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Controlled-Release Fertilizer on the Growth of Yerba Mate Seedlings

Fertilizante de Liberação Controlada no Crescimento de Mudas de Erva-Mate

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Abstract

To obtain quality seedlings of yerba mate and productive plants with a high standard raw-material, it is necessary the adequate nutrition for the seedlings in the nurseries. Fertilization management is one of the key factors that contribute to the better quality of seedlings, survival, and growth after planting in the field. Therefore, this work hypothesizes that controlled nutrient-release fertilizer can be used as base fertilizers in the production of yerba mate seedlings. Thus, the objective of this work was to evaluate the growth and quality of *Ilex paraguariensis* seedlings subjected to doses of controlled-release fertilizer, in order to define the most suitable dose for this stage of the crop. For all the analyzed variables a significant treatment effect was observed, indicating a positive response of the species to fertilization. Increasing doses of controlled-release fertilizer provided increments in height, collar diameter, height and collar diameter ratio, leaves number, leaf area, shoot, root and total dry mass, shoot and root dry mass ratio, height and shoot dry mass ratio and Dickson quality index, compared to unfertilized yerba mate seedlings. Controlled release fertilization promotes the growth and quality of yerba mate seedlings. Doses from 6 g L^{-1} of Basacote® Mini 6M fertilizer (13-6-16 + 1.4) can be used in the base fertilization of the seedlings.

Keywords: Basacote. Base Fertilizer. Dickson Quality Index. *Ilex paraguariensis* A.St.-Hil. Morphological Attributes.

Resumo

Para a obtenção de mudas de erva-mate de qualidade e plantas produtivas com alto padrão de matéria-prima é de suma importância a nutrição adequada das mudas nos viveiros. O manejo da adubação é um dos principais fatores que contribuem para a maior qualidade das mudas, sobrevivência e crescimento após o plantio no campo. Fertilizantes de liberação controlada de nutrientes podem ser utilizados como adubação de base na produção de mudas de erva-mate. O objetivo foi avaliar o crescimento e a qualidade de mudas de Ilex paraguariensis submetidas a doses de fertilizante de liberação controlada, de forma a definir a dose mais indicada para essa fase da cultura. Para todas as variáveis analisadas foi verificado efeito significativo do tratamento, indicando resposta positiva da espécie à adubação. Doses crescentes de fertilizante de liberação controlada proporcionaram aumentos na altura, diâmetro do coleto, relação altura e diâmetro do coleto, número de folhas, área foliar, massa seca da parte aérea, radicular e total, relação massa seca parte área e radicular, relação altura e massa seca parte aérea e índice de qualidade de Dickson, em comparação com as mudas de erva-mate não fertilizadas. Adubação de liberação controlada favorece o crescimento e a qualidade das mudas de erva-mate. Doses a partir de 6 g L^{-1} de fertilizante Basacote® Mini 6M (13-6-16 + 1,4) podem ser utilizadas na adubação de base das mudas.

Palavras-chave: *Basacote. Adubação de base. Índice de Qualidade de Dickson. Ilex paraguariensis A.St.-Hil. Atributos Morfofisiológicos.*

1 Introduction

Ilex paraguariensis A.St.-Hil. (Aquifoliaceae) known as yerba mate is an arboreal species, native to Brazil (Flora do Brasil, 2020). Its geographic distribution is associated, in its great majority, with the Atlantic Domain, with a subtropical and humid temperate character (Silva *et al*., 2018). In addition to the traditional use in the form of beverages such as chimarrão and tererê, its chemical composition has the potential to be used in food preservatives and supplements, dyes, hygiene products, and cosmetics (Croge *et al*., 2021).

Seedlings with genetic, physiological, and sanitary quality and, consequently, productive plants with a high-standard raw material (Duarte *et al*., 2019) are obtained with the satisfactory nutrition of the seedlings in the nurseries, as the management of the base or topdressing fertilization is one of the key factors that contribute to the higher quality of seedlings, survival, and growth after planting in the field (Araújo *et al*., 2018). However, information on such a topic is still scarce for most native species (Emer *et al*., 2020).

The yerba mate productive sector still lacks basic information, especially regarding the production of seedlings. In addition, some works still use soil as a substrate for cultivation in containers (Schafer *et al*., 2015; Zavistanovicz *et al*., 2017). However, it has been increasing the number of studies on alternative sources such as substrates based on sewage sludge and coal residues (Gabira *et al*., 2020b), mixtures of coconut fiber, and industrial by-products, including those from residues from the yerba mate processing (Gabira *et al*., 2020a).

