AFRICAN MAHOGANY SUBMITTED TO DRIP IRRIGATION AND FERTILIZATION

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ABSTRACT – African mahogany (Khaya ivorensis A. Chev.) is a tree species that has been increasing in Brazilian commercial planting. However, the lack of water and nutrition are great obstacles for crop production. The aim of this study was to evaluate the growth of young mahogany plants submitted to drip irrigation and topdressing. The experimental design was of randomized blocks, with three repetitions in subdivided plots. Treatments consisted of drippers: 1, 2 and 3plt⁻¹; flows: 2, 4 and 8Lh⁻¹, and a treatment without irrigation. For topdressing, subplots levels were, as follows: 1) 17.5 and 25.2; 2) 35.1 and 50.1; 3) 52.5 and 75.0; 4) 70.0 and 100.2; and 5) 87.5 and 125.1 g plant⁻¹ N and K₂O, respectively, divided into five bimonthly applications, which started in the 4th month after planting. Plant height, diameter at root collar and at breast height (DBH), and stem height were evaluated. Results showed statistically significant differences (P>0.05) between irrigated and non-irrigated plants. Mean plant height ranged (from 2 to 20 months in field) from 0.33 to 3.25 and 2.67m for irrigated and non-irrigated plants, respectively. Mean stem height ranged from 0.23m to 0.87 and 0.71m for irrigated and non-irrigated plants, respectively. Thus, irrigation with 1 dripper per tree and flow of 2L h⁻¹ was able to supply mahogany water requirements in the first two years in field. Trees have not responded to N and K topdressing at the beginning of the cycle.

Keywords: Water stress; Hardwoods; Nitrogen.

MOGNO AFRICANO SUBMETIDO À IRRIGAÇÃO POR GOTEJAMENTO E ADUBAÇÃO

RESUMO – O mogno africano (Khaya ivorensis A. Chev.) é uma das espécies arbóreas que vem se destacando no Brasil em plantios comerciais. Os déficits hídrico e nutricional são grandes entraves para a produção vegetal. O objetivo deste estudo foi avaliar o crescimento de plantas jovens de mogno submetidas à irrigação por gotejamento e adubação de cobertura. O delineamento experimental foi blocos casualizados - DBC, com três repetições em parcelas subdivididas. Os tratamentos foram: gotejadores: 1, 2 e 3plt⁻¹; vazões: 2, 4 e 8Lh⁻¹; e sem irrigação; e as subparcelas, adubação de cobertura: 1) 17,5 e 25,2; 2) 35,1 e 50,1; 3) 52,5 e 75,0; 4) 70,0 e 100,2; 5) 87,5 e 125,1g planta⁻¹ de N e K2O, respectivamente, parceladas em cinco aplicações bimestrais iniciadas no 4º mês após o plantio. Avaliaram-se: altura de planta, diâmetro de caule e altura de fuste. Os resultados mostraram que houve diferença estatística significativa (P>0,05) entre as plantas irrigadas e não irrigadas. A altura média das plantas variaram (dos 2 aos 20 meses de idade) de 0,33m a 3,25 e 2,67m irrigadas e não irrigadas, respectivamente. Variaram de 0,23
m a 0.87 e 0.71 m em altura de fuste, com e sem irrigação. Assim, a irrigação com um gotejador por planta, de vazão 2L h⁻¹ foi suficiente para atender as demandas de água do mogno nos primeiros dois anos de cultivo. As plantas não responderam à adubação de N e K.

Palavras-chave: Déficit hídrico; Madeira nobre; Nitrogênio.

1. INTRODUCTION
The use of forest products currently faces the problem of raw material decrease in the sector, both due to ecological pressures, aimed at reducing exploitation of native forests, as well as due to the scarcity of forest products, which are increasingly distant from consumer areas. Among the affected sectors, sawmills and laminations are highlighted, which, in Brazil, survive from native forest extraction regarding “hardwood”.

In order for planted forests to serve the consumer market, there is the need to choose the appropriate species and silvicultural techniques to be employed. In addition, forests must produce timber in quality and quantity compatible with market expectations. Among hardwood exotic species introduced in Brazil, the African mahogany (Khaya ivorensis A. Chev.) stands out. The species aforementioned had its origin in countries from the west coast of the African continent, which has similar edaphoclimatic characteristics to some Brazilian regions, explaining the rapid adaptation of the species in Brazil. For Brito et al. (2013), a large part of the territory of Goiás State has edaphoclimatic aptitude for African mahogany cultivation, which may represent the addition of one more crop with good economic profitability for the State and perhaps for other places with similar characteristics.

