotic tree species such as the African mahogany (Nikler et al., 2008; Karan et al., 2012).

Brazil has considerably grown despite the recent global economic crisis, and the forestry sector productive chain accounts for part of this growth. According to Associação Brasileira de Produtores de Florestas Plantadas (ABRAF), the total area planted with forests in Brazil was 7,185,943 ha in 2012 (ABRAF, 2013). In addition, the Brazilian forest product market accounted for US$ 7.54 billion of the national exports in that same year.

The depletion of native forests and the high demand for timber have sparked the interest of rural producers in investing in forest monoculture. According to Serviço Florestal Brasileiro (SFB) and Instituto de Pesquisa Ambiental da Amazônia (IPAM), the average demand for timber derived from native forests was estimated at 21 million m^3 $year^{-1}$ (SFB & IPAM, 2011). Thus, it would be necessary planting a 36 million ha area over a 30-year cycle in order to meet this demand.

The genus *Khaya* sp., which is popularly known as African mahogany, has been indicated for commercial plantations due to its excellent adaptation to the Brazilian edaphoclimatic conditions and to its high value in the international market (Ribeiro et al., 2016, 2017). Its wood shows reddish color and relatively-low density, which are features required by the furniture industry (Falesi & Baena, 1999; Nikler et al., 2008). In addition, it is highly resistant to *Hypsipyla grandella*, which is a pest species limiting the cultivation of *Swietenia macrophylla* King (popularly known as Brazilian mahogany) (Zanetti et al., 2017). *Khaya ivorensis* is one of the species reforesters seek the most. It grows up to 40 m^{-3} ha^{-1} $year^{-1}$ under favorable conditions, and the cubic meter of sawn timber may exceed US$ 2,000.00 (Lemmens, 2008). Given the productive potential of the African mahogany species in Brazil, it is necessary conducting studies in order to characterize and improve this species.

Fertilization is the most common and perhaps the most effective cultural practice used to improve the quality of forest species (Turner et al., 2018). According to Santana et al. (2002), setting economically viable forests requires knowing the sylvicultural practices to be adopted, in details. The climatic conditions in Brazil enable a long growing season, differently from temperate regions, where most of the agricultural technique recommendations used in the country come from. Accordingly, it is necessary “tropicalizing” these techniques, and this concept is perfectly suited to the use of fertilizers (Benites et al., 2010).

Thus, thinking that soil correction and fertilization have been widely studied is a very common mistake, since several practices need to be reviewed and adapted to each crop and soil type, mainly when it comes to forestry. The fertilization conducted according to the specific nutritional needs of the crop is able to provide increased timber productivity with reduced investment, as well as to cause minimum environmental impact (Moreno et al., 2017). Therefore, the aim of the present study was to assess the effect of base saturation, as well as of different nitrogen (N), phosphorus (P) and potassium (K) levels, on the initial growth of African mahogany (*Khaya ivorensis*) seedlings. It is believed that the current study may be useful to the practices to be adopted in the cultivation of the herein investigated species in Cerrado soils, since it is the first study assessing how nutritional aspects may influence the initial growth of an important forest species.

2. Material and Methods

2.1 Experimental Station

The present study was developed at Hiroshi Okajima Experimental Station, Bonfinópolis County, Goiás State, Brazil. The region is located at latitude 16°35′37.32″ South, longitude 49°1′56.13″ West, and altitude 780 m. According to the Köppen-Geiger’s classification, the climate in the region is Aw, tropical, megathermal, with summer rains and no winter. The mean temperature in the coldest month remains above 18 °C, whereas the annual rainfall is higher than the annual potential evapotranspiration.

The experiment was conducted in an 8-ha area, which had been previously used as pasture and showed 6% slope. The soil sampling was performed in the total area for chemical and textural analysis, before the experiment was conducted at the depths 0-20 cm and 20-40 cm (Table 1). The soil was classified as Dystrophic Red Latosol, with clay loam texture.

Table 1. Chemical attributes and soil texture resulting from the sample collected in the total area before the experiment and after the localized application of 600 kg ha^{-1} and 1800 kg ha^{-1} limestone, at the depths 0-20 cm and 20-40 cm, at Hiroshi Okajima Experimental Station, Bonfinópolis (GO, Brazil)

Attributes	Measurement units	0-20 cm	20-40 cm
Ca+Mg	cmol$_c$ dm^{-3}	2.2	1.1
Ca		1.7	0.8
Mg		0.5	0.3
Al		0.0	0.0
H+Al		2.9	3.0
K		0.1	0.06
CTC (T)		5.22	4.17
K	mg dm^{-3}	40.0	24
P (Mel)		1.3	1.7
S		2.0	2.0
Na		5.0	3.0
Zn		0.6	0.1
B		0.17	0.15
Cu		3.0	2.8
Fe		62.4	62.3
Mn		32.0	22.4
V	%	44.48	28.13
M		0	0
OM	g dm^{-3}	27.00	23.00
OC		15.66	13.34
Sand	g kg^{-1}	54	59
Silt		90	90
Clay		370	320
pH (CaCl)	5.2	5.1	

Note. V: base saturation. M: aluminum saturation. OM: organic matter. OC: organic carbon.

