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DESENVOLVIMENTO INICIAL DE MUDAS DE GUANANDI SUBMETIDAS A DOIS NÍVEIS DE LENÇOL FREÁTICO E DOSES CRESCENTES DE FÓSFORO[1]

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1 RESUMO

O guanandi é uma espécie nativa com potencial para reflorestamento, porém com poucos resultados na literatura sobre seu cultivo. Diante disto, objetivou-se avaliar o desenvolvimento inicial de mudas de guanandi submetidas a dois níveis de disponibilidade de água no solo e doses crescentes de fósforo. O cultivo foi realizado de fevereiro a junho de 2016, utilizando-se dez lisímetros de lençol freático constante, simulando duas alturas do lençol freático, 0,40 m e 0,70 m. Em cada lisímetro, foram colocados seis vasos contendo uma muda por vaso. As doses de fósforo foram de 0, 40, 80, 120 e 160 mg dm^{-3} de solo. O delineamento experimental adotado foi em fatorial 2 x 5, com seis repetições, considerando cada vaso uma unidade amostral, totalizando 60. Os parâmetros avaliados foram: altura e diâmetro final, massa fresca da parte aérea, raízes e total, teor relativo, potencial de água na folha (Ψf) e consumo de água. Os resultados permitem inferir que, nas condições avaliadas, a dose de 160 mg dm^{-3} de fósforo associada ao fornecimento de 537,2 mm de água nos primeiros cinco meses de implantação da cultura, proporciona melhor desenvolvimento morfológico e fisiológico.

Palavras chaves: irrigação, lisímetro, adubação fosfatada.

CARVALHO, R. S. C.; MELO, M. R. M.; GOMES, F. G.; KLAR, A. E. INITIAL DEVELOPMENT OF GUANANDI SEEDLINGS SUBJECTED TO TWO LEVELS OF WATER TABLE AND INCREASING DOSES OF PHOSPHORUS

2 ABSTRACT

The guanandi is a native species with potential for reforestation, but with few results in the literature about its cultivation. Because of this, the objective was to evaluate the initial

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development of guanandi seedlings subjected to two levels of water availability in the soil and crescent phosphorus dosages. The cultivation was conducted from February to June 2016 by using ten lysimeters of constant water table, simulating two heights of the water table, 0.40 m and 0.70 m. In each lysimeter, one of them, six pots were placed, with one seedling by pot. The crescent phosphorus dosages used were 0, 40, 80, 120, and 160 mg dm^{-1} of soil. The experimental design adopted was the factorial 2 x 5, with six replications, in which each, pot was considered a plot, totalizing 60 of them. The evaluated parameters were final height and diameter, aerial parts fresh mass, root fresh mass, total fresh mass, relative water level, water potential in the leaf (Ψf), and consumption of water. The results allow us to infer that, under the conditions evaluated, the dosage of 160 mg dm^{-3} of phosphorus associated with the supply of 537.2 mm of water in the first five months of crop implantation provides better morphological and physiological development, under the conditions evaluated.

Keywords: irrigation, lysimeter, phosphate fertilization.

3 INTRODUCTION

Guanandi (*Calophyllum brasiliense* Cambèss.) is a forest species distributed in Mexico and throughout South America (PETIT; MONTAGNINI, 2006). In Brazil, it is found from the Amazon region to the north of Santa Catarina, mainly in the Atlantic Forest (MARQUES; JOLY, 2000), and according to Zacarias et al. (2012), this species is adapted to a wide gradient of soil moisture, being able to develop greater size and a selective advantage over other species in permanently waterlogged areas.

The area of planted forests in Brazil is just over 9 million hectares, and approximately 95% are eucalyptus and pine plantations, with the remainder being composed of unconventional species (INDÚSTRIA BRASILEIRA DE ÁRVORES, 2020). According to Campelo et al. (2015), there is a great diversity of promising forest species for the timber sector, but research on this topic is scarce. Guanandi is a native species identified in research as a potential option for forestry production owing to the quality of its wood and the numerous possibilities for its uses (PETIT; MONTAGNINI, 2006; LISBOA et al., 2012).

management allows crops to meet their water needs and reduces disease, nutrient leaching, and water and energy consumption. In the case of forest species, water and nutrient supplies during early development can be essential to ensure seedling rooting at the final planting site; they are also determining factors in plant diversity and distribution (FRANÇA et al., 2017). In the literature, studies have focused predominantly on exotic species, particularly eucalyptus and pine. However, information regarding guanandi's nutritional and water requirements is sparse.