Among factors limiting plant production, water deficit is highlighted, which occurs in large cultivable areas, affecting plant-water relations and plant metabolism (Nogueira et al., 2000). Additional water supply through irrigation allows species cultivation outside their natural environments, ensuring good growth and plant development, which is observed in their yield. Studies have demonstrated the positive effect of irrigation on arboreal species growth and yield for guava (Silva, 2012), citrus (Alves Júnior et al., 2011), and eucalyptus (Lopes et al., 2007). On the other hand, some plants do not respond to irrigation or fertilization, as is the case of pequi (Alves Junior et al., 2013). In addition, tree species have nutrient demand variation depending on the species, development stage and climatic conditions (Fernandes et al., 2000).

Due to the limited water resources in many regions, localized drip irrigation is a great alternative, because it has high water application efficiency.

Many studies have argued that water and nutritional availability are the most limiting factors for plant development in the Cerrado biome. Thus, the objective of this study was to evaluate the growth of African mahogany plants submitted to irrigation and fertilization, considering the potential for exploitation of African mahogany and the lack of information on this forest species in Brazil.

2. MATERIAL AND METHODS
The experiment was conducted in an experimental area in Bonfinópolis, GO (16°35’49” S; 49°16’39” W, elevation of 780 m), with annual mean temperature of 23 ºC, relative humidity of 71% and accumulated rainfall of 1487 mm. The study location has well-defined dry (May-September) and rainy (October-April) seasons. According to Köppen, climate was defined as Aw, tropical savannah, megathermal. Mean annual evaporation (Class A pan) is 1915 mm. The strongest winds are recorded in September (Silva et al., 2007). In the region, a dystroferric Red Latosol (Oxisol), clay texture, Cerradão subperennial stage and flat relief predominates (Silva et al., 2007). Soil analysis was performed before preparation of the area for two depths, 0-20 and 20-40 cm, and the following chemical characteristics were found: pH (CaCl₂) = 5.1 and 5.0; OM = 2.1 and 1.2%; P (Mehlich) = 4.2 and 1.4 mg dm⁻³; Al = 0.0 and 0.0 mmol dm⁻³; H⁺Al = 2.8 and 2.8 mmol dm⁻³; K = 45.0 and 26.0 mg dm⁻³; Ca = 0.9 and 0.5 mmol dm⁻³; Mg = 0.3 and 0.2 mmol dm⁻³; CEC = 4.1 and 3.6 mmol dm⁻³; V(%) = 32.0 and 21.5%. Moreover, the following physical characteristics were found: Sand = 38.0 and 47.0%; Silt = 24.0 and 23.0% and Clay = 38.0 and 30.0% (clay loam texture) with water retention estimated at 1.5 mm cm⁻¹.
The experiment was carried out in the field (March/2012), containing 450 African mahogany plants (*Khaya ivorensis* A. Chev.) with approximately 30 days old (mean diameter: 0.8 cm; mean height: 32 cm; stem height 7.5 cm) and 5 x 5 m spacing. Area preparation was carried out in August 2011 (3 months before planting) with disk plowing and two harrows, in which dolomitic limestone was added, increasing the base saturation to 70%. The irrigation system was installed in April 2012. At planting, holes were fertilized with 100 g P<sub>2</sub>O<sub>5</sub> (single superphosphate). Immediately after planting, 5 L of water was placed per plant, including the non-irrigated treatment, in order to guarantee survival. Rainfall equal to 2216.2 mm was recorded during the experiment period (March/2012 to November/2013).

A Randomized Complete Block (RCB) experimental design was used, with three repetitions in subdivided plots and 50 treatments. Ten irrigation plots (Table 1) were subdivided into 5 topdressing doses (Table 1). Each experimental plot consisted of 15 plants, with 3 plants for each subplot, totaling 150 plants per block and 450 plants in the experiment. In addition to border