The area was divided in 8 blocks. The soil analysis results were used to calculate the amount of limestone required to increase the base saturation (V%) to 55% and 75%. Thus, 600 kg ha^{-1} of dolomitic limestone were applied and incorporated to blocks 1 to 4, whereas 1800 kg ha^{-1} of it were applied and incorporated to blocks 5 to 8, as shown in Figure 1. The entire area received 600 kg ha^{-1} gypsum; 500 kg ha^{-1} of reactive phosphate were applied to the planting rows during the subsoiling process.

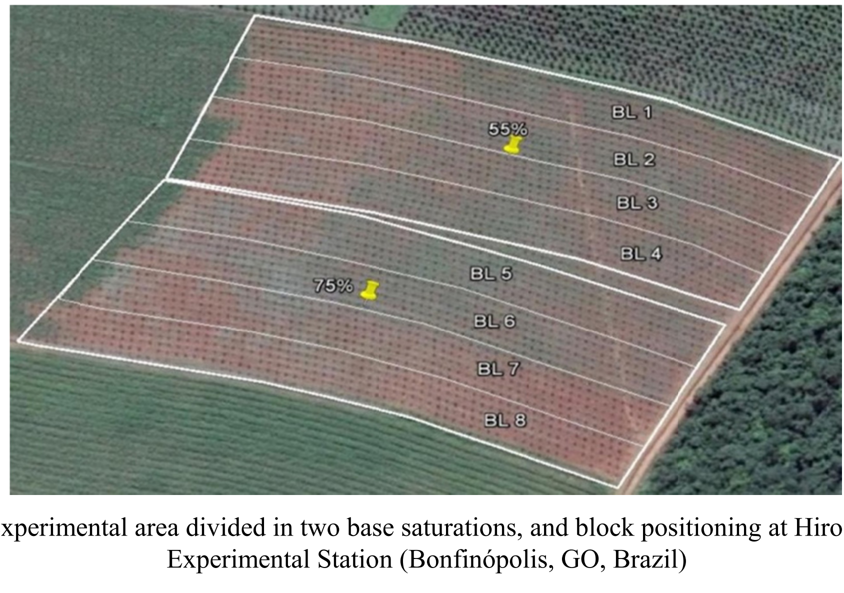

Figure 1. Experimental area divided in two base saturations, and block positioning at Hiroshi Okajima Experimental Station (Bonfinópolis, GO, Brazil)

Then, 3,120 African mahogany (*Khaya ivorensis* A. Chev.) seminal seedlings showing mean height 33 cm and root collar diameter of approximately 6 mm were planted. The herein adopted spacing was 5.0 × 5.0 m, and the density was 400 plants/hectare. Soon after planting, 20 grams of NPK (10-30-10 per plant) were applied to side pits. As the planting was carried out during the dry period (June 2013), it was necessary supplying water to the plants through a small water cart coupled to a tractor. Each plant received 10 L of water every three days, during the first month; the first three watering procedures used 250 g hydrogel/5000 L water. The plants received the same water volume once a week, between July and October. The watering was performed on a weekly basis, during the Indian summers, using 5 L of water per plant. New soil sampling was carried out during the rainy season in 2014 in order to assess the base saturation after the limestone application. The data are shown in Table 2.

Table 2. Soil analysis results after the localized application of 600kg ha^{-1} and 1800kg ha^{-1} limestone, at the depths 0-20 cm and 20-40 cm, at Hiroshi Okajima Experimental Station (Bonfinópolis, GO, Brazil)

Attributes	Measurement units	600 kg, Jan/14		1800 kg, Jan/14	
		0-20 cm	20-40 cm	0-20 cm	20-40 cm
Ca+Mg	cmol$_c$ dm^{-3}	3.4	2.90	6.30	5.20
Ca		2.5	2.1	4.4	3.8
Mg		0.9	0.8	1.9	1.4
Al		0	0.01	0	0
H+Al		2.8	2.4	2.1	2.5
K		0.13	0.11	0.15	0.13
CTC (T)		6.36	5.41	8.58	7.53
K	mg dm^{-3}	50	42	57	52
P (Mel)		2.1	3.4	2.4	1.8
S		3.4	-	7.1	-
Na		8	-	8	-
Zn		0.5	0.4	0.4	0.8
B		0.19	-	0.23	-
Cu		4	-	3.1	-
Fe		60.1	-	60.6	-
Mn		37.3	-	52.1	-
V	%	56.05	55.64	75.58	68.07
M		0.00	3.22	0	0
OM	g dm^{-3}	48	35	35	29
OC		27.84	20.3	20.3	16.82
Sand	g kg^{-1}	50.00	-	-	-
Silt		10	-	-	-
Clay		40	-	-	-
pH (CaCl)		5.20	4.9	5.8	5.5