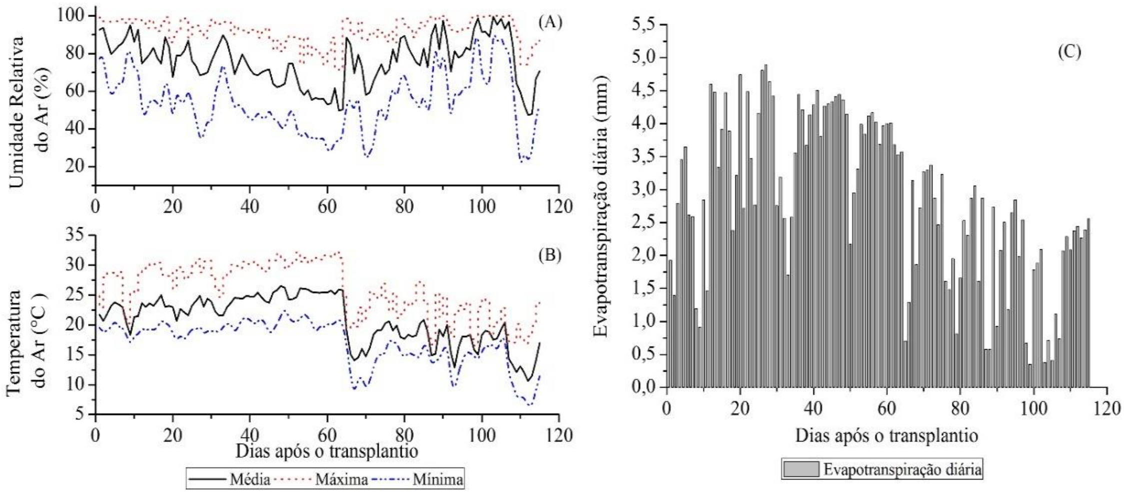
Given the need for studies and research to understand crop development potential, this work aimed to evaluate the morphological and physiological responses and water consumption of guanandi in the initial growth phase of seedlings subjected to two levels of soil water availability and increasing doses of phosphorus.

4 MATERIALS AND METHODS

The cultivation was carried out from February to June 2016 at the facilities of the Department of Rural Engineering of the Faculty of Agricultural Sciences (FCA), belonging to São Paulo State University "Júlio de Mesquita Filho" (Unesp), located in the municipality of Botucatu, state São Paulo, whose geographic coordinates are latitude 22° 51' S, longitude 48° 26' W and altitude of 786 m. According to the Köppen classification, the region has a Cfa climate type, humid subtropical climate (CUNHA; MARTINS, 2009; ALVARES et al., 2013).

During the evaluation period, the temperature, relative humidity and reference evapotranspiration (Penman–Monteith) (Figure 1) of the area where the greenhouse was installed were monitored.

Figure 1 Relative humidity (A), air temperature (B), and reference evapotranspiration (Penman–Monteith) of the external area of the greenhouse (C) for the period from February 23 to June 12, 2016, Botucatu, SP



The research was conducted in a greenhouse consisting of a metal structure with an arched roof covered with transparent diffuser polyethylene, with a ceiling height of 3 m and dimensions of 30 m long by 6.40 m wide, and sides enclosed by shade cloth. To evaluate the effects of two water table levels on the initial development of guanandi in the greenhouse, ten constant-water table lysimeters were used, with a continuous water supply through an individual graduated reservoir.

In each lysimeter, six vessels made of 150 mm nominal diameter PVC pipes, 0.40 m and 0.70 m high, were placed, simulating the effects of two constant water table depths. A 150 mm PVC cap, perforated to allow capillary rise, was used to close the bottom of each vessel. A geotextile blanket was also placed to prevent soil loss.

