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INITIAL FERTILIZATION FOR SEEDLING FORMATIONS OF *Khaya senegalensis* (desr.) A. JUSS. IN NURSERY

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Abstract: The objective of the study was to evaluate the effect of increasing doses of NPK on the initial development of *Khaya senegalensis* in nursery, aiming to define the ideal dosage of application for the formation of quality seedlings of this species. The plants were cultivated on a substrate of Red Yellow Latosol, with five levels of NPK (0, 0.5, 1.0, 1.5 and 2.0 g per seedling). The treatments were distributed in a completely randomized design with ten replicates. It was observed that *Khaya senegalensis* is little influenced by the supply of increasing doses of NPK. 1.56 g was the most indicated dosage for its fertilization in nursery.
Keywords: Seedling quality; African mahogany; plant nutrition

INTRODUCTION

In recent years, there has been a large increase in forestry areas in Brazil, contributing to the economy of the country and society in general, since the forest sector cooperates with the generation of products, taxes, jobs and income, collaborating with the quality of life. This is not only a source of strategic supply of raw materials, but also contributes to the conservation of nature, reducing the pressure on native forests in the supply of products and mitigating the negative effects of global warming (Grupioni et al., 2018; Silva & Dias, 2016).

With the increasing demand of the population for forest products, and as a result of the environmental degradation resulting from the disorderly extraction of native species from several biomes, together with the commercial value of wood, the cultivation of exotic species such as *Khaya senegalensis* (Desr.) A. JUSS, popularly known as African mahogany, has increased significantly in Brazil (Pereira et al., 2019; Santos et al., 2018).

Mahogany of African origin is becoming a very important species, used as an alternative to Brazilian mahogany (*Swietenia macrophylla King.*), due to the susceptibility of this species to the attack of *Hypsipyla grandella Zelle* (Ribeiro et al., 2016). In this way, species of the genus *Khaya spp*., an important alternative for the development of forest plantations that supply noble wood, promote the country's economy (Ribeiro et al., 2017; Ribeiro et al., 2018).

However, for the establishment of productive forest stands, factors such as quality seeds, well-nourished seedlings to be planted in the field and their constant maintenance should be considered. One of the difficulties found for the production of seedlings is the determination of the ideal fertilization for each species. Corcioli et al. (2016) state that the correct supply of nutrients is one of the main factors contributing to the growth and adequate development of the forest essences.

The understanding of the nutritional requirements of the species is of great importance for adequate recommendation of fertilization, maximizing its efficiency and reducing environmental damage that may occur with applications that do not meet or exceed the needs of the plants, in order to guarantee sufficient nutritional contents for the growth of the seedlings (Andrade et al., 2018; Gonçalves et al., 2014).

Knowledge about nutritional requirements in the initial phase of African mahogany in the nursery is scarce, as well as information on its silvicultural behavior. Thus, this study aimed to evaluate the growth response in a *Khaya senegalensis* nursery to increasing doses of NPK fertilizer, to define the appropriate application dosage for the formation of quality seedlings.

MATERIALS AND METHODS

The experiment was conducted in the experimental area of the Forest Nursery of the Federal University of Tocantins (UFT), Gurupi Campus, from October 2014 to February 2015. The altitude of the experimental area was 280 m, latitude 11º43'45" S and longitude 49º04'07" W. According to Köppen, the climatic classification of the area is BlwA'a, moist with moderate water deficiency (Kriticos et al., 2012). The average annual temperature is 29.5°C, with an annual average rainfall of 1804 mm, and with a rainy summer and a dry winter.

The material used as substrate was collected in the subsurface layer (10 to 20 cm) of a medium-textured Red Yellow Latosol (EMBRAPA, 1999), located at the University Campus of Gurupi. The soil was dewormed, dried outdoors and passed through a 4 mm aperture mesh sieve.

Liming was done to correct the soil acidity at 0.5 t/ha or 0.250 kg limestone with 100% PRNT for every 1000 kg of substrate. The substrate was incubated for 30 days for its dissociation and for the limestone to react with the soil. After this period, a sample was taken for chemical and textural analyses of the soil (Table 1).