Note. V: base saturation. M: aluminum saturation. OM: organic matter. OC: organic carbon.

2.2 Crop Handling

Periodic cleanings were conducted in the study area during the experiment. They consisted of two mechanical weeding procedures using a tractor pulling a harrowing grid between the rows. Chemical weeding's carried out between plants using glyphosate (3 L ha^{-1}) and flumizin (100 g ha^{-1}). The plants were subjected to manual weeding in an 80-cm radius from the stem, before each top-dressing fertilization. Pest monitoring was continuously carried out. Leaf-cutting ants were controlled by applying formicide bait and fipronil (80 g ha^{-1}). With respect to plants presenting lateral sprouting, the most rectilinear sprout was chosen and the others were removed using pruning shears.

2.3 Conducting the Experiment

The study was conducted in an African mahogany commercial forest, during the second implantation month. Treatments combining 4 nitrogen (N), 4 phosphorus (P), and 4 potassium (K) doses were set. There were 64 treatments, in total, according to the composition shown in Figure 2.

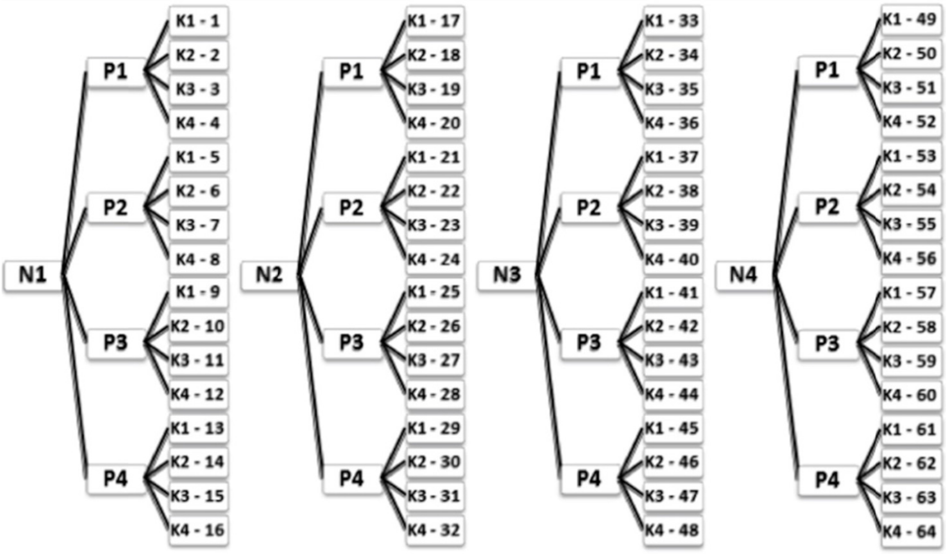

Figure 2. Composition of the treatments conducted according to the herein described factorial scheme, through the combination of nitrogen, phosphorus and potassium doses at Hiroshi Okajima Experimental Station (Bonfinópolis, GO, Brazil)

The experimental design followed randomized complete blocks; 4 blocks were allocated in the treated area to obtain 55% base saturation, whereas 4 blocks were allocated to obtain 75% base saturation. Each block was composed of 6 rows, with 11 plots each. The blocks were randomized through the drawing of plots within the block. The experiment comprised 512 experimental plots with 6 plants each. Concurrently, 6 non-fertilized plots were selected and subjected to the Tukey test in order to compare their means to the means of the other treatments.

Nitrogen, phosphorus and potassium were supplied to the plants through urea, triple superphosphate and potassium chloride. Sulfur, boron, manganese and zinc were supplied to the plants in each fertilization through FTE application at 5% the amount of NPK applied per plant. The fertilization was divided in 4 applications, one every two months, as described in Appendix 1.

The first fertilization was carried out in August/2015, when the plants had mean height 39.0 cm and root collar diameter 7.8 mm. The fertilizer was applied to two lateral pits 20 cm away from the plant stem and 15 cm deep; it was reapplied in October of the same year. The other fertilizations were carried out in December 2013 and in February 2014. As the amount of fertilizers was doubled, the application was carried out in two lateral furrows (30 cm long and 15 cm deep) 40 cm away from the plants.