Nevertheless, the supply of mineral elements is necessary, because in most cases, the substrate does not present the nutrients in sufficient amounts for the seedlings' good development. The use of controlled-release fertilizer (CRF) is considered an alternative as a source of nutrients for forest species produced in nurseries, as they induce rapid initial growth and show lower seedling losses after planting in the field (Araújo *et al*., 2019).

Controlled-release fertilizer gradually provide the nutrients to the plants through controlled-diffusion mechanisms, with low leaching losses in addition to reducing the salinization of the environment in the nurseries. The adequate use of these fertilizers has greater agronomic and environmental benefits in comparison to conventional fertilization practices (Shaviv, 2001).

In the production of yerba mate seedlings, the use of this type of fertilizer is still incipient. Zavistanovicz *et al*. (2017) used 6 g L^{-1} of Osmocote® 15-09-12 and observed a similar performance when compared to conventional fertilization with 0.7 g L^{-1} of urea, 8.0 g L^{-1} of simple superphosphate, and 0.4 g L^{-1} of potassium chloride. Gortari *et al*. (2020) added 3 kg m^{-3} of Plantacote® Plus 6M to the composted pine bark substrate for the production of yerba mate seedlings propagated by seeds and cuttings.

The quality of nursery-produced seedlings can be evaluated through easily measurable morphological attributes such as height, collar diameter, and leaves number, with non-destructive evaluations that can be obtained over time. Moreover, destructive methods such as dry matter, leaf area, length, and root volume can also be used (Landis *et al*., 2010; Araújo *et al*., 2018). Through the morphological attribute data, it is possible to calculate indexes such as the height and collar diameter ratio, the height and shoot dry mass ratio, the shoot and root dry mass ratio and Dickson quality index (Dickson *et al*., 1960; Gomes *et al*., 2002).

Thus, the hypothesis of this work is that the use of nutrient controlled-release fertilizer can be used as a base fertilizer in the production of yerba mate seedlings. Given the above, the objective of this study was to evaluate the growth and quality of *I. paraguariensis* seedlings subjected to doses of controlled-release fertilizer, in order to define the most suitable dose for this stage of the crop.

2 Material and Methods

Yerba mate seeds collected in January 2018 in Arvorezinha, Rio Grande do Sul state (28º50'56" S and 52º14'14" W) were placed for stratification in white polyethylene trays (192 x 116 x 64 mm) with sand added with 4.0 g L^{-1} of Basacote Plus 6M® controlled-release fertilizer (CRF) (16-8-12 + 2) for six months. After this period, the seedlings were sown in conical polypropylene tubes, with a capacity of 110 cm^3, containing a Sphagnum peat-based commercial substrate (Table 1) and different fertilization treatments. Five seeds were sown in each tube.

For the fertilization treatments, CRF Basacote® Mini 6M (13-6-16 + 1.4) was used, with a particle size from 1.0 to 2.5 mm and an effective duration of 6 months (Table 1). The following doses were used: zero (control), 2, 4, 6, 8 and 10 g L^{-1}, incorporated into the substrate before filling the tubes. Topdressing fertilization was not carried out and irrigation was performed using a sprinkler, with a flow rate from 8 to 20 mm day^{-1}, according to the plants' needs observed through the monitoring at least three times a week. The experiment was kept in a greenhouse and the trays with tubes were covered with a black shading screen with 50% light interception, placed 50 cm above the upper part of the trays for seven months, and removed in the last 30 days of cultivation.

Table 1 - Chemical characteristics of controlled-release fertilizer (CRF) and physical and chemical characteristics of the commercial substrate used in the production of yerba mate (*Ilex paraguariensis* A.St.-Hil.) seedlings

Basacote® Mini 6M (13-6-16 + 1.4)		**Commercial Substrate**	
N (%)	**13 total***	**Physical Characteristics**	
P_2O_5 (%)	6	DD (kg m^{-3})	135.76
K_2O (%)	16	TP (%)	77.85
S (%)	10	AS (%)	21.24
B (%)	0.02	RAW (%)	16.82
Cu (%)	0.05	BW (%)	3.43
Fe (%)	0.26	RW (%)	36.35
Mn (%)	0.06	Chemical characteristics	
Mo (%)	0.015	EC	0.1 mS cm^{-1}
Zn (%)	0.02	pH	6.01

*8% N in the ammoniacal form and 5% N in the nitric form; DD=dry density; TP=total porosity; AS=air space; RAW=readily available water; BW=buffering water; RW=remaining water; EC=electrical conductivity obtained in a 1:5 (v/v) solution; pH=determined in water, dilution 1:5 (v/v).