The five treatments consisted of increasing doses of NPK nutrients, in a 1, 3.5 and 2 proportion respectively, based on the 0.5 g orientation by Pinheiro et al. (2011) of NPK 4-14-8 per seedling (Table 2). The treatments were distributed in a completely randomized design with ten replicates. Each experimental unit (plastic bag) was constituted by a plant and its respective treatment. The doses were solubilized in distilled water, incorporated into the soil and conditioned in plastic bags with a diameter of 20 cm and height of 30 cm (9.42 dm^3).

The seeds used for the production of the seedlings were purchased from a private company. They were seeded in sand with the yarn positioned downwards, burying only half of the seed, and then irrigated daily. Twenty days after sowing, seedlings with

pH $CaCl_2$	H+Al	Al	Ca	Mg	T	t	SB	K	P	Fe	Cu	Mn	Zn
			$cmol_c\ dm^{-3}$							mg dm^{-3}			
6,4	1,20	0,0	1,9	1,0	4,37	3,17	3,17	104	1,7	11	0,5	0,8	0,3

m	V	O.M	O.C	Clay	Silt	Sand
	%				g kg^{-1}	
0	72	1,5	0,9	298	50	652

T: Cation exchange capacity; t: Effective cation exchange capacity; SB: sum of the bases; O.M: organic matter; O.C: organic carbon e V: saturation bases

Table 1. Chemical and physical characteristics of the substrate used for seedling production of Khaya senegalensis

Treatament	(mg)				
	N	P_2O_5	K_2O	Ca	S
T0	0	0	0	0	0
T1	20	70	40	50	40
T2	40	140	80	100	80
T3	60	210	120	150	120
T4	80	280	160	200	160

Table 2. Amount of nutrients added per treatment

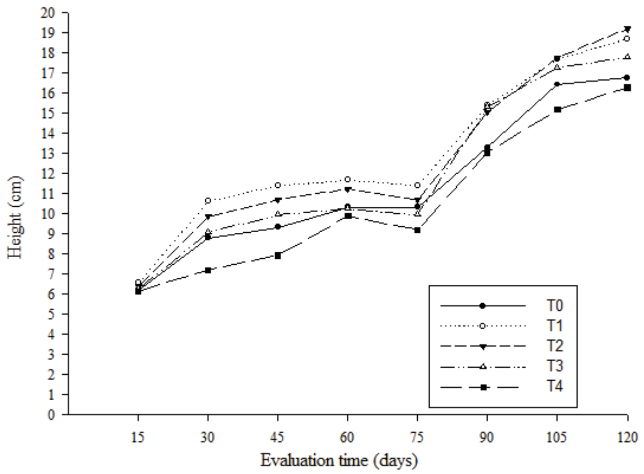

Figure 1. Average height and seedlings of *K. senegalensis*, depending on the doses of nutrients provided, in relation to the evaluation time

good phytosanitary aspects and with a height between 4 and 6 cm were selected. After the selection, the seedlings were transplanted into plastic bags containing the different treatments, irrigated daily at the end of the afternoon and kept in a screened nursery (50% sombre). No cover fertilization nor pest and disease control were performed.

The plant height (H) and neck diameter (D) evaluations were done at 15, 30, 45, 60, 75, 90, 105 and 120 days after transplanting of the seedlings. A graduated ruler was used to measure the height of the plant, from the base to the apical bud (cm). The neck diameter was obtained through a digital caliper (mm).

At the end of the experiment period (120 days), aerial part dry mass (APDM), root dry mass (RDM) and total dry mass (TDM), ratio of shoot height/lap diameter (H/D) and the Dickson quality index proposed by Dickson (DQI) were calculated.

The substrate adhered to the roots was removed with weak water jets, using a 2 mm sieve in order to avoid root loss. To determine the weight of dry matter, the roots were separated from the aerial part, washed and then packed in properly identified paper bags and placed to dry in a forced ventilation oven at a temperature of 60°C until obtaining constant weight with a precision scale of 0.01 g.