The parameters assessed in the current study were seedling total height and root collar diameter. The assessments were carried out after each fertilization period. A measuring tape was used to measure plant height, whereas a digital caliper was used to collect the root collar diameter data. The plants' behavior towards different base saturations (V%) was assessed through the block effect.

2.4 Statistical Analyses

All data were initially subjected to the Anderson-Darling normality test, which was followed by the Levene variance homogeneity test. Next, the data were subjected to analysis of variance (ANOVA) according to the factorial model 4 × 4 × 4, using 4 nitrogen (N), 4 phosphorus (P) and 4 potassium (K) doses. The Tukey test was applied at 5% probability level in case of significant F. All analyses were performed in the Sanest software (Zonta & Machado, 1995).

3. Results and Discussion

Only the NPK interaction showed statistically significant difference in the variable "height", as shown in Appendix 2. The root collar diameter showed significant differences between N doses and between blocks. The large number of repetitions adopted in the current experiment and, consequently, the high degree of freedom of the residue allowed seeing small differences as statistically significant. On the other hand, the base saturation influence was assessed through the block effect. Table 5 shows the mean total height and root collar diameter of the plants belonging to each block.

Table 5. Mean height, mean root collar diameter and base saturation levels (V%) in each block planted with 12-month-old African mahogany (*Khaya ivorensis*) plants, at Hiroshi Okajima Experimental Station, Bonfinópolis (GO, Brazil). Means followed by equal letters in the column do not differ from each other, according to the Tukey test, at 5% probability level

Block (V%)	Height (cm)	Root collar diameter (mm)
1 (55%)	214.59 a	46.90 b
2 (55%)	218.92 a	49.91 a
3 (55%)	217.95 a	49.59 a
4 (55%)	217.17 a	50.11 a
5 (75%)	213.62 a	43.96 c
6 (75%)	215.96 a	46.44 b
7 (75%)	220.23 a	49.33 a
8 (75%)	217.68 a	51.10 a
Mean	217.30	48.32
CV (%)	6.92	8.02

There was no statistically significant difference in the variable "height" in plants subjected to different base saturation levels. However, the opposite occurred in the variable "root collar diameter". Thus, it is possible assuming that the difference found between blocks may be related to random factors rather than to the herein used treatments. The block design allows greater local control, since this design is appropriate to heterogeneous experimental environments if one wants to control a variation factor. The blocks allows isolating any necessary operational modification from the treatment effect. According to Moretti et al. (2011), the plant diameter development is strongly influenced by plant's genetics. As planting was carried out using seminal seedlings, this variable would not have been affected by treatments yet, as suggested in Table 6.

Table 6. Mean height and root collar diameter values of 12-month-old African mahogany (*Khaya ivorensis*) plants subjected to different liming and base saturation (V%) levels, at Hiroshi Okajima Experimental Station (Bonfinópolis, GO, Brazil)

Blocks	V%	Final V%		Heicht (cm)	Root collar diameter (mm)
		0-0.20 m	0.2-0.40 m		
01 to 04	55	56.05	55.64	216.2	48.9
05 to 08	75	75.58	68.07	216.6	47.6

It is possible seeing that the increased application of corrective agents did not lead to plant development during the first year in African mahogany plantations. Among the herein tested limestone doses, it is possible stating that 55% base saturation is the most economically indicated for *Khaya ivorensis* development.

According to Favare et al. (2012), liming positively affects the absorption of all macro and micronutrients, except for zinc. The accumulation of nutrients in the shoot of teak plants happens in the following decreasing order: N > Ca > K > Mg > P > S > Fe > Mn > B > Zn > Cu. The species development and nutrient accumulation apex lies between 60 and 80% base saturation. Silva et al. (2007) have analyzed maize (*Swietenia macrophylla*) seedlings subjected to increasing corrective agent doses and found that liming has positively affected N, P, K, Ca, Mg, Mn absorption, whereas it negatively affected Fe absorption.

On the other hand, Corcioli et al. (2014) have found that African mahogany plants grown in nutrient solution with N omission showed lower development, thin stem and small leaves. The 0 dose was not used, in compliance with the experimental data. All the tested doses showed satisfactory plant development, whereas none of the treatments showed visible deficiency symptoms.

The parameter "root collar diameter" showed statistically significant difference between the tested N doses. The treatments using the highest N doses have negatively influenced plant development, as shown in Table 7.

Although the statistical values did not show influence of the tested doses on plant height, the plant growth tended to decrease as the N doses increased. This effect can be seen in Figure 3A.