Source: research data.

The stratification period was from March to September 2019 and seedling production was from September 2019 to May 2020. The minimum (Min T°), average (Mean T°) and maximum (Max Tº) temperatures, minimum (Min RH), average (Mean RH), and maximum (Max RH) relative humidity during the period of seedling development were monitored using an AK174 Akso® datalogger (Figure 1).

Figure 1A - Minimum, average and maximum temperatures and relative humidity (%) during the period of development of the yerba mate (*Ilex paraguariensis* A.St.-Hil.) seedlings

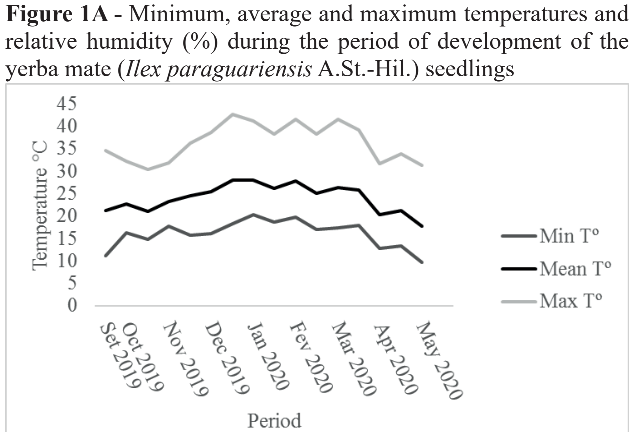
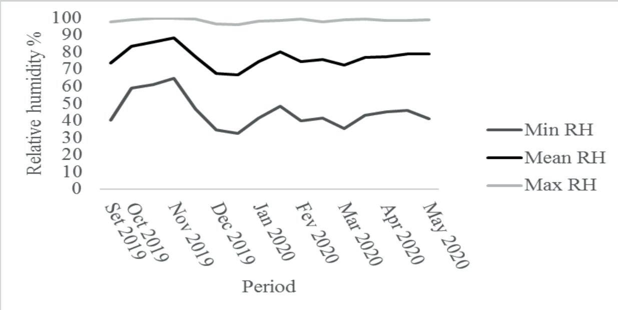


Figure 1B - Minimum, average and maximum temperatures and relative humidity (%) during the period of development of the yerba mate (*Ilex paraguariensis* A.St.-Hil.) seedlings



Source: research data.

After eight months of cultivation, data on the seedling height (H) (cm) (distance from the collar to the apical bud) were obtained using a millimeter ruler; collar diameter (CD) (mm) was measured with a digital caliper (0.01 mm); leaf number (LN) and leaf area (LA) (cm^2) was obtained by detaching the leaves from the stem and their arrangement on a dark surface for photographic image taking, followed by analysis using the ImageJ software (cm^2) (Araújo *et al*., 2018; Zavistanovicz *et al*., 2017). To obtain data on the shoot dry mass (SDM) and root dry mass (RDM) (g), the aerial part was detached from the root system, followed by washing the roots in running water to remove the excess substrate. Then, they were individually wrapped in paper bags for drying in an oven at 65 °C until reaching constant weight. After, they were weighed on an analytical balance (0.00001 g). The total dry mass (TDM) was obtained by the sum of the shoot dry mass and root dry mass (g).

Next, it was calculated the height (cm) and collar diameter (mm) ratio (HCDR) (Dickson *et al*., 1960), the height and shoot dry mass ratio (HSDMR), and the shoot and root ratio dry mass (SRDMR) by dividing the values between them (GOMES *et al*., 2002).

The Dickson Quality Index (DQI) (DICKSON *et al*., 1960) was calculated using the following formula:

$$DQI = \frac{TDM}{\frac{H}{CD} + \frac{SDM}{RDM}}$$

Where:
TDM – Total dry mass (g)
H – Height (cm)
CD – Collar diameter (mm)
SDM – Shoot dry mass (g)
RDM – Root dry mass (g)

The experimental design was completely randomized with six treatments and five replications, with nine seedlings in each repetition. Data on H, CD, HCDR, LN, LA, SDM, RDM, TDM, SRDMR, HSDMR, and DQI were submitted to analysis of variance (ANOVA). When significance was observed, the means were analyzed by regression using the SigmaPlot 11.0 software. The data of LA, SDM, RDM, TDM, and DQI did not meet the assumption of normality, being transformed to log x/10. The same happened with HSDMR, which was transformed to √x+10, but the results are presented in their absolute values.