Based on data gathered, the Dickson Quality Index (DQI) was calculated with the following equation (Dickson et al., 1960):

$$DQI = \frac{TDM}{\left(\frac{H}{D}\right) + \left(\frac{APDM}{RDM}\right)}$$

Where: DQI - Dickson Quality Index; TDM - total dry mass (g); H - height (cm); D - neck diameter (mm); APDM - aerial part dry mass (g); RDM - root dry mass (g).

Subsequently, the dry of the aerial part and of the roots was milled and submitted to analysis to determine the nutritional composition of the plants. The N content was obtained by digestion in sulfuric acid and the contents of P, K, Ca, Mg and S were obtained by perchloric nitro digestion.

The data of the variables obtained in the evaluations were evaluated for homoscedasticity and normal distribution of residues using the Hartley and Shapiro-Wilk test respectively, with a 5% significance. When non-parametric, the data were transformed with a Box-Cox test. The regression analyses were chosen based on the significance of the coefficients of the regression equation (r^2), using the SigmaPlot 10 program. For the determination of the doses corresponding to the points of maximum growth of the quadratic functions, its first derivative was equal to zero.

Based on the amount of nutrients that were added in what was extracted from the African mahogany seedlings, and considering what was already in the soil, the fertilization efficiency was calculated for the recommendation of the appropriate nutrient doses for seedlings of *Khaya senegalensis*.

RESULTS AND DISCUSSION

Regarding height, from days 15 to 90 of evaluation, the highest means were presented in T1 treatment. In the following evaluations, it was noticed that the highest means occurred in T2 treatment, reaching 19.2 cm in the first 120 days (Figure 1). The highest growth in height of the T1-treated plants in the first months can be explained by the fact that the smaller amount of nutrients provided could meet the nutritional needs of the species. Over time and with growth, this dose was not enough, and the seedlings required larger amounts of nutrients.

In a study conducted with Australian cedar (*Toona ciliata* M. Roemer var. Australis), Marco et al. (2013) observed that as the percentage of NPK increased, there were larger increases in the height of the species. However, these authors failed to observe an optimum NPK fertilization point for the species, since as the dose tested increased, the growth in height also increased.

Evaluating the effect of nutrient solution on two African mahogany species, Alves et al. (2016), at 150 days after transplanting, found that the seedlings of *Khaya senegalensis* presented a mean height of 75 cm and the seedlings of *Khaya ivorensis A, Chev.* reached a mean height of 55 cm.

There was a negative effect on this variable in the T4 treatment, since the treatment without addition of nutrients evidenced higher growth averages when compared to this treatment, suggesting that this quantity could compromise the growth of the species in the same way as the lack of nutrients. From days 60 and 75 of evaluation, there was a stagnation of growth (Figure 1). In relation to the lower growth in height in T4 treatment, the appearance of *Cercospora spp.* in the leaves of *Khaya senegalensis* can be related, considering that this fungus affects all the shoot of the plant, being able to diminish the growth rate in height of the seedlings in this period.

For the diameter variable, in day 15, the T4 treatment presented the highest mean values. In days 30 and 45, the diameter showed higher results for the T1 treatment and, in day 60, the T3 treatment was the one that expressed the largest diameter increments (Figure 2). In day 120, maximum growth was reached with a dose of 131.63 mg NPK dm^{-3} substrate. These results showed that, similar to what happened to the height variable, the growth of the seedling implies higher nutritional requirements.

All the evaluated treatments exceeded the evidence, treatment T0. Treatment T3 proved to be the one which provided greater increases in diameter in 60 days of evaluation (Figure 2). Regarding the diameter, it was possible to show that this parameter had a higher correlation with the available nutrient doses than height.

Marco et al. (2013) observed a positive response of the diameter of the *Toona ciliata* seedlings at the highest doses of NPK (09-33-12), with maximum efficiency at the dose of 7300 mg dm^{-3} of substrate.