<table>
<thead>
<tr>
<th>Plot</th>
<th>No. of drippers</th>
<th>Per plant</th>
<th>Flow rate (L h&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>Wet area(m&lt;sup&gt;2&lt;/sup&gt;)</th>
<th>Vol(m&lt;sup&gt;3&lt;/sup&gt;plant&lt;sup&gt;-1&lt;/sup&gt;)</th>
</tr>
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<td>2</td>
<td>0.29</td>
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<tr>
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<td>K&lt;sub&gt;2&lt;/sub&gt;O</td>
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<td>3.5</td>
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<td>10.5</td>
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<tr>
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<td>14.0</td>
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<td>5</td>
<td>17.5</td>
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African mahogany trees in Bonfinópolis-GO, Brazil.
For the first year, irrigation was performed during the period from May to October 2012, and in the second year, irrigation was carried out from June to September 2013. In irrigated treatments, irrigations were performed daily, and the applied water amount was estimated from crop evapotranspiration (ETc), which is the product of reference evapotranspiration (ETo) and crop coefficient (Kc). ETo was estimated by Penman-Monteith equation and the adopted Kc was 0.5 for the first year and 0.7 for the second. Kc data was obtained from fruit plant studies due to lack of information on African mahogany.

The meteorological variables of the experimental area (minimum and maximum air temperatures, solar radiation, relative air humidity, wind speed and rainfall) were collected with the aid of an automated weather station (Davis Vantage PRO2).

Gross irrigation volume was calculated in relation to the wet area in each treatment. The wet area (WA) was determined from the diameter wetted by the bulb, estimated by the model proposed by Schwartzman; Zur (1986). Irrigation application efficiency was 90%.

The volume of water applied per plant (Vol, m$^3$) and the irrigation time (IT, h) were obtained by equations [1] and [2], respectively:

\[ Vol = ETo \cdot Kc \cdot Kloc \cdot AP \]
\[ IT = \frac{(q/ef)}{Vol} \]

Where:

- \( Kc \) is the crop coefficient (0.5 for the first year and 0.7 for the second),
- \( Kloc \) is the evapotranspiration reduction coefficient for localized irrigation, \( AP \) is the useful area of each plant (m$^2$), \( q \) is the dripper flow rate (L h$^{-1}$), and \( ef \) is the water application efficiency (90%). For \( Kloc \) calculation with wet area percentage of less than 20% (Fereres, 1981, apud Mantovani et al., 2009), equation 3 was used:

\[ Kloc = 1.94PM + 0.1 \]

Where \( PM \) is the wet area percentage, in absolute value.

The wet diameter (D, m) was obtained from the model proposed by Schwartzman & Zur (1986):

\[ D = 1.82 \cdot Vol^{0.22} \left( \frac{Ks}{q} \right)^{0.17} \]

Where \( Ks \) is the saturated soil hydraulic conductivity (m s$^{-1}$) and \( q \) is the dripper flow rate, given in m$^3$ s$^{-1}$.

Plant growth assessments were conducted every two months (May, July, September and November 2012, and January, March, May 2013) by measuring the following phenometric variables: plant height - measured from the upper end of the orthotropic branch to ground level, using a millimeter precision ruler; stem height – measured from ground level to the first leaf insertion; and trunk diameter - carried out five centimeters from the ground, with the aid of a pachymeter.

For data statistical analysis, the SISVAR software - Variance Analysis System, was used. For irrigation treatments, analysis was qualitative between treatments and in time, and mean comparison was conducted by Tukey’s test at 5% error probability. For fertilization treatments, data quantitative analysis was made through regression analysis.

3. RESULTS

Plant growth in both height and diameter was influenced by irrigation, showing statistical differences (Table 2) between irrigated and non-irrigated treatments (p<0.05). Height growth rate was 25% higher in irrigated treatments compared to the non-irrigated treatment. Mean plant height at the beginning of the study was of 0.33 m (2 months of age). In the last evaluation, plants reached 3.25 m and 2.67 m (20 months of age) when irrigated and not irrigated, respectively. Stem height growth rate was 33% higher, starting with a mean of 0.23 m, at 2 months of age, and reaching 0.87 m and 0.71 m at 20 months of age, when irrigated and not irrigated, respectively. Diameter at root collar growth rate was 19% higher, starting with a mean of 0.79 cm (2 months of age), reaching 5.9 cm and 5.1 cm at 16 months of age in irrigated and non-irrigated plants, respectively. The diameter at breast height (DBH) growth rate was 24% higher, reaching 20 months 4.6 cm and 3.7 cm a 20 months of age for irrigated and non-irrigated plants, respectively.

Plant heights in irrigated treatments differed from the non-irrigated treatment from July 2013 (Table 2), the 4th month after planting (full drought season).