3 Results and Discussion

For all the variables analyzed, the significant effect of treatment was verified, indicating a positive response of the yerba mate seedlings to fertilization. Increasing doses of controlled-release fertilizer (CRF) provided increases in H, CD, HCDR, LN, LA, SDM, RDM, TDM, SRDMR, HSDMR, and DQI concerning not-fertilized yerba mate seedlings (Table 2). The morphological parameters such as H, CD, LN, SDM, RDM, and TDM, evaluated in this work, are the most used for the determination of the quality standard of seedlings, and the results are easily understood by nursery workers (Gomes *et al*., 2002). With these results, if the seedlings do not show satisfactory growth, the nursery worker can intervene in the management, changing some factors that may be affecting the performance, such as fertilization, irrigation, seedling density, and light intensity.

Table 2 - Variance analysis in the development of yerba mate (*Ilex paraguariensis* A.St.-Hil.) seedlings produced in different doses of controlled-release fertilizer (CRF) (Basacote® Mini 6M 13-6-16 + 1.4)

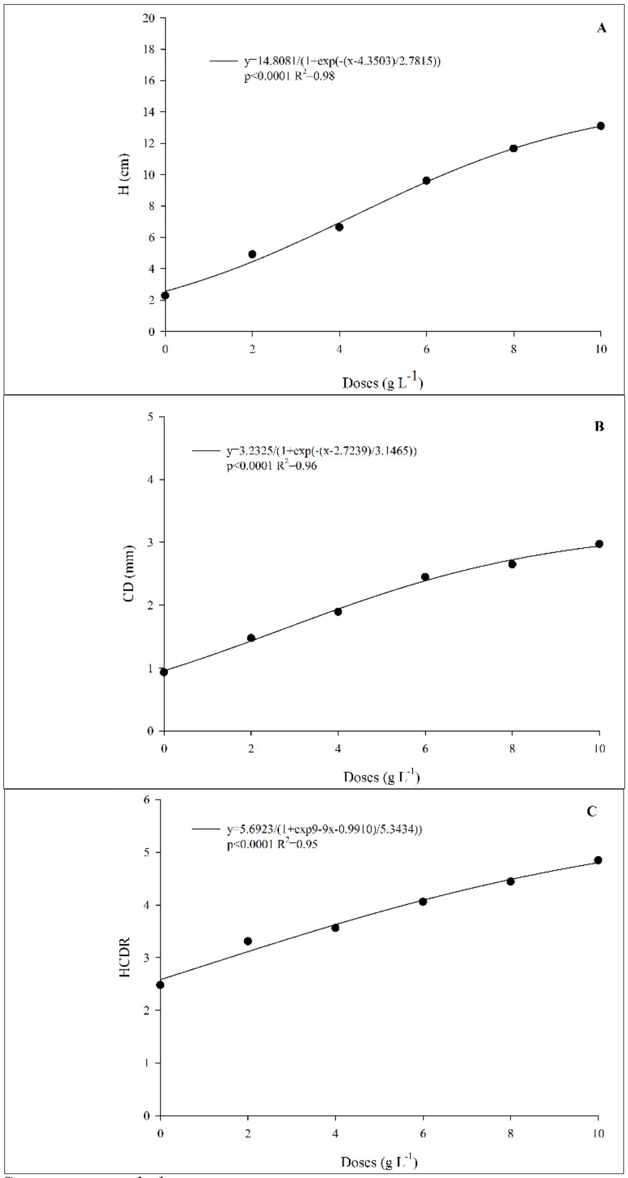
Variables	p value	CV (%)	Mean	Transformed to
H (cm)	<0.001	11.09	8.04	-
CD (mm)	<0.001	11.54	2.06	-
HCDR	<0.001	6.90	3.71	-
LN	<0.001	12.66	7.58	-
LA (cm^2)	<0.001	14.28	59.14	log(x/10)
SDM (g)	<0.001	5.87	0.48	log(x/10)
RDM (g)	<0.001	6.45	0.21	log(x/10)
TDM (g)	<0.001	6.39	0.69	log(x/10)
SRDMR	<0.001	15.57	1.95	-
HSDMR	<0.001	7.74	57.82	raiz(x+10)
DQI	<0.001	4.96	0.11	log(x/10)

CV=coefficient of variation; H=height; CD=collar diameter; HCDR=height and collar diameter ratio; LN=leaves number; LA=leaf area; SDM=shoot dry mass; RDM=root dry mass; TDM=total dry mass; SRDMR=Shoot and root dry mass ratio; HSDMR=height and shoot dry mass ratio; DQI=Dickson Quality Index.