For forest species, Gomes & Paiva (2011) consider that the quality seedling should have a height between 20 and 35 cm and a neck diameter between 5 and 10 mm. The height variable, at 120 days after transplanting, did not reach the lower limit proposed by the author, with the diameter of the collar reaching the suggested minimum value in day 90 of evaluation, except for the T0 (control) treatment, which only reached this limit in day 105 after transplanting. It was demonstrated that the diameter variable was more influenced by higher availability of nutrients, since the treatment without addition of NPK took longer to reach the minimum diameter needed to be considered a quality seedling.

Different results were found by Alves et al. (2016). When using a nutrient solution, *Khaya senegalensis* seedlings reached quality aspects in day 60 after transplanting, with a height of 24 cm and a diameter of 7 mm, and *Khaya ivorensis* seedlings showed a desired pattern in day 90 after transplanting, with a height of 28 cm and a neck diameter of 5.5 mm.

For the H/D variable, averages ranging from 2.28 to 2.64 were found (Figure 3). These values show that the seedlings grew little in height and, in contrast, reached a great size in diameter, presenting maximum growth between treatments 1 and 2, at the equivalent point to 75.37 mg NPK dm^{-3} of substrate.

The ratio of H/D should be intermediate, and in cases of large variation, the lowest values are preferred, choosing the most resistant seedlings, because the lower the quotient obtained by the H/D ratio, the more

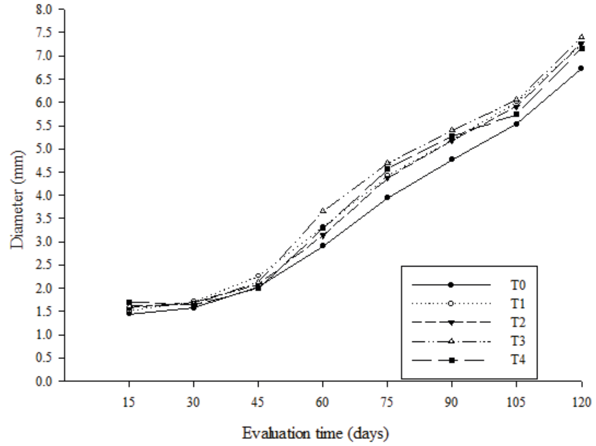

Figure 2. Average seedlings diameter of *K. senegalensis*, depending on the doses of nutrients provided, in relation to the evaluation time

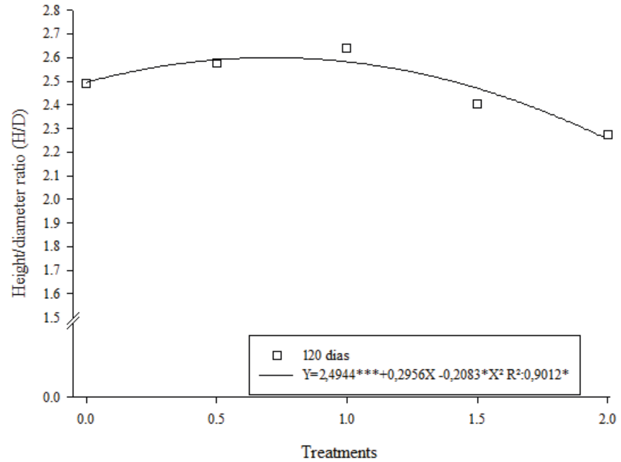

Figure 3. Height/diameter relationship at 120 days of seedling evaluation of *K. senegalensis* as a function of the doses of nutrients provided

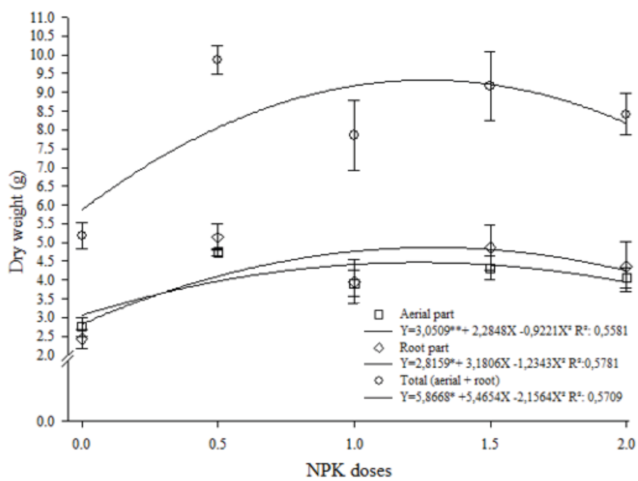

Figure 4. Dry mass of aerial, root and total seedlings of K. senegalensis as a function of nutrient doses supplied

