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Black pepper plantlets under controlled-release fertilizer: growth and chlorophyll contents

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Abstract

The study aimed to investigate the effect of controlled-release fertilizer N14-P14-K14 (CRF) on the morphological traits and chlorophyll indices of black pepper plantlets (*cv.* Bragantina). One experimentation was carried out in a greenhouse between March and July 2018 in the Rio de Janeiro state/Brazil. Were tested four doses' equivalents to 0.0, 2.5, 5.0, and 10.0 kilogram of CRF per cubic meter of the substrate, which was obtained by mixing clayey soil and crushed coconut fiber, on 1:3 volume proportion. The experimental design was completely randomized, with 17 replicates to assess the morphological characteristics and nine replicates to assess the chlorophyll contents. At 120 days after transplanting were assessed main stem height (H), the number of leaves (NL), leaf area index (LAI), total dry matter (TDM), shoot dry matter (SDM), and root dry matter (RDM). Chlorophyll *a*, *b*, *a+b* contents and *a/b* ratio were assessed too. The application of CRF fertilizer increased the NL and SDM values until 9.6 kg m^{-3} dose. The values of H, TDM, LAI, and RDM increase until 9.3, 8.4, 8.2, and 6.4 kg m^{-3} doses, respectively. The chlorophyll *a* and *b* contents increased until 7.7 kg m^{-3} dose. It's recommended to apply 8.4 kg of CRF 14N-14P-14K per cubic meter of the substrate to produce black pepper plantlets with adequate commercial pattern and chlorophyll levels.

Keywords: Commercial standard, mineral fertilizer, *Piper nigrum* L., potting

Introduction

Brazil is one of the five largest producers of black pepper (*Piper nigrum* L.) in the world (FAO, 2019). The Brazilian production in the 2017 year was 46.9 thousand tons and was more important in Pará and Espírito Santo states, which produced around 48.5% and 45.9%, respectively of this amount (IBGE, 2021).

Between 2012 and 2017 there was an average increase of 3,200 hectares of new areas cultivated with black pepper in Brazil (IBGE, 2021), which may have represented the demand of approximately 6.4 million plantlets per year, considering a planting density of 2,000 plants per hectare.

As the vegetative propagation by cuttings is the most common method of reproduction of black pepper in Brazil, some criteria must be adopted for the selection of the inputs involved in this process, such as pathogen-free propagative material and quality substrates (Cruz et al., 2022; Secundino et al., 2019).

In general, Brazilian producers of black pepper plantlets use standard substrates composed of soil, sand, and organic matter (Serrano et al., 2012). For this purpose, the use of subsurface soil is recommended, given the lower possibility of infection by *Fusarium solani* f.sp. *piperis*.

However, in Brazil, mineral soils with clay 1:1 and 2:1 predominate, which may have low nutrient reserves, making it necessary to use chemical correction for adequate nutrition of black pepper plantlets (Freire et al., 2017; Serrano et al., 2012).

In this line, the use of controlled-release fertilizers (CRF) has been shown to be efficient in several crops. Cabreira et al. (2019) obtained seedlings of *Schizolobium parahyba* with better growth characteristics when applying 8.3 kg cm^{-3} of CRF 15-09-12. Chatzistathis et al. (2020) observed an increase in biomass, micronutrient content and PSII activity in plants of *Olea europaea*

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L. (cv. 'Koroneiki') subjected to fertilization with CRF 19-06-11, compared to organic manure application. Menegathi et al. (2020) observed positive quadratic responses of morphological variables of young plants of *Prunus persica* L. (Batsch), cv. Capdeboscq, as a result of the application of CRF 19-06-10, with the dose of maximum technical efficiency around 6.2 g L^{-1}. Serrano et al. (2012) observed effects of doses of CRF 15-09-12 on the morphological characteristics of three cultivars of black pepper, with the highest accumulations of total dry matter occurring at doses of 4.4 kg m^{-3} (cv. 'Guajarina'), 6.4 kg m^{-3} (cv. 'Iaçará') and 5.3 kg m^{-3} (cv. 'Singapura').

In addition to meeting the nutritional demand of plants, the use of CRF is capable of considerably reducing fertilizer application rates. By using CRF to apply only 70% of the amount of NPK commonly used in commercial plantations of *Macadamia hildebrandii* and *Melaleuca alternifolia*, Achilea et al. (2010) observed an increase of 33% in total and grain yields and a 19% increase in the amount of collected leaves and essential oils, respectively.

However, it is important to expand the scientific knowledge base in the use of CRF on the cultivation of black pepper seedlings, especially when considering photosynthetic traits and the use of non-commercial substrates. Chlorophyll levels are indicators of the N state of plants (Valença et al., 2018).

This study aimed to evaluate the effect of the application of controlled-release fertilizer NPK 14-14-14 on morphological traits and chlorophylls indices of black pepper plantlets (cv. Bragantina) cultivated in a non-commercial substrate.

Materials and Methods

The experiment was conducted between March and July 2018 in Seropédica-RJ, Brazil (22°45'50" S, 43°41'51" W, 26 m altitude), in a greenhouse. The greenhouse had a thermal control system by exhaustion and water circulation, which was adjusted to actuated whenever the air temperature was higher than 30 °C, allowing that this parameter was relatively stable during the experiment (Figure 1).

Plantlet's production

The plantlets used in the experiment were produced from cuttings with one bud and one leaf, rooted for 75 days in a sandy medium. The cuttings were collected from orthotropic branches from adult (3-year-old) donor plants of black pepper, cv. Bragantina, without symptoms of diseases or nutritional deficiency, is maintained in a commercial nursery located in São Mateus-ES.

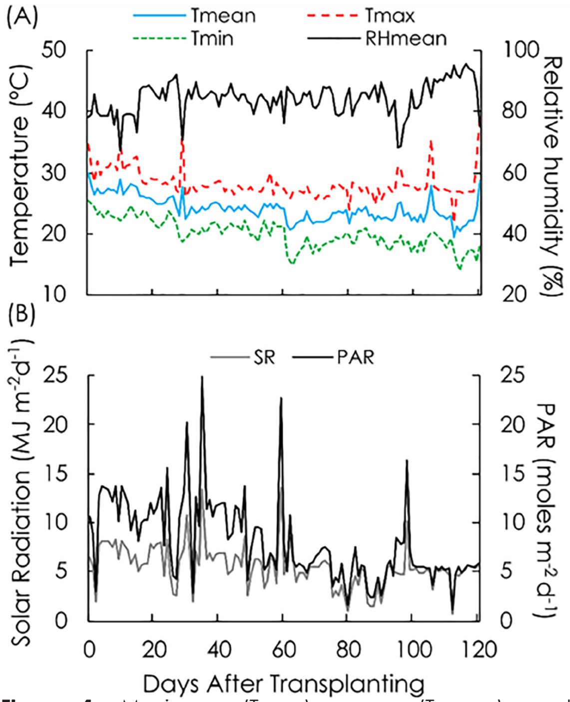

Figure 1. Maximum (Tmax), mean (Tmean), and minimum (Tmin) values of daily air temperature, mean relative humidity (RHmean), and accumulated daily values of solar radiation (SR) and photosynthetically active radiation (PAR), recorded inside the greenhouse during the experimental period.

Before planting in the sand medium (rooting process), the cuttings were sanitized by immersion in fungicide solution based on Carbendazim (2 g c.p. L^{-1}) for five minutes, followed by shade drying for 30 minutes. Rooting induction was performed by applying indole-butyric acid (4.0 g kg^{-1} of inert powder) directly at the base of the cuttings (Secundino et al., 2019).

Treatments and statistical design

The experimental design was completely randomized, with four doses of controlled-release fertilizer Forth Cote® 14N-14P-14K (CRF) equivalents to: 0.0; 2.5; 5.0; and 10.0 kg of CRF per m^{-3} of the substrate. For the evaluation of morphological characteristics, 17 replicates were considered (each replicate consisted of one plant), among which nine were randomly chosen to estimate leaf chlorophyll contents.

According to the fabricant guarantees the CRF contains 14% total N (8,2% NH_3^+-N and 5,8% NO_3^--N), 14% P_2O_5 (soluble in ammonium neutron citrate + water), and 14% K_2O (soluble in water). To determine the levels of other nutrients in the CRF, we carry out chemical analyzes. Thus, it was possible to identify that in addition to N, P, and K, the CRF had about 5.7% of Ca, 0.4% of Mg, and 0.1% of Fe.

Transplantation

After the rooting process, the plantlets have been their root system washed in running water to remove the sand excess and they were transplanted to plastic tubes containers (290 cm^3), which was filled with substrate obtained by mixing clayey soil and crushed coconut fiber (3:1 proportion, in volume basis).

The application of CRF occurred before transplanting by manual mixing, according to the doses tested.

Coconut fiber used in the mixing was the commercial product Golden Mix, standard 11 (Amafibra, Artur Nogueira/SP), indicated for the production of eucalyptus and coffee clonal plantlets. While the clayey soil was collected from subsurface layers of Ultisol soil, located near the experimental site.

The bioavailable chemical characteristics of the substrate were: pH in H_2O = 5.1; Total N (Kjeldahl) = 3.4 g kg^{-1}; P^{4+} = 26 mg dm^{-3}; K^+ = 57 mg dm^{-3}; Ca^{2+} = 4.0 $cmol_c$ dm^{-3}; Mg^{2+} = 1.6 $cmol_c$ dm^{-3}; Fe^{2+} = 145 mg dm^{-3}; Mn^{2+} = 37 mg dm^{-3}; Zn^{2+} = 2.3 mg dm^{-3}; Cu^{2+} = 0.9 mg dm^{-3}; H + Al = 3.2 $cmol_c$ dm^{-3}; Al^{3+} = 0.1 $cmol_c$ dm^{-3}; Cation exchange capacity (CEC) = 9.1 $cmol_c$ dm^{-3}; and Base saturation (V value) = 64%.

Thus, the substrate had medium acidity; low content of K^+, medium contents of available P, Ca^{2+}, and Cu^{2+}, high contents of Mg^{2+}, Zn^{2+}, Fe^{2+}, and Mn^{2+}, and V value and CEC considered medium (Prezotti et al., 2007).

After transplantation, the tubes were accommodated in plastic trays positioned on benches, approximately 0.8 m high, resulting in a planting density of 68 plants m^{-2}.

Before the beginning of the experiment, the substrate moisture was standardized, being manually raised to near saturation (0.62 cm^3 cm^{-3}). The substrate packing density was approximately 0.52 g cm^{-3}, and the parameters of Van Genuchten equation were: α = 0.1554; n = 1.957; θ_r = 0.121 cm^3 cm^{-3}; θ_s = 0.616 cm^3 cm^{-3}; and m =1-1/n.

The water supply was carried out by a drip irrigation system, automatically managed. To this were used two simplified irrigation controllers - SIC (Valença et al., 2018) installed in reference plantlets, which were fertilized with a dose of 5.0 kg of CRF per cubic meter of the substrate. Thus, the number, frequency, and duration of irrigation during the experiment were dependent on these control plants' water demand.

The SIC's were made with a sensor body, composed by a porous capsule. This sensor, allied to the other SIC components, was able to measure the water retention tension in substrates (WRT) by the tensiometer principle, triggering the irrigation system (IS) always when WRT was about 4 kPa. In the same way, once started the IS, the SIC was able to automatically identify the return of the initial water condition (WRT near to 0 kPa), turning off the IS until the next event (Sousa et al., 2020).

To allow the use in containers with small dimensions, as those used in the present work, the porous capsules of the SICs were manually manufactured from porcelain filter elements, commonly used in water filters for domestic consumption in Brazil (Bezerra et al., 2019). The final capsule dimensions were approximately 0.5 cm in diameter and 5.0 cm in length.

Data collection

At 120 days after transplanting (DAT), the following parameters were evaluated: main stem length (H), number of leaves (NL), leaf area index (LAI), shoot dry matter (SDM), root dry matter (RDM), total dry matter (TDM), chlorophyll *a* (Chl_a) and chlorophyll *b* content (Chl_b).

Chl_a and Chl_b were estimated using a chlorophyll meter - ClorofiLOG CFL 1030 model (Falker Automação Agrícola - Porto Alegre/RS), with three measurements in the middle portion of each younger and fully expanded leaf per plant. The Chl_a and Chl_b values were used to calculate the total chlorophyll (Chl_{a+b}) content (by the sum of them) and the chlorophyll *a* and *b* ratio ($Chl_{a/b}$).

Measurements of H and NL were performed directly, in the first case using a millimeter measuring tape, taking the distance between the stem and the apical bud of the longest stem, and in the second case by counting the adhered and fully expanded leaves.

After these measurements, the plants were harvested with a cut close to the surface of the substrates. They were then divided into leaves, stems, and roots, and each part was packed in properly labeled paper packages. The leaf area per plant was determined by summing the leaf areas, in a leaf area integrator - LAI 3010 model (Licor Inc., Lincoln, NE, USA). LAI was the ratio between leaf area and the average area occupied by each plant (about 147 cm^2).

After the harvest, the root system was washed in running water and dried in shade for 30 minutes. The root material was placed in labeled paper bags and dried in a forced circulation oven at 65 °C for 72 hours, or until reaching constant weight, and their RDM was determined by weighing on a semi-analytical scale. For the determination of SDM, the dry matters of leaves and stems were summed. The TDM value consisted of the sum of SDM and RDM.

At the end of the experimental period, substrate samples were collected for the determination of pH in water.

Statistical analyzes

Normality and homogeneity of residuals were verified by the Shapiro-Wilk and Bartlett's tests, respectively, at 5% probability level. LAI, SDM, and Chl_b data were transformed to $x^{0.5}$. After that, analysis of variance (ANOVA) was performed using the F test at 5% probability level.

When at least one treatment differed from the others, according to ANOVA, regression analyses were performed, testing linear and second-order polynomial models. Regression models were analyzed by the least square method, through the application of matrix algebra (Ferreira, 2011). The most appropriate regression model was chosen when occurred: non-significant regression deviation; significance of the model fit at 5% probability level by F test; the highest value of the coefficient of determination (R^2).

All statistical analyses were performed using the computational programs R, version 3.6.0 and Sisvar, version 5.6 (Ferreira, 2011).

Results and Discussion

Morphological traits of black pepper plants were significantly (p≤0.05, F test) affected by the application of CRF. The highest values of NL (8.3 leaves) and SDM (1.92 g $plant^{-1}$) have occurred when the CRF doses were 9.6 kg m^{-3} of the substrate. The highest values of H (31.0 cm), TDM (2.44 g $plant^{-1}$), LAI (1.6 m^2 m^{-2}), and RDM (0.55 g $plant^{-1}$) occurred when the CRF doses were 9.3, 8.4, 8.2, and 6.4 kg m^{-3} of the substrate, respectively (Figure 2).

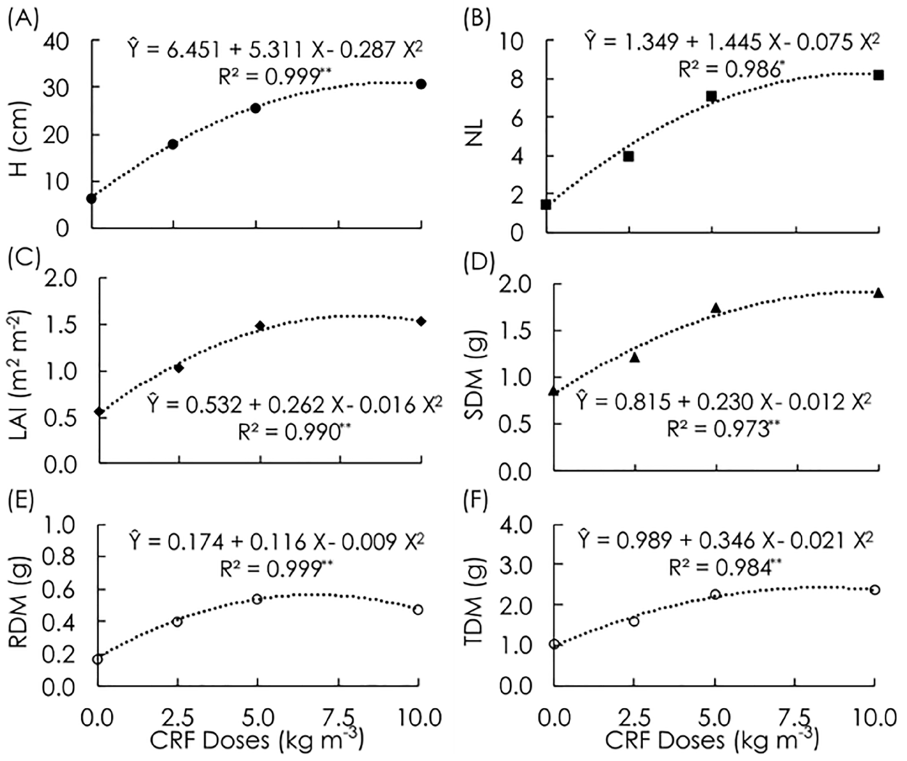

Figure 2. Morphological traits of black pepper plants, cv. Bragantina, at 120 days after transplantation, as a function of doses of controlled-release fertilizer (CRF