Table 7. Height and diameter of 12-month-old African mahogany (*Khaya ivorensis*) plants subjected to different nitrogen (N) doses, at Hiroshi Okajima Experimental Station (Bonfinópolis, GO, Brazil). Means followed by equal letters in the column do not differ from each other, according to the Tukey test, at 5% probability level

N Dose	Height (cm)	Root collar diameter (mm)
60	218.00 a	48.82 a
120	217.64 a	48.87 a
180	216.25 a	48.72 a
240	216.18 a	47.27 b
Control	162.87	36.09

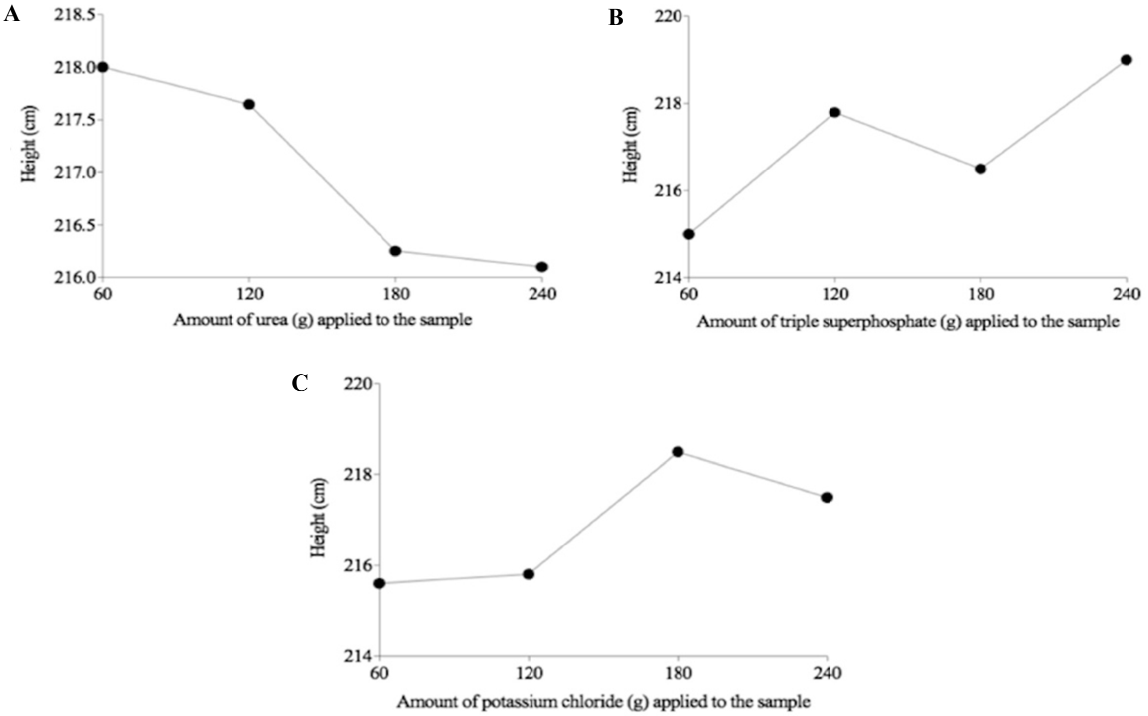

Figure 3. Influence of N (A), P (B) and K (C) doses on the growth of *Khaya ivorensis* plants during the first twelve months of cultivation at Hiroshi Okajima Experimental Station (Bonfinópolis, GO, Brazil)

The African mahogany (*K. ivorensis*) plants have demanded less nitrogen in the first development year; they have also shown tolerance to the excess of this nutrient in the crop. Despite the decreased growth resulting from the highest N doses, none of the plants showed toxicity symptoms. According to Ciriello et al. (2014), guanandi (Calophyllum brasiliensis) plants grew less as the N doses increased from 33 mg dm^{-3} on. Each 40 mg dm^{-3} of N added to the plants led to 2.9 mm reduction in stem diameter.

As per Tucci et al. (2009), nitrogen fertilization has positively influenced the growth of *S. macrophylla* plants. However, the maximum applied dose (240 kg t^{-1} of substrate) had negative effect on stem diameter and on shoot dry matter, thus impairing seedling quality; therefore, it is possible suggesting that the recommended N dose is 57.5 kg per ton of substrate. Tucci and Pinto (2003) have also found negative influence of high N doses on the growth of Brazilian mahogany seedlings.