Each lysimeter consisted of a metal tray 0.40 m wide by 0.60 m long and 0.14 m high, containing a 0.05 m layer of washed sand. A constant water level in the tray was maintained via an intermediate chamber fitted with a float. This chamber was supplied by a water reservoir graduated in millimeters, made of PVC pipe with a nominal diameter of 150 mm and a height of 0.80 m. The vessels were buried in the sand to obtain a 0.04 m water table from their bases. From these, two water table depths were established, 0.40 m and 0.70 m, from the vessel surface to the water table.

To measure crop evapotranspiration in the pots, the interstices between them were filled with paraffin to prevent water evaporation from the trays. The soil used in the experiment, a clayey soil, was sieved through a 5 mm mesh and air-dried to 2% moisture content before the pots were filled. To assess the need for soil acidity correction and fertilization, chemical and physical analyses were performed according to the methodology described by Van Raij et al. (1997), and the results are presented in Table 1.

Table 1. Physical and chemical characteristics of the clay soil used for the cultivation of guanandi (*Calophyllum brasiliense* Cambess) in pots, Botucatu, SP.

Sand	Clay	Silt	Soil texture	pH	MO
--------------------------(g kg $^{-1}$)-------------------------				$CaCl_2$	g dm $^{-3}$
351	469	180	Clayey	6.5	21

P resin	S	Al^{3+}	H+AL	K	Here	Mg	SB	CTC	V
mg dm $^{-3}$		------------------------------mmol $_c$ dm $^{-3}$ ------------------------							%
11	24	0	16	2.9	59	12	75	91	82

Legend: MO organic matter; SB: sum of bases; CEC: cation exchange capacity; V%: base saturation.
Source: Soil Physics Laboratory and Soil Fertility Laboratory, FCA, UNESP.

The initial nitrogen and potassium fertilization of the crop was calculated according to the values proposed by Silva (2005) for planting native trees. To evaluate the influence of phosphorus fertilization on the initial development of the crop at two water table depths, 0.40 m and 0.70 m, increasing doses of phosphorus, 0, 40, 80, 120, and 160 mg dm $^{-3,}$ were established. Thus, the experimental design used was a 2 × 5 factorial design (two water table depths and 5 phosphorus doses), with six replicates, in which each pot was considered a sampling unit, totaling 60 experimental units.

The seedlings were transplanted into pots 90 days after emergence, after which they were ready for field planting. For the first 30 days, each pot was irrigated directly to allow rooting. After this period, irrigation was suspended, and only capillary rise irrigation was used. Actual crop evapotranspiration (ET) in the six pots of each lysimeter was assessed via daily collection, which was characterized by water loss in each pot related to the plant and soil.

Actual crop evapotranspiration can be obtained from the water balance equation, which, according to Moraes et al. (2015), is considered a direct method for studying the dynamics of water absorption by agricultural crops and involves variables such as irrigation, precipitation, deep drainage, surface runoff, and storage variation. However, the calculation of crop evapotranspiration in this work during the plant evaluation period was carried out via another methodology, since there was no irrigation, and deep drainage and surface runoff did not occur, as the system was kept closed on the sides and bottom.

Storage variations were considered negligible during the time interval in which ET was determined, as the soil water content was approximately constant, given the automatic water supply, making this parameter virtually null. Thus, the only variable that influenced ET was capillary rise, which was quantified by taking daily readings of the water level in the supply reservoir at the same time, 1:00 p.m., via the following equation:

$$\mathrm{ET} = \frac{(\mathrm{L1}-\mathrm{L2})}{6} \qquad (1)$$

where ET is the actual crop evapotranspiration (mm); L1 is the reading of the day, obtained at the supply reservoir scale (mm); and L2 is the previous reading, obtained at the supply reservoir scale (mm).

Thus, from the difference between the water level in the supply reservoir and the level of the previous day, divided by the six pots, the actual daily ET of the crop was obtained, expressed in mm, during the 80-day period in which the initial development of the guanandi was evaluated.

At 80 days after transplanting, a physiological evaluation was carried out on three plants from each treatment, chosen at random, to measure the relative leaf water content (TRA) following the methodology proposed by Jadoski and Klar (2011), and the leaf water potential (Ψf) was estimated via the Scholander pressure chamber method (SCHOLANDER; HAMMEL; BRADSTRRET, 1965).