Source: research data.

The treatment without fertilizer showed the lowest height (H) of seedlings (2.3 cm) and as the fertilizer dose was increased, an increase was observed for this variable, with the highest height (13.1 cm) at the highest concentration (10 g L^{-1}) (Figure 2A). Similar behavior was observed for the collar diameter (CD), where seedlings had 2.98 mm in diameter at the highest concentration (10 g L^{-1}) against 0.93 mm in the control (0 g L^{-1}) (Figure 2B). For HCDR, a variation from 2.5 to 4.8 was observed for the control and the maximum concentration of fertilizer, respectively (Figure 2C).

Figure 2 - Height (H) (cm) (A), collar diameter (CD) (mm) (B) and height and collar diameter ratio (HCDR) (C) of yerba mate (*Ilex paraguariensis* A.St.-Hil.) seedlings produced in different doses of controlled-release fertilizer (CRF) (Basacote® Mini 6M 13-6-16 + 1.4)



Source: research data.

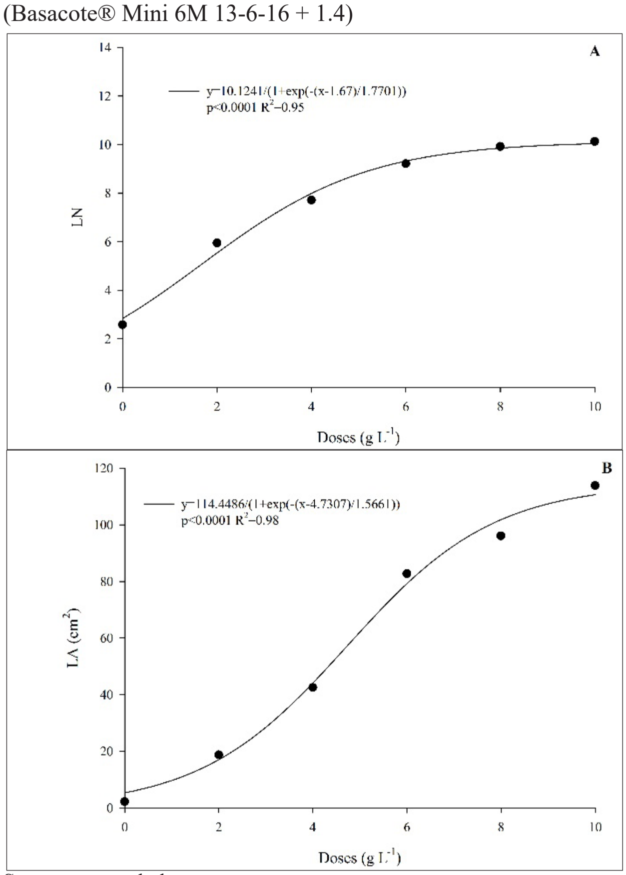
For the classification and selection of seedlings, height is one of the most used parameters (Gomes *et al*., 2002) which, together with the collar diameter, are non-destructive and easy to be measured (Araújo *et al*., 2018, 2020; Gomes *et al*., 2002). Furthermore, they are the most important and most used morphological characteristics in the evaluation of seedling quality. The collar diameter is a good indicator that can be correlated with seedling development in the field (Landis *et al*., 2010).

Regarding height, Cabreira *et al*. (2021) also found that *Inga laurina* (Sw.) Willd seedlings without fertilization had the lowest mean height. For collar diameter, seedlings of *Melanoxylon brauna* Schott (Gibson *et al*., 2019) showed an increasing linear behavior for this variable with the use of CRF Basacote Mini 6M (13-6-16) when compared to seedlings without fertilization, demonstrating the potential of the seedlings to respond to CRF, as observed in this work.

Plant height is directly related to nursery management; however, if analyzed individually, it may not be a good indicator of seedling quality (Araújo *et al*., 2018). Thus, the analysis of the height and collar diameter ratio (HCDR) is a simple way to visualize the balance between development and firmness of the aerial part, which is synonymous of robustness (Landis *et al*., 2010). In this study, it was observed that starting with 6 g L^{-1}, this ratio is 4.1, indicating that, from this concentration onwards, the seedlings are more robust, with balanced aerial part (Figure 2C).

For the leaves number (LN), the treatment without fertilizer application resulted in 2.6 leaves per plant, as the fertilizer dose was increased, this variable increase as well. The use of 6 g L^{-1} of fertilizer resulted in plants with 9.2 leaves and 10.1 leaves with 10 g L^{-1}, indicating a stabilization for this variable from 6 g L^{-1} (Figure 3A). For the leaf area (LA), the more leaves in the plants the more larger leaves resulted. In the control, the seedlings had 2.2 cm^2 of leaf area, with 4 g L^{-1} they already had 42.5 cm^2, and with 6 g L^{-1}, there was an increase of 105% (82.7 cm^2). And at the highest concentration, the seedlings had the largest leaf area (113.9 cm^2) (Figure 3B).

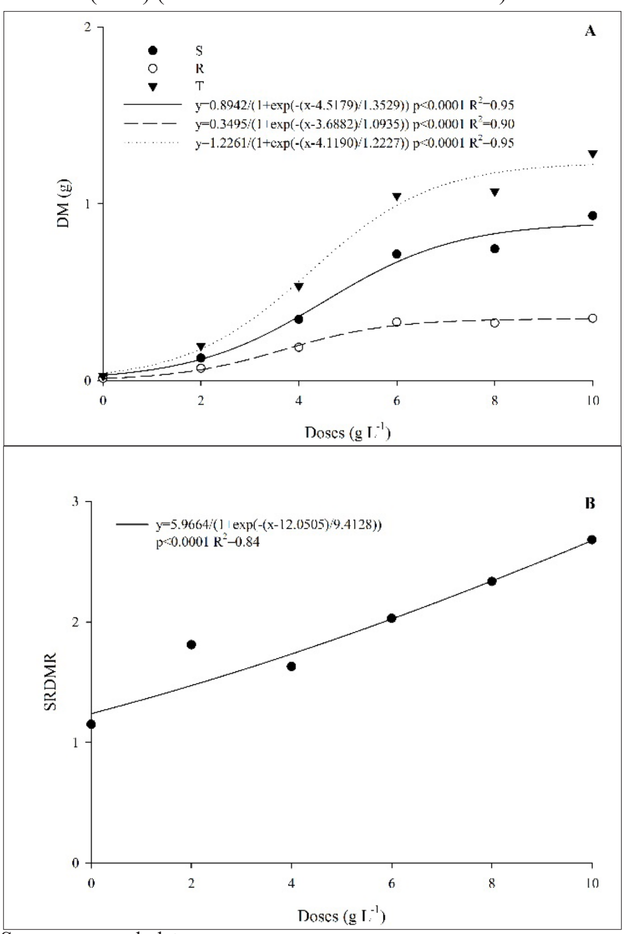
Figure 3 - Leaves number (LN) (A) and leaf area (LA) (cm^2) (B) of yerba mate (*Ilex paraguariensis* A.St.-Hil.) seedlings produced in different doses of controlled-release fertilizer (CRF) (Basacote® Mini 6M 13-6-16 + 1.4)



Source: research data.

The shoot (SDM), root (RDM), and total dry mass (TDM) had similar behavior, with less accumulation of dry mass in the control. From 6 g L^{-1} on, the accumulation of SDM, RDM and TDM increased considerably when compared to lower concentrations (Figure 4A). The 6 g L^{-1} resulted in plants with 0.72 g of SDM, 0.33 g of RDM, and 1.05 g of TDM, and with 10 g L^{-1} of fertilizer, the values were 0.93 g, 0.35 g, and 1.28 g, respectively. The SRDMR ranged from 1.1 to 2.7 and, again, the lowest value was for the treatment without fertilizer and the highest for the maximum tested dose (10 g L^{-1}) (Figure 4B). From 6 g L^{-1} on, the ratio was greater than 2.0.

Figure 4 - Shoot dry mass (SDM), root dry mass (RDM) and total dry mass (TDM) (g) (A) and shoot and root dry mass ratio (SRDMR) (B) of yerba mate (*Ilex paraguariensis* A.St.-Hil.) seedlings produced in different doses of controlled-release fertilizer (CRF) (Basacote® Mini 6M 13-6-16 + 1.4)



Source: research data.

The number of leaves and leaf area are directly related to the physiological capacity of the seedlings, with effects on productivity, as they play a role in the interception of light energy used in metabolic processes that convert it into chemical energy through the synthesis of carbon compounds (Araújo *et al*., 2018). In this study, as the fertilizer dose was incremented, the number of leaves increased, but from 6 g L^{-1} onwards, this variable stabilized. However, for the leaf area, this behavior was not observed because, at the highest dose (10 g L^{-1}), an increase of 38% compared to the dose of 6 g L^{-1} was observed. Fertilization doses increased the shoot, root, and total dry mass, a behavior similar to that observed for leaves number, stabilizing from 6 g L^{-1} onwards.

These results may be associated with the management in the nursery, since a particular accumulation of dry mass and leaves number there was stabilization of these variables and the plants, probably as a result of competition for light, they started to invest in increasing the leaf area. Higher leaf area indices are observed in higher seedling densities as an alternative to increasing solar interception (Trautenmüller *et al*., 2017). It was observed in this work that the seedlings were not spaced and, as they grew, the leaf area increased, with stagnation in the leaves number and dry mass from 6 g L^{-1} on. Plants are expected to have plasticity when they grow in environments with different resources (water, light, and/or nutrients), which helps to maintain the stability of physiological characteristics, such as dry mass accumulation (Olguim *et al*., 2020).

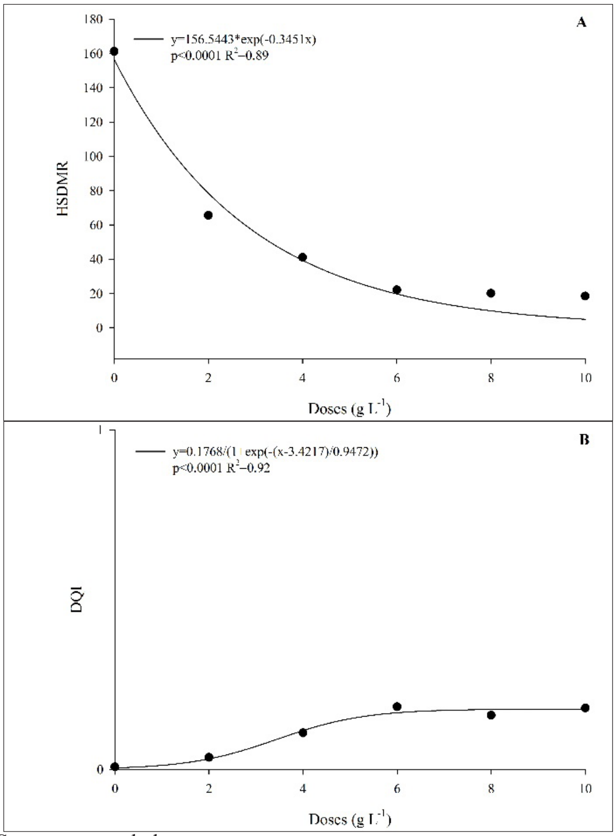
Plants' densification can cause shading on the lower leaves (Araújo *et al*., 2018), however, for climax species, such as yerba mate, which is environmentally adapted to conditions with a high level of shading, it can grow under conditions of closed canopy in little light (Poletto *et al*., 2010). This fact corroborates the results observed in this study, which demonstrated the capacity of the species to invest in increasing leaf area to be more efficient in intercepting solar radiation.

Silva *et al*. (2019) found that increasing doses of Osmocote Plus in the cultivation of *Acacia mangium* contributed to increasing the shoot and root dry mass, with positive effects on seedling development. For seedlings of *Euterpe oleraceae*, root dry mass increased with doses of Osmocote fertilizer (Araújo *et al*., 2019).

Dry mass is a consequence of the photosynthetic process in the plant. It is the outcome of net photosynthesis, that is, plant maintenance expenses such as respiration, fluorescence, among others are discounted (Araújo *et al*., 2018). In general, the value of the shoot dry mass is greater than the root dry mass, so the relationship between these two parameters (SRDMR) is another indication of seedling quality (Araújo *et al*., 2018), usually being a good indicator of seedling performance in the field (Landis *et al*., 2010). The SRDMR value is associated with factors inherent to the species, such as container size and nursery management, with values ranging from 1 to 3 (Araújo *et al*., 2018). The higher the ratio, the greater the chances of the seedlings in surviving periods of drought in the field and the better the competition with weeds (Matos *et al*., 2021).

For HSDMR, it was found that the higher the concentration of fertilizer, the lower the relationship between the two variables (Figure 5A). For the treatment without fertilizer, this ratio was 161.2 and with 10 g L^{-1} of Basacote, the value was 18.5. Dickson's quality index (DQI) increased as fertilizer doses were increased; however, at doses greater than 6 g L^{-1} this increase was less significant with a tendency to stabilize (Figure 5B).

Figure 5 - Height and shoot dry mass ratio (HSDMR) (A) and Dickson quality index (DQI) (B) of yerba mate (*Ilex paraguariensis* A.St.-Hil.) seedlings produced in different doses of controlled-release fertilizer (CRF) (Basacote® Mini 6M 13-6-16 + 1.4)



Source: research data.

The relationship between height and shoot dry mass ratio (HSDMR) is another index that presents a relative contribution to the quality of seedlings (Gomes *et al*., 2002), being synonymous of rusticity (Dutra *et al*., 2016). For this index, it was observed that the higher the fertilizer concentration, the lower the relationship between height and shoot dry mass (Figure 5A). A similar result was observed for *Peltophorium dubium* where, the increment in the dose of Osmocote increased seedling rusticity (Dutra *et al*., 2016).

The DQI varies among species and, in general, the data available for species from the Atlantic Forest are still scarce (Cabreira *et al*., 2021). For *Inga laurina*, there was an increase in the DQI with the doses of CRF (Cabreira *et al*., 2021), whereas for *Peltophorium dubium*, no significant effect was observed for the Osmocote fertilizer (Dutra *et al*., 2016). In the present work, DQI stabilized with the use of 6 g L^{-1}, presenting a behavior similar to that observed for LN and DM, which may be related to the lack of spacing between the seedlings as they were growing. A positive effect of fertilization on HSDMR and DQI was also observed for *Acacia manguium* seedlings, cultivated with CRF (Silva *et al*., 2019).

The doses of CRF vary in the production of seedlings of native species, as they have different nutritional needs and the type of substrate must be considered (Cabreira *et al*., 2021). This was shown in this study because even with the use of a commercial substrate containing nutrients in its formulation, they were not sufficient for the growth of the yerba mate seedlings as observed for the control. Fertilization is an essential practice in nurseries for biomass accumulation, as nutritional deficiencies affect plant metabolism and reduce seedling growth (Zavistanovicz *et al*., 2017). However, it is extremely important to use adequate doses to avoid wasting resources, in addition to avoiding the toxic effects caused by the excessive use of mineral fertilizers. In general, the addition of CRF for the production of forest species seedlings has positive responses (Gibson *et al*., 2019). Seedlings of *Cedrela fissilis* (Navroski *et al*., 2016), *Moringa oleifera* (Rosa *et al*., 2018) and *Euterpe oleraceae* (Araújo *et al*., 2019) show good growth with base fertilization consisting of CRF. Well-fertilized *Inga laurina* seedlings showed a higher survival rate after 12 months of field planting (Cabreira *et al*., 2021), confirming the importance of using well-nourished seedlings.

The measurable parameters in the nursery must be related to the performance of seedlings in the field; however, they are linked to the species, inputs, and management. Another difficulty is the establishment of standards in the evaluation of these attributes since exotic species (*Pinus* and *Eucalyptus*) are used as a reference for the cultivation of native species due to limitations in studies with local species (Araújo *et al*., 2018).

The demand for nutrients is determined by climatic conditions and the rate of growth of the species. Seedlings produced in spring and summer need higher doses of fertilizer in relation to those produced in autumn and winter because in the period with higher temperatures there is greater metabolic activity (Araújo *et al*., 2018). Thus, the results of this work are linked to the specific environmental conditions of the study period.

The results of the variables analyzed in this work validated the hypothesis that CRF can be used for the production of yerba mate seedlings. (Figure 6). Thus, from the dose of 6 g L^{-1} of Basacote® Mini 6M (13-6-16 + 1.4) satisfactory development was observed for most of the morphological characters analyzed in this work, as well as for the indices obtained from these variables.

Figure 6 - Morphological aspect of yerba mate (*Ilex paraguariensis* A.St.-Hil.) seedlings produced with different doses of controlled-release fertilizer (CRF) (Basacote® Mini 6M 13-6-16 + 1.4)

Source: research data.

Native forestry has advanced, but further studies are needed to establish the ideal nutritional conditions for each species (Gibson *et al*., 2019). More studies in the area of production of yerba mate seedlings should be carried out taking into account different substrates, tube sizes, types, and doses of fertilizers, in addition to monitoring and evaluating the performance of these seedlings in the field, providing subsidies to nursery workers and producers of this important production chain.

4 Conclusion

Controlled-release fertilizer promotes the growth and quality of yerba mate seedlings. For the conditions of this study, doses from 6 g L^{-1} of Basacote® Mini 6M (13-6-16 + 1.4) can be used in the base fertilization of yerba mate seedlings.

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