According to Souza et al. (2010), nitrogen did not affect the initial growth of Brazilian mahogany plants. The justification presented was that the organic matter in the soil may have supplied enough N to the species through the mineralization process. Similarly, Feitosa et al. (2011) have tested different ammonium sulfate, ammonium nitrate and calcium nitrate doses in *Astronium fraxinifolium* plants and found that the N source did not influence the initial plant development. However, the plant growth decreased when the N doses exceeded 75 mg dm^{-3}. On the other hand, according to Mews et al. (2015), nitrogen fertilization has positively influenced the growth of yellow ipê (*Handroanthus ochraceus*) seedlings. Therefore, these data suggest that an adequate nitrogen nutrition improves the N and P leaf contents in the studied species, thus increasing plant growth and producing quality seedlings.

It is consensus that phosphorus is a determinant element in plant growth. According to Souza et al. (2012), this nutrient is considerably important to carbon metabolism, as well as to the formation of phosphate sugars. However, despite the significant importance of phosphorus to different crops, the doses tested in the current study did not influence the height and root collar diameter increase in *Khaya ivorensis* plants. Table 8 shows the mean values of the treatments using different phosphorus doses. Unlike what was observed in the nitrogen fertilization, the highest phosphorus doses tended to result in taller plants, as shown in Figure 3B.

Table 8. Height and diameter of 12-old-month African mahogany (*Khaya ivorensis*) plants subjected to different phosphorus (P) doses, at Hiroshi Okajima Experimental Station (Bonfinópolis, GO, Brazil). Means followed by equal letters in the column do not differ from each other, according to the Tukey test, at 5% probability level

P Dose	Height (cm)	Root collar diameter (mm)
60	215.00 a	47.61 a
120	217.68 a	48.76 a
180	216.64 a	48.52 a
240	218.75 a	48.78 a

The current data are similar to those found by Santin et al. (2013), who studied the nutrition of yerba mate (Ilex paraguariensis) plants and found the same responses regardless of the tested doses. However, it was possible stating that the species grows in soils showing high P content, since it did not show toxicity symptoms resulting from this nutrient.

However, previous studies have found discrepant results regarding the effects of different phosphorus doses on the development of some forest species. According to Tucci et al. (2011), phosphorus addition to the substrate of Brazilian mahogany seedlings did not help increasing biometric parameters, fact that suggests the low potential of the species to respond to P addition during the growth phase. On the other hand, Santos et al. (2008) have applied increasing phosphorus doses to Brazilian mahogany seedlings and found seedling growth increase in all assessed traits (plant height, stem diameter). A study conducted by Moretti et al. (2011) found that phosphorus omission has limited the growth of Australian cedar (*T. cilliata)* plants. The same result was found by Ciriello et al. (2014) in studies conducted with guanandi (*Calophyllum brasiliensis*) plants; it was evident that P was the most important nutrient for the species' root development.

According to Corcioli et al. (2014), African mahogany plants tend to show total growth reduction, as well as reduced leaf-size, when they face lack of potassium. The authors could find chlorosis, which was followed by necrosis in the tips and margins of old leaves.

The potassium doses used in the current study did not lead to statistically significant differences in the assessed biometric parameters. However, it is possible stating that African mahogany plants develop well when they are subjected to small amounts of potassium, as well as that they are quite tolerant to the excess of this nutrient, as shown in Table 9.

Table 9. Height and diameter of 12-month-old African mahogany (*Khaya ivorensis*) plants subjected to different potassium (K) doses, at Hiroshi Okajima Experimental Station, Bonfinópolis (GO, Brazil). Means followed by equal letters in the column do not differ from each other, according to the Tukey test, at 5% probability level

K Dose	Height (cm)	Root collar diameter (mm)
42	215.85 a	47.81 a
84	215.98 a	48.34 a
126	218.76 a	48.88 a
168	217.48 a	48.65 a

Plants subjected to the highest potassium doses tended to show better results, which was similar to their response to phosphorus and different from their response to nitrogen (Figure 3C). This result may be explained through the regulation of the African mahogany plant osmotic potential, which reduced the water stress effect during the dry period and during the intense Indian summers in the experimental period.

Finally, the means of each N-P-K combination were subjected to the Tukey test in order to assess the best fertilization to be applied to African mahogany (*Khaya ivorensis*) plants in the first cultivation year; the test considered each dose combination as an isolated treatment. Appendix 3 summarizes the results of the analysis of variance.

The parameter "plant height" showed significant difference between all treatments, whereas the parameter "root collar diameter" showed differences between the treatments and the control, only (Table 11).