At the end of the period, three random plants from each treatment were collected to evaluate the following morphological aspects: height (cm), stem base diameter (mm), total fresh mass (TFM), fresh root mass (FRM) and fresh shoot mass (FSAM). Samples of newly developed leaves were sent to the Plant Tissue Analysis Laboratory to determine the foliar contents of macro- and micronutrients, following the methodology established by Van Raij et al. (1997).

The collected results were subjected to analysis of variance (ANOVA) and subsequently compared via the mean test (Tukey) at 0.05 probability via ASSISTAT statistical software (SILVA; AZEVEDO, 2016).

5 RESULTS

The factors evaluated significantly affected only the height and final diameter of the plants (Table 2). For the other parameters evaluated, presented in Table 3, there was no significant interaction.

Table 2. Analysis of variance for height (cm) and diameter (mm) of the Guanandi plants at the end of the experimental period.

Causes of variation	GL	Mean Square	
		Height	Diameter
Depth to water table (PLF)	1	14852.27 **	11040.55 **
Phosphorus (P) Doses	4	704.85 **	10.91 **
PLF x P interaction	4	519.93 **	5.05 *
Treatments	9	2194.60 **	19.36 **
Residue	50	61.3	1.69
Coefficient of variation	(%)	9.86	12.3

*,**Significant at 0.05 and 0.01 probability, respectively; GL - degree of freedom.

Table 3. Analysis of variance for total fresh mass (TFM), fresh root mass (FRM), fresh shoot mass (FSAM), relative water content (RWC) and leaf water potential (Ψf) of the Guanandi plants.

Causes of variation	GL	Mean Square				
		MFT	MFR	MFPA	TRA	Ψf
Depth to water table (PLF)	1	31033.75 **	2993.40 **	14750.58 **	0.91 ns	15.55 **
Phosphorus (P) Doses	4	2349.57 **	376.48 **	893.34 *	51.29 ns	0.47 ns
PLF x P interaction	4	754.58 ns	160.73 ns	265.91 ns	33.91 ns	0.99 ns
Treatments	9	4827.82 **	571.36 **	2154.18 **	37.97 ns	2.38 **
Residue	20	471.6	69.81	240.84	42.92	0.44
Coefficient of variation	(%)	19.78	22.93	21:15	8.15	29.66

Legend: *,**Significant at 0.05 and 0.01 probability, respectively; ns - Not significant, by F test; GL - Degrees of freedom.

The interaction of the two factors provided the plants cultivated with a water table at a depth of 0.40 m and a dose of 160 mg dm $^{-3}$ P, with the highest average height and diameter (Table 4).

Table 4. Interaction effects between the depth of the water table and the phosphorus dose on the average height and final diameter of the plants were investigated.