It is noteworthy that, even with the beginning of rainfall in October, non-irrigated plants failed to obtain enough growth rates to match irrigated plant means (Table 2). For stem height, this effect was only observed from the beginning of the drought period.
African mahogany submitted to drip... of the following year (March 2013), in plants with one year of planting.

Topdressing effect (Table 3) was verified on biometric variable growth rates by multiple regression, and no statistical significance was observed.

4. DISCUSSION

Young Brazilian mahogany (*Swietenia macrophylla*) plants tolerate periods of 15 to 30 days of water deficiency (Cordeiro et al., 2009). This species also belongs to the Meliaceae family, as well as the
African Mahogany, although the first one is native to the Amazon biome.

_Eucalyptus grandis_ and _Pinus elliotti_ plants cultivated in the Triângulo Mineiro Cerrado had a higher growth when submitted to irrigation, corroborating with the results found in this study (Fernandes, 2009).

Although plants survived (95% survival) to the water deficit period in the experimental area (Figure 1A), typical of the cerrado biome (dry season = 6 months), this was reflected in non-irrigated plants growth, since some woody species under water deficit conditions limit stomatal opening, resulting in CO$_2$ assimilation rate reduction and lower plant growth (Franco, 1998; Mattos et al., 2002; Silva et al., 2005; Albuquerque et al., 2013).

Lower non-irrigated plant growth can be explained by the planting season (March/2012), which coincided with the end of rainfall in the region. Afterwards, a drought period advanced until October/2012 (Figure 1A), which may have impaired both plant adaptation and plant growth.

Considering that the mahogany is a large species, which can reach 70 m height and 3.5 m DBH (Carvalho, 2007), plants evaluated in this study are young. In addition, the radius explored by young mahogany plant roots was only 0.50 m until 6 months of age, and 1.0 m until 1 year of age. Because of this, a single dripper with a flow rate of 2 L h$^{-1}$ was enough to supply plant water requirements. In treatments with 2 and 3 drippers, regardless of flow rate, drippers were arranged in a way that, in the treatment with 2 drippers, the plant was in a median region between emitters. Moreover, in the treatment with 3 drippers, the water provided by border emitters was outside the young mahogany root system water absorption zone. The distance between emitters was 60 cm, and based on the treatment with 8 L h$^{-1}$ and 3 drippers, operating 1 hour per day, a wet radius of 0.38 cm was obtained. That is, all the water that was expelled by border emitters was probably lost in that crop stage.

Although plant growth increased during the first months, plant growth rates intensified in the summer (December - March), probably as an influence of maximum water availability (Figure 1A) in the soil and photoperiod effect, with higher energy availability (Figure 1B).

In general, irrigated and non-irrigated treatments showed lower growth rates up to 160 days after planting (Figure 2), which may have occurred due to seedlings ripening stage and low energy availability. This effect was more accentuated in the non-irrigated treatment, since there was water restriction (Figure 1A). From

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**Table 3** – Regression analysis summary with the mean square for plant height, stem height and Diameter at breast height (DBH) of African mahogany in response to topdressing (N and K).

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of freedom</th>
<th>Mean Square</th>
<th>Mean Square</th>
<th>Mean Square</th>
</tr>
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<td>86.83**</td>
<td>10.87**</td>
<td>0.005 ns</td>
</tr>
<tr>
<td>Quadratic regression</td>
<td>1</td>
<td>86.80**</td>
<td>7.34**</td>
<td>0.0006 ns</td>
</tr>
</tbody>
</table>

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**Figure 1** – A: Water balance by Thornthwaite & Matter method (Pereira et al., 2002); and B: Temperature and global radiation for the period from March/2012 to November/2013, Bonfinópolis, GO, Brazil.

**Figura 1** – A: Balanço hídrico pelo método de Thornthwaite & Matter (Pereira et al., 2002), e: B: Temperatura média do ar e radiação solar para o período de Março/2012 a Novembro/2013, Bonfinópolis-GO.
African mahogany submitted to drip irrigation

Figure 2 – Mean growth data of African mahogany trees (total height, stem height, diameter and DBH) from 2 to 20 months in the field, Bonfinópolis, GO, Brazil.

November/2012, higher growth rates were observed in both irrigated and non-irrigated treatments (p <0.05) for all variables analyzed, decreasing again in the dry period of the following year (2013), with effect in irrigated treatments (Figure 2). Thus, the importance of irrigation for African mahogany plant growth in the first two years of forest implantation was noticed.