rustified will be the seedling and the greater the chance of survival and establishment at the definitive site (Gomes & Paiva, 2011). In the treatments using nutritive solution, Alves et al. (2016) found lower values of H/D for *Khaya senegalensis* and *Khaya ivorensis* in day 140 of evaluation, when compared to treatments without nutritive solution.

The dry weight of aerial part and root reached peak growth point with 131.63 and 136.94 mg of NPK per dm^{-3} of substrate, respectively. The lowest dry weight means were observed in the T0 treatment, without addition of NPK (Figure 4).

The addition of NPK to the dose of 134.81 mg of NPK per dm^{-3} of substrate, point of maximum growth for total dry weight, was considered favorable, providing the formation of seedlings with greater rusticity.

The root dry weight has been recognized as one of the best and most important variables to estimate the survival and initial growth of the seedlings in the field, emphasizing that the survival is greater the more abundant the root system, with a small correlation with the height of the aerial part (Gomes & Paiva, 2011).

Marco et al. (2013) observed a quadratic response of the root dry mass of the *Toona ciliata* seedlings, with a dose of 5500 mg dm-3 of substrate, which provided the highest weight of this variable. Alves et al. (2016) observed a higher dry weight increase in the species *Khaya senegalensis* and *Khaya ivorensis* when they received complete nutrient solution (64.67 and 32.48, respectively) in comparison to the plants that did not receive this solution (33.81 and 30.75, respectively).

For the evaluation of the quality of the seedlings, it is recommended to use several parameters, since the determination of isolated indices may not adequately assess their quality. The Dickson Quality Index (DQI) is indicated as an effective indicator of the quality of seedlings considering the robustness and the balance of biomass distribution in its calculation (Gomes & Paiva, 2011).

In relation to DQI, the higher the value, the better quality will be the seedling produced (Silva et al., 2013). Gomes & Paiva (2011) considers the minimum value of 0.20 for a seedling to present an ideal quality standard. It was observed that the seedlings of all treatments evaluated in the present study had good quality indexes, with DQI values always above 0.20 (Figure 5).

The lowest DQI mean was found in the T0 treatment, without addition of nutrients (Figure 5), evidencing the importance of fertilization for the production of African mahogany seedlings with better quality. DQI of 0.36 was reached at the peak of 171.97 mg of NPK per dm^{-3} of substrate.

Regarding quantification of nutrients, a higher accumulation of all the macronutrients was mostly observed in the aerial part than in the roots, indicating a high redistribution of these nutrients to the aerial part (Figures 6 and 7). This may be related to the phenological stage of the plant, which is in initial growth. Considering that the roots translocate the nutrients to the aerial part, aiming at its expansion.

The highest nutrient contents in the seedlings were in the following decreasing order: potassium, nitrogen, calcium, magnesium, and phosphorus and sulfur (Figures 6 and 7). When evaluating the omission of macronutrients in the development of African mahogany seedlings (*Khaya anthotheca* (Welw.) C. DC.) and considering the concentrations in the seedlings of the species in complete solution, Vieira et al. (2014) found that the requirement in its initial phase of growth was: N > S > K > P > Mg > Ca.