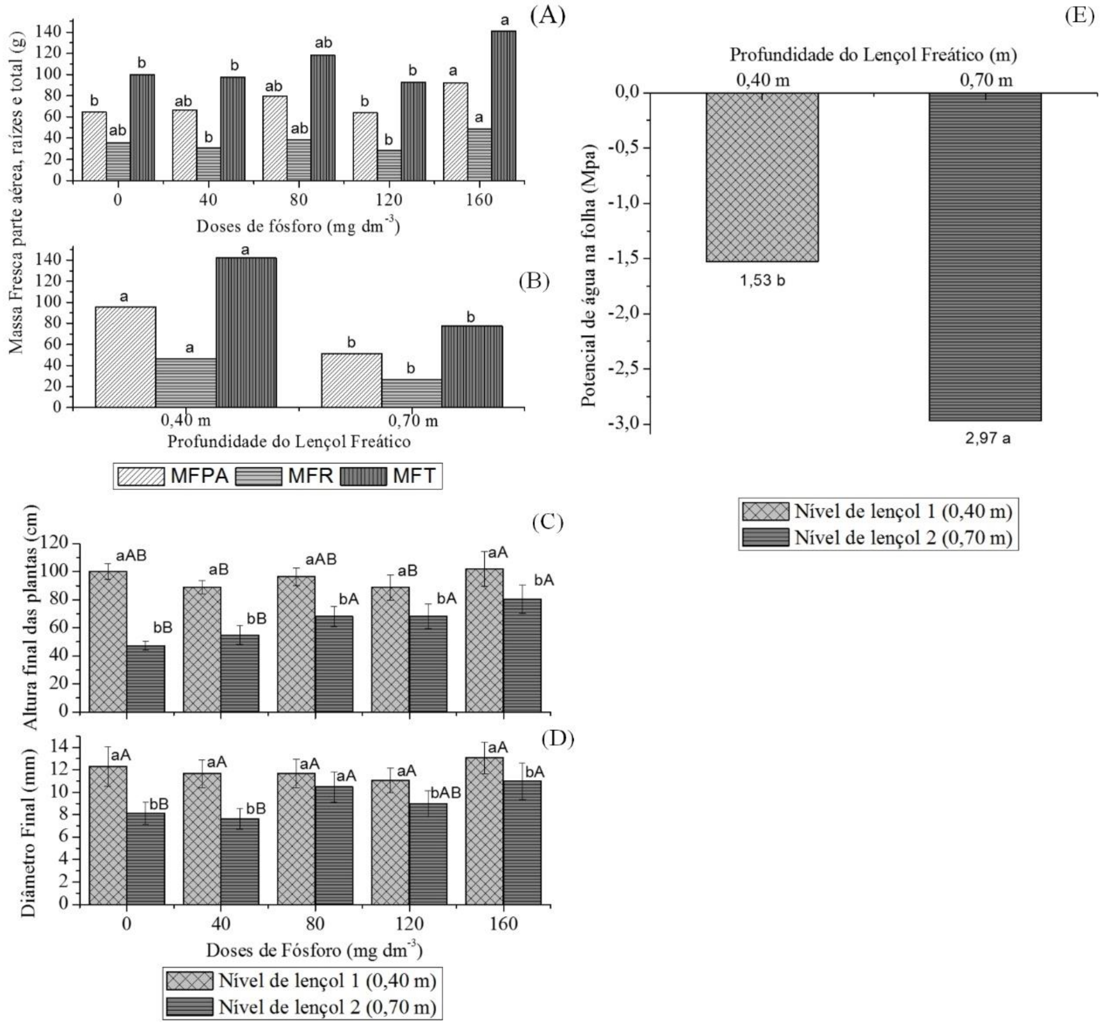
	Height (cm)				
Water Table Depth	Phosphorus Doses (mg dm-3)				
	0	40	80	120	160
0.40 m	100.00 aAB	89.00 aB	96.33 aAB	88.66 aB	101.83 aA
0.70 m	47.16 bB	54.83 bB	68.00 bA	68.17 bA	80.33 bA
CV(%)	9.86				
	Diameter (mm)				
Water Table Depth	Phosphorus Doses (mg dm $^{-3}$)				
	0	40	80	120	160
0.40 m	12.28 aA	11.66 aA	11.69 aA	11.06 aA	13.06 aA
0.70 m	8.15 bB	7.63 bB	10.47 aA	8.97 bAB	10.98 bA
CV(%)	10.74				

Means followed by the same uppercase letters in the row and lowercase letters in the column do not differ from each other according to the Tukey test. CV: coefficient of variation.

Plants grown without phosphate fertilization and with a water table at a depth of 0.70 m had the lowest average height, and in relation to diameter, the dose was 40 mg dm $^{-3}$ of phosphorus. This nutrient is part of protein synthesis in plants, and when available for absorption, it is reflected in greater vegetative growth (SILVA et al., 2018), as can be observed in the responses obtained (Table 4).

When the factors were evaluated separately, the two simulated water table depths had highly significant effects on plant development, according to the results presented in Tables 2 and 3 for the variables height, diameter, total fresh mass (TFM), fresh root mass (FRM), fresh shoot mass (FSAM), and leaf water potential (Ψf). The average results of these parameters were subjected to the Tukey test ($p<0.05$) as a function of phosphorus dose and water table depth and are shown in Figure 2.