Table 11. Comparison between mean diameter and height of 12-month-old African mahogany (*Khaya ivorensis*) plants subjected to NPK fertilization at Hiroshi Okajima Experimental Station (Bonfinópolis, GO, Brazil). Means followed by the same letters in the column do not differ from each other, according to the Tukey test, at 5% probability level

Treatment	NPK combination	Height (cm)		Root collar diameter (mm)	
0	0	162.87	c	36.09	b
1	111	207.87	b	48.20	a
2	112	209.75	ab	47.35	a
3	113	211.00	ab	49.52	a
4	114	215.87	ab	49.10	a
5	121	221.25	ab	48.64	a
6	122	221.87	ab	50.53	a
7	123	218.00	ab	48.93	a
8	124	211.75	ab	46.53	a
9	131	214.37	ab	47.53	a
10	132	218.62	ab	47.37	a
11	133	209.75	ab	48.47	a
12	134	225.50	ab	48.64	a
13	141	220.37	ab	50.92	a
14	142	220.37	ab	48.05	a
15	143	225.00	ab	49.87	a
16	144	236.87	a	51.50	a
17	211	220.50	ab	45.54	a
18	212	220.87	ab	48.99	a
19	213	222.00	ab	48.30	a
20	214	214.00	ab	46.80	a
21	221	226.25	ab	48.84	a
22	222	222.12	ab	51.07	a
23	223	212.75	ab	49.35	a
24	224	219.00	ab	49.18	a
25	231	205.25	b	48.04	a
26	232	217.62	ab	49.23	a
27	233	214.87	ab	50.18	a
28	234	221.75	ab	49.43	a
29	241	223.12	ab	49.78	a
30	242	212.25	ab	49.05	a
31	243	218.50	ab	49.41	a
32	244	224.00	ab	51.65	a
33	311	210.00	ab	46.14	a
34	312	220.50	ab	49.67	a

35	313	218.50	ab	48.69	a
36	314	217.25	ab	46.92	a
37	321	216.12	ab	49.80	a
38	322	209.62	ab	46.55	a
39	323	213.12	ab	48.63	a
40	324	221.25	ab	51.25	a
41	331	220.50	ab	48.33	a
42	332	205.00	b	47.20	a
43	333	230.12	ab	49.85	a
44	334	209.50	ab	50.00	a
45	341	207.37	b	47.06	a
46	342	216.37	ab	48.75	a
47	343	231.37	ab	50.03	a
48	344	213.50	ab	49.32	a
49	411	223.00	ab	46.55	a
50	412	205.37	b	47.16	a
51	413	215.25	ab	46.12	a
52	414	220.87	ab	46.98	a
53	421	215.37	ab	47.83	a
54	422	221.50	ab	47.07	a
55	423	224.62	ab	49.73	a
56	424	208.62	b	46.64	a
57	431	211.00	ab	47.33	a
58	432	221.25	ab	48.06	a
59	433	219.62	ab	47.91	a
60	434	224.00	ab	48.56	a
61	441	211.37	ab	44.42	a
62	442	215.37	ab	47.12	a
63	443	216.00	ab	47.25	a
64	444	208.50	b	47.51	A
CV (%)	6.80				

All the herein tested treatments showed better biometric parameters than the control. Treatment 16 (1-4-4) showed the best plant height results. The worse results were found in treatments 1, 25, 42, 45, 50, 56 and 64, which used high N doses and/or low P and/or K doses. These results corroborate the trends shown in Figures 4, 5 and 6.

According to Souza et al. (2006), forest species showed different behavioral features in response to fertilization. However, studies about the nutrition of *Khaya ivorensis* species remain incipient, fact that makes it difficult to compare results. Thus, it is worth continuing the current research, as well as conducting new studies about such species.

4. Conclusion

Based on the herein found results and according to the experimental conditions, it can be concluded that: 1) Liming and mineral fertilization are essential to the development of African mahogany plants; 2) The 55% base saturation increase is satisfactory for the development of *Khaya ivorensis* plants; 3) The studied species is able to develop when it is subjected to small amounts of fertilizers and it is very tolerant to the excess of nutrients; 4) Among the herein studied macronutrients, only the excess of N has negatively influenced the plant growth. However, the crop showed no significant losses up to the herein tested limit; 5) Finally, the best treatment was the one that used the minimum N dose along with the maximum P and K doses.

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Appendix

Appendix 1. Urea, triple superphosphate and potassium chloride amounts applied to each lot and total amount used per treatment, at Hiroshi Okajima Experimental Station (Bonfinópolis, GO, Brazil)