It was observed that, in the first reading, conducted in May 2012 (2 months of age), plants obtained mean values of 0.008 m diameter, 0.32 m total height and 0.23 m stem height. As of November 2013 (20 months of age), in the last evaluation, DBH, total height and stem height mean data were, respectively: 0.045; 3.25 and 0.87 m for irrigated plants and 0.037, 2.67 and 0.71 m for non-irrigated plants. In general, it was observed that mahogany plants developed slightly less than expected, including irrigated ones. The literature shows that Brazilian Mahogany plants transplanted with 0.60 m height, that is, approximately the double of the initial height of plants in this study (0.32 m), obtained a mean total height of 3.40 m during a period of 14 months (Cordeiro, 2012). The value aforementioned corresponds to a growth rate of 0.24 m month⁻¹, which was higher than the rate obtained by plants of the present study, 0.15 m month⁻¹ when irrigated and 0.12 m month⁻¹ when not irrigated. This may be due to transplanted seedling size, or due to species and region differences. The mahogany (*Swietenia macrophylla*) is known as the Brazilian mahogany and is a species native to the Amazon region, where the study was conducted. Therefore, the plant is already adapted to the environment conditions.

Differences were not detected for variables that expressed plant growth in relation to the different fertilization rates (Table 3). In studies with Brazilian mahogany and its nutritional needs, it was verified that the order of necessity follows $P > S > K > N$ (Souza et al., 2010), which may explain the absence of a significant African mahogany response to potassium (K) and nitrogen (N), as these elements are not the most necessary in the initial growth of this plant. Increasing N doses of 0, 20, 40, 60, 80, 100 and 120 g N ton⁻¹ of substrate increased Brazilian Mahogany (*Swietenia macrophylla* King) seedlings growth in terms of stem and root dry matter and plant height, up to the optimal dose of 61.5 g N Mg⁻¹. The maximum dose used in this study (120 g N Mg⁻¹) caused negative effect, impairing seedling quality (Tucci et al., 2009).

Rosa (2014), in a study on African mahogany (*Khaya ivorensis*) seedlings in pots (90 days), reported that nitrogen fertilization only improved plant leaf area, while the other variables (height, stem and diameter) did not show significant differences between treatments (Figure 2). Thus, the importance of irrigation for African mahogany plant growth in the first two years of forest implantation was noticed.

Moreover, considering that *Cerrado* soils are naturally low in phosphorus (Souza et al., 2004), which was confirmed in this study (4.2 and 1.4 mg dm⁻³ for 0-20cm and 0-40 layers, respectively) (Fig. 1), the lack of P application may have caused lower growth, as it is known that phosphorus is a plant growth limiting factor for many plants, such as *Cedrela fissilis* (Silva and Muniz, 1995), *Acacia mangium*, *Tibouchina*...
granulosa and Aspidosperma polyneurom (Braga et al., 1995).

In addition, African mahogany can adapt to poor soils. In Indonesia, mahogany of Swietenia macrophylla King. species is developed in very poor soils (Soemianegara and Lemmens, 1993). For Carvalho (2007), there are several tolerable soil conditions for mahogany (Swietenia macrophylla), ranging from deep and poorly drained soils, acidic and swampy clay soils, to well-drained alkaline soils, including soils derived from igneous and metamorphic rocks. Due to Swietenia macrophylla and Khaya ivorensis species proximity, it can be inferred that the African mahogany is adapted to Cerrado environmental conditions. According to Sallenave (1959), who studied mahogany special characteristics and properties, this species originated in African west coast countries, mainly in Ivory Coast, Ghana, Togo, Nigeria, Cameroon, Congo and Angola.

In general, the predominant soils found in these countries are classified as Oxisols, Ultisols and Entisols (Soll Survey Staff, 2006), which, according to the Brazilian classification (Embrapa, 2006), represent, respectively: Latosols, Argisols and Neosols, which are in the Cerrado of Goiás.

5. CONCLUSIONS

Young African mahogany plants, up to two years of age, respond positively to drip irrigation.

Irrigation with one drip per plant and flow rate of 2 L h⁻¹ is enough to meet the water demands of African mahogany in the first two years of cultivation.

Plants did not respond to the different Nitrogen and Phosphorus topdressing doses, applied every 2 months, at the beginning of the cycle.

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