Figure 2a function of phosphorus dose (A), water table depth (B), final height (C) and final stem diameter (D) of the Guanandi plants as a function of the two water table depths.



Averages followed by the same letter do not differ from each other, lowercase letters represent comparisons between columns, and uppercase letters represent comparisons within a row.

Among the different phosphorus doses, a significant difference was observed only in the morphological parameters. The average leaf water potential (Ψf) and relative water content (RWC) did not significantly differ. When comparing the average height and diameter results for each phosphorus dose in relation to the two water table depths, the difference was significant, suggesting that, in situations of lower water availability for guanine, phosphorus absorption may be compromised; however, in this case, water is the most limiting factor. This result is related to the absorption of this nutrient by diffusion, in which water acts as a means of transporting P from the soil to the roots (DOMINGHETTI et al., 2014).

With respect to the physiological evaluation of the crop, the influence was also highly significant for leaf water potential (Table 3), with the deepest water table having the highest average leaf water potential, indicating lower soil moisture, as this condition is dependent on soil moisture. In contrast, for the relative water content of the leaves, there was no difference between the two water table levels (Table 3).

The results related to the relative water content in the leaves corroborate those of Costa et al. (2015), who reported that plants can present similar TRA values and different LWE values. According to Rocha et al. (2016), in the initial development phase, guanandi, when subjected to a period of water stress and another period of rehydration, recovers; however, it can cause irreversible damage to its cellular structure and function.

Compared with the deeper water table of 0.70 m, plants grown under this condition developed less than those grown at the shallower water table of 0.40 m. This was characterized by a reduction in all morphological parameters evaluated owing to lower water availability and, consequently, greater energy expenditure to reach the wetter area of the soil. In nurseries, taller plants with larger stem base diameters are considered to be of better quality (FREITAS et al., 2017), as these characteristics can favor their performance in the initial growth phase in the field.

The guanandi crop is sensitive to water stress, resulting in reduced gas exchange and photosynthesis (CAMPELO et al., 2015) and, consequently, slower development. According to Jadoski and Klar (2011) and Chen et al. (2010), there are differences between plant species regarding resistance to leaf abscission under water stress conditions. These authors consider that premature leaf fall is a characteristic that indicates greater plant sensitivity to water deficiency.

Compared with plants growing in pots with the most superficial water table, those growing in pots with the deepest water table presented a significant reduction in the development of their leaves and roots, as shown in Figure 2, item B.

The highest dose of phosphorus (160 mg dm $^{-3}$) resulted in greater height and greater total fresh mass, with significant differences for the P doses of 0, 40 and 120 mg dm $^{-3,}$ and the plants subjected to a depth of 0.40 m presented greater height, diameter and fresh mass and lower water potential in the leaves.

Phosphorus in growing plants is most abundant in meristematic tissues, where respiration and protein synthesis are most intense (TAIZ; ZEIGER, 2013); hence, there is a need for an adequate supply of this nutrient during the initial development of the crop. However, according to Siqueira et al. (1998), climax species, such as guanandii, grow independently of the phosphorus supply, as they present slower initial growth, larger seed sizes and greater amounts of P. The results of this study demonstrate that phosphate fertilization, when provided together with the water supply, promotes greater crop growth. However, in the absence of this nutrient, its development does not cease, rather than slowing.

Sereda et al. (2016), when evaluating guanandi crops under conditions of low soil fertility, high aluminum content, and low N content, concluded that the leaves of the crop are sclerophyllous, meaning that they are harder and more resistant to nutrient loss. This adaptability of the crop to low-fertility soils was reported by Resende et al. (1999), who evaluated the responses of forest species, including guanandi, to the P supply and concluded that the requirements of this species are inconclusive.