Response curves of nitrogen and potassium showed similar behavior in the aerial part,

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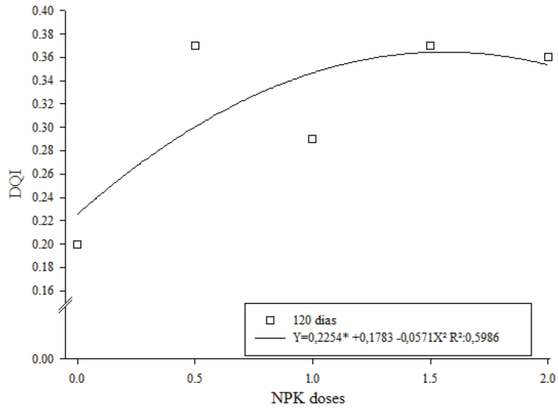

Figure 5. Concentration of nutrients in the aerial part of K. senegalensis seedlings as a function of different nutrient doses

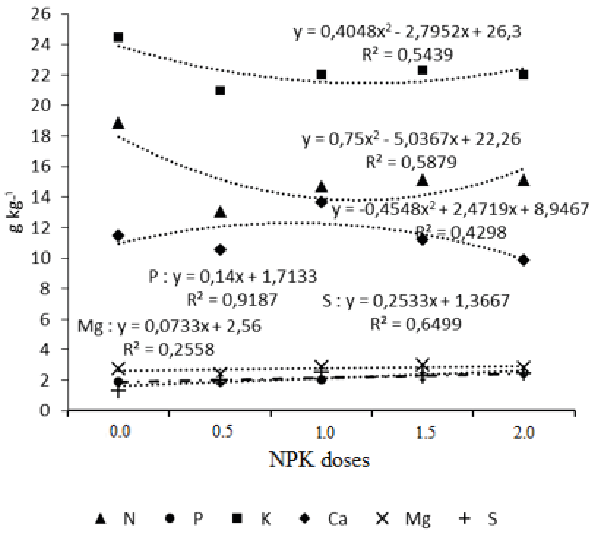

Figure 6. Concentration of nutrients in the roots of seedlings of *K. senegalensis* as a function of different doses of nutrients

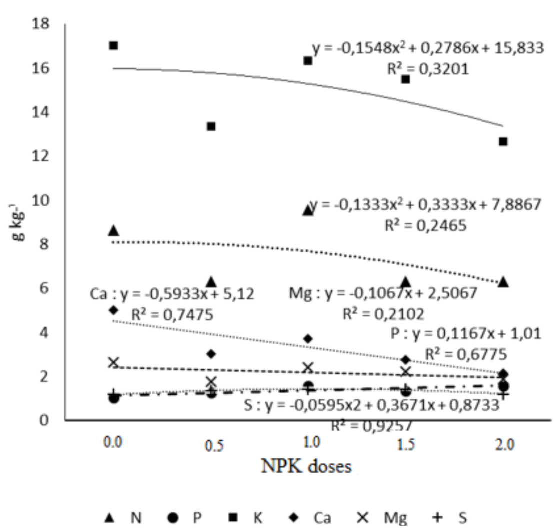

Figure 7. Seedling quality index proposed by Dickson (DQI) for seedlings of *K. senegalensis* as a function of the doses of nutrients provided

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while the calcium curve showed an inverse relationship between them (Figures 6). This fact can be explained by the relationship between nutrients, where nitrogen and potassium are synergistic, and the greater absorption of one increases the absorption of the other; in contrast, potassium and calcium can be antagonistic, competing for active sites, so that the increase in the concentration of one of these elements in the medium implies the decrease of the absorption of the other (Malavolta et al., 1997).

Nitrogen is an integral element of nucleic acids and chlorophyll, and the leaf is the organ of the plant with the greatest amount of these constituents, favoring the highest concentration (Malavolta, 1997). Alves et al. (2016) found the highest concentrations of N in the aerial part for the species *Khaya senegalensis* and *Khaya ivorensis*, indicating high mobility of this nutrient.

The concentrations of foliar nitrogen considered adequate for forest essences vary from 12 to 35 g kg^{-1} (Malavolta et al., 1997). Thus, in all treatments evaluated in the present study, concentrations are within this range (Figure 6). According to Corcioli et al. (2014), *Khaya ivorensis* plants cultivated in nutrient solution with N omission presented inferior development, fine stem and small leaves, thus evidencing the great importance of this nutrient for the development of seedlings of forest species of the genus *Khaya spp*.