Treatment	Urea			Triple Superphosphate			Potassium Chloride		
	Application		Total	Application		Total	Application		Total
	1 and 2	3 and 4		1 and 2	3 and 4		1 and 2	3 and 4	
	g								
1	0	0	0	0	0	0	0	0	0
2	10	20	60	10	20	60	7	14	42
3	10	20	60	10	20	60	14	28	84
4	10	20	60	10	20	60	21	42	126
5	10	20	60	10	20	60	28	56	168
6	10	20	60	20	40	120	7	14	42
7	10	20	60	20	40	120	14	28	84
8	10	20	60	20	40	120	21	42	126
9	10	20	60	20	40	120	28	56	168
10	10	20	60	30	60	180	7	14	42
11	10	20	60	30	60	180	14	28	84
12	10	20	60	30	60	180	21	42	126
13	10	20	60	30	60	180	28	56	168
14	10	20	60	40	80	240	7	14	42
15	10	20	60	40	80	240	14	28	84
16	10	20	60	40	80	240	21	42	126
17	10	20	60	40	80	240	28	56	168
18	20	40	120	10	20	60	7	14	42
19	20	40	120	10	20	60	14	28	84
20	20	40	120	10	20	60	21	42	126
21	20	40	120	10	20	60	28	56	168
22	20	40	120	20	40	120	7	14	42
23	20	40	120	20	40	120	14	28	84
24	20	40	120	20	40	120	21	42	126
25	20	40	120	20	40	120	28	56	168
26	20	40	120	30	60	180	7	14	42
27	20	40	120	30	60	180	14	28	84
28	20	40	120	30	60	180	21	42	126
29	20	40	120	30	60	180	28	56	168
30	20	40	120	40	80	240	7	14	42
31	20	40	120	40	80	240	14	28	84
32	20	40	120	40	80	240	21	42	126
33	20	40	120	40	80	240	28	56	168
34	30	60	180	10	20	60	7	14	42
35	30	60	180	10	20	60	14	28	84
36	30	60	180	10	20	60	21	42	126
37	30	60	180	10	20	60	28	56	168
38	30	60	180	20	40	120	7	14	42
39	30	60	180	20	40	120	14	28	84
40	30	60	180	20	40	120	21	42	126
41	30	60	180	20	40	120	28	56	168
42	30	60	180	30	60	180	7	14	42
43	30	60	180	30	60	180	14	28	84
44	30	60	180	30	60	180	21	42	126
45	30	60	180	30	60	180	28	56	168
46	30	60	180	40	80	240	7	14	42
47	30	60	180	40	80	240	14	28	84
48	30	60	180	40	80	240	21	42	126
49	30	60	180	40	80	240	28	56	168

50	40	80	240	10	20	60	7	14	42
51	40	80	240	10	20	60	14	28	84
52	40	80	240	10	20	60	21	42	126
53	40	80	240	10	20	60	28	56	168
54	40	80	240	20	40	120	7	14	42
55	40	80	240	20	40	120	14	28	84
56	40	80	240	20	40	120	21	42	126
57	40	80	240	20	40	120	28	56	168
58	40	80	240	30	60	180	7	14	42
59	40	80	240	30	60	180	14	28	84
60	40	80	240	30	60	180	21	42	126
61	40	80	240	30	60	180	28	56	168
62	40	80	240	40	80	240	7	14	42
63	40	80	240	40	80	240	14	28	84
64	40	80	240	40	80	240	21	42	126
	40	80	240	40	80	240	28	56	168

Appendix 2. Summary of variance analysis showing the degrees of freedom (DF), mean square (MS), significance level and coefficient of variation for variables such as height (h) and root collar diameter (rcd) according to N, P and K doses applied to African mahogany (Khaya ivorensis) plants grown at Hiroshi Okajima Experimental Station (Bonfinópolis, GO, Brazil)

Variation source	DF	MSh	MSrcd
N	3	112.18^{ns}	76.20*
P	3	326.75^{ns}	39.01^{ns}
K	3	242.44^{ns}	27.52^{ns}
NP	9	410.88^{ns}	19.45^{ns}
NK	9	311.58^{ns}	4.55^{ns}
PK	9	229.83^{ns}	10.05^{ns}
NPK	27	481.64**	15.63^{ns}
Block	7	307.15^{ns}	371.24**
Residue	441	225.32	15.06
Total	511		
CV%		6.92	8.02

Note. ^{ns}: non-significant according to the Tukey test, at 5% probability level; *: significant according to the Tukey test, at 5% probability level; **: significant according to the Tukey test, at 1% probability level.

Appendix 3. Summary of variance analysis showing the degrees of freedom (DF), mean square (MS), significance level and coefficient of variation for variables such as height (h) and root collar diameter (rcd) according to the NPK fertilization treatments conducted at Hiroshi Okajima Experimental Station (Bonfinópolis, GO, Brazil)

Variation source	DF	MSh	MSrcd
Treatment	64	705.7889**	36.8516**
Block	7	315.1228^{ns}	369.9585**
Residue	448	215.7344	15.6099
Total	519		
CV%		6.80%	8.19%

Note. ^{ns}: non-significant according to the Tukey test, at 5% probability level; **: significant according to the Tukey test, at 1% probability level.

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