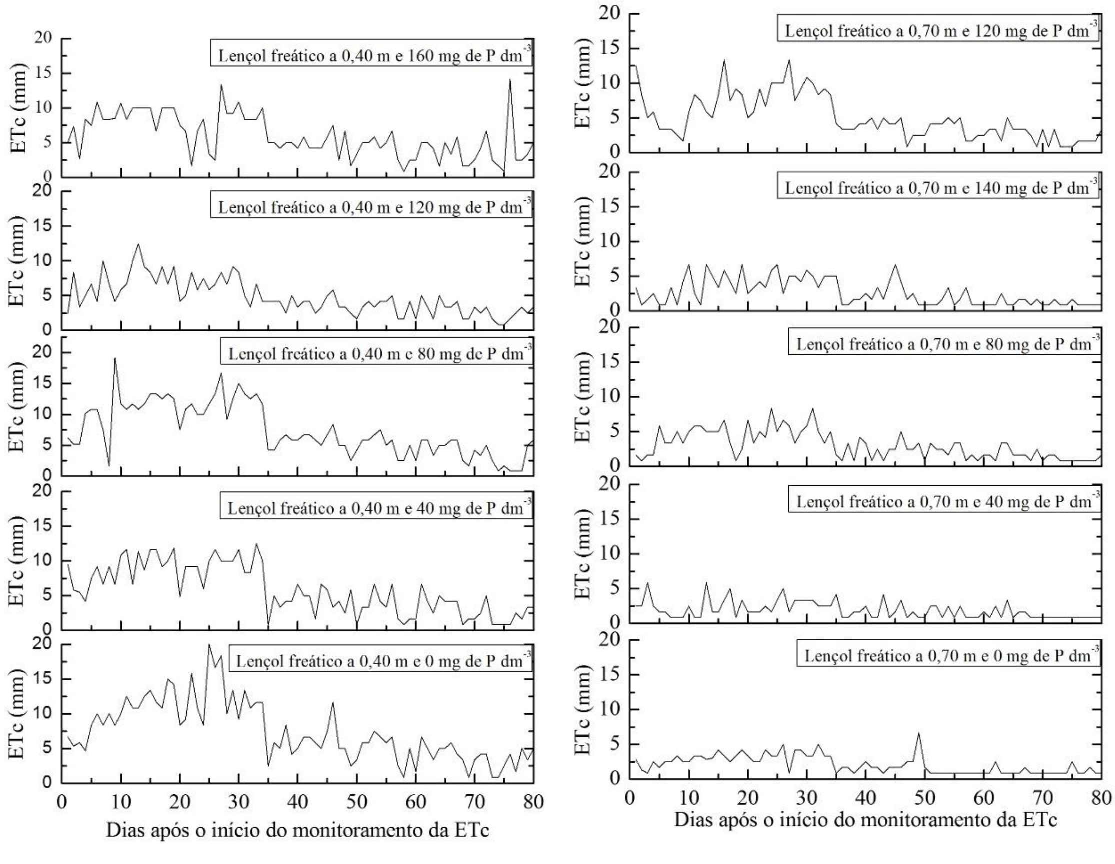
When the final water consumption (Table 5) through crop evapotranspiration (ETc), measured daily throughout the evaluated period (Figure 3), was evaluated, the plants cultivated with a more superficial water table presented greater evapotranspiration.

Table 5. Total crop evapotranspiration at the end of the evaluation period (80 DAT) for the different treatments.

Treatments	Evapotranspiration of Guanandi crop (mm)	Treatments	Evapotranspiration of Guanandi crop (mm)
1.1	611.67	2.1	172.50
1.2	486.00	2.2	156.67
1.3	610.83	2.3	245.83
1.4	490.83	2.4	214.17
1.5	486.67	2.5	410.17

Legend: 1.1 Water table at 0.40 m and 0 mg of P dm $^{-3}$; 1.2 Water table at 0.40 m and 40 mg of P dm $^{-3}$; 1.3 Water table at 0.40 m and 80 mg of P dm $^{-3}$; 1.5 Water table at 0.40 m and 120 mg of P dm $^{-3}$; 1.5 Water table at 0.40 m and 160 mg of P dm $^{-3}$; 2.1 Water table at 0.70 m and 0 mg of P dm $^{-3}$; 2.2 Water table at 0.70 m and 40 mg of P dm $^{-3}$; 2.3 Water table at 0.70 m and 80 mg of P dm $^{-3}$; 2.4 Water table at 0.70 m and 120 mg of P dm $^{-3}$; 2.5 Water table at 0.70 m and 160 mg of P dm $^{-3}$.

Figure 3 Evapotranspiration (ETc) (mm) of the Guanandi crop for the different treatments**,** measured daily throughout the experimental period.



Crop evapotranspiration is directly related to the available soil water content, plant morphological development, and atmospheric conditions at the growing site. Direct contact between root hairs and soil particles increases the surface area for water absorption (TAIZ; ZEIGER, 2013). In this study, plants grown in shallower water tables presented greater root and shoot development, resulting in greater water absorption and greater evapotranspiration (Figure 3).

The average water consumption values per plant over the experimental period, as calculated from Table 5, were 537.2 mm and 239.9 mm for plants growing at water tables of 0.40 m and 0.70 m, respectively. This result suggests that if split irrigation is carried out during the initial period of crop establishment, to achieve a depth of 537.2 mm, the plants may present better development under conditions close to those evaluated in this study.

The macronutrient and micronutrient contents of the aerial parts of the plants are described in Table 6. The values found for all the treatments are in agreement with the expected contents for forest species, as proposed by Van Raij et al. (1997).

Table 6. Leaf nutrient contents of the different treatments of the Guanandi plants at the end of the experimental period (80 DAT).

Treatments	N	P	K	Her e	Mg	S	B	Ass	Fait h	Mn	Zn
	g kg $^{-1}$						mg kg $^{-1}$				
1.1	11	0.6	7	7	1.7	1.3	10	11	118	95	20
1.2	11	0.5	4	6	1.4	1,2	8	8	89	40	15
1.3	13	0.6	5	9	1.9	1.5	9	9	216	42	17
1.4	11	0.5	5	9	1.7	1.3	8	8	128	30	17
1.5	13	0.6	5	9	1.7	1.3	9	9	276	36	19
2.1	15	0.5	6	9	2.1	1,2	13	8	140	351	18
2.2	12	0.5	4	8	2.1	1.1	11	8	110	89	16
2.3	13	0.5	5	7	1.5	1,2	8	8	125	60	22
2.4	15	0.6	6	9	1.7	1,2	12	10	103	90	37
2.5	12	0.5	4	8	1.9	1.3	9	9	160	31	24

Legend: 1.1 Water table at 0.40 m and 0 mg of P dm $^{-3}$; 1.2 Water table at 0.40 m and 40 mg of P dm $^{-3}$; 1.3 Water table at 0.40 m and 80 mg of P dm $^{-3}$; 1.5 Water table at 0.40 m and 120 mg of P dm $^{-3}$; 1.5 Water table at 0.40 m and 160 mg of P dm $^{-3}$; 2.1 Water table at 0.70 m and 0 mg of P dm $^{-3}$; 2.2 Water table at 0.70 m and 40 mg of P dm $^{-3}$; 2.3 Water table at 0.70 m and 80 mg of P dm $^{-3}$; 2.4 Water table at 0.70 m and 120 mg of P dm $^{-3}$; 2.5 Water table at 0.70 m and 160 mg of P dm $^{-3}$.

The increased phosphorus intake evaluated in this experiment did not result in different phosphorus levels in the leaves. This result can be explained by the fact that phosphorus reacts with other soil components and is therefore converted to forms unavailable for plant absorption. Therefore, Rodrigues et al. (2017) suggested subdividing phosphorus fertilization recommendations and prioritizing slow-release fertilizers. In addition to this characteristic of soil phosphorus fixation, guanandii plants have a reduced demand for this element in their early stages of development, as mentioned above.

With respect to water availability, Table 5 shows that leaf nutrient levels remained within the expected range for the crop (VAN RAIJ et al*.,* 1997), demonstrating that the two water table levels did not influence these results. The initial management of this experiment may have influenced this result, as fertilization was applied at the time of planting the seedlings in each pot, and during the first 30 days, these plants received the necessary water supply to allow their rooting, which may have resulted in the absorption and accumulation of nutrients necessary for the evaluated period.

6 CONCLUSIONS

The results of this work allow us to infer that the dose of 160 mg dm^{-3} of phosphorus associated with the supply of a 537.2 mm water depth in the first five months of implementation of the Guanandi crop provides better morphological and physiological development under the conditions evaluated.

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