The potassium concentration was observed above the upper limit suggested by Malavolta et al. (1997), which is between 10 and 15 g kg^{-1} for most forest essences (Figure 5). This nutrient participates in the mechanism of opening and closing stomata and osmoregulation, among other processes, which also helps explain the higher concentration of these nutrients in the leaves (Taiz & Zeiger, 2013).

In the present study, the higher the dose of NPK applied, the higher the concentration of these macronutrients on aerial part and roots. Tucci et al. (2011), when evaluating the effect of potassium fertilization on *Swietenia macrophylla*, observed that the addition of potassium to the soil did not affect significantly the height and diameter of the plants. The lowest dose was considered satisfactory for the development of the crops. However, for Corcioli et al. (2014), the lack of potassium fertilization in *K. ivorensis* plants resulted in a reduction in total growth and reduced leaf size. It is thus possible to suggest that K is extremely important for the development of African mahogany seedlings.

Phosphorus presented an increasing linear response, both in the aerial part and in the roots (Figures 6 and 7). This result indicates that the fraction of this nutrient available in the substrate for absorption of the African mahogany seedlings was below the ideal supply. This can be explained by the fact that it is an element with high fixing power in soil colloids and low mobility. Thus, the higher fertilization dose provided greater availability of this nutrient for absorption. The results were similar to those presented by Tucci et al. (2011), where the contents of P in the aerial part of the species *S. macrophylla* increased with the addition of increasing doses.

When studying the Brazilian mahogany (*S. macrophylla*), Souza et al. (2010) observed that P is the nutrient that most limits the growth of seedlings of the species. The authors observed that the omission of P limits the growth in height, diameter and dry weight yield of aerial part, root and total shoots in Brazilian mahogany seedlings.

The foliar contents of P considered adequate for the forest essences are in the range of 1.0 to 2.3 g kg^{-1} (Malavolta et al., 1997). Thus, taking into account this assertion, all treatments presented adequate concentrations (Figure 6). Tree species tend to exhibit high P uptake capacity in the initial phase of growth, and may have a significant potential for P-inorganic accumulation in the cell vacuole (Taiz & Zeiger, 2013).

The highest Ca concentration occurred in the aerial part (Figure 6), which may have occurred due to the high transpiration rate of the plants, because the Ca is transported in a single direction by the xylem, via the transpiratory stream, from the roots to the aerial part (Marenco & Lopes, 2009).

The experimental region presents high temperature averages. In this way, the high transpiration rate of the plants is expected, due to high ambient temperatures and low relative humidity. Malavolta et al. (1997) report that foliar calcium concentrations between 3.0 and 12.0 g kg-1 are considered adequate for forest essences. In all treatments evaluated in the present study, adequate concentrations of this nutrient were observed.

The concentrations considered suitable for Mg in forest species are 1.5 to 5.0 g kg^{-1} (Malavolta et al., 1997). Thus, all the treatments evaluated in the present study had concentrations within the range considered adequate (Figure 6).

The sulfur concentration found in the aerial part of *K. senegalensis* in the T0 treatment (Figure 6) was below that considered adequate (1.4 to 2.0 g kg^{-1}) for forest essences (Malavolta et al., 1997). On the other hand, the other treatments had averages above the upper limit considered adequate.

Based on the fertilization of the T3 treatment, which presented higher DQI mean and, consequently, better quality seedlings, the application of 26,56; 42.59; 34.78; 54,47 and 20,82 mg dm^{-3} of N, P_2O_5, K_2O, Ca and S, respectively, is recommended for the basic fertilization of the seedlings of *Khaya senegalensis* in nursery.

CONCLUSIONS

The highest concentration of nutrients was observed in the aerial part of the plants, for all evaluated treatments, with nutrient contents obeying the following decreasing order: potassium, nitrogen, calcium, magnesium, and phosphorus and sulfur alike.

The recommended application is the following: 26.56; 42.59; 34.78; 54,47 and 20,82 mg dm^{-3} of N, P2O5, K2O, Ca and S, respectively, for the basic fertilization of *Khaya senegalensis* seedlings in nursery, using a medium-textured Red Yellow Latosol substrate collected in the subsurface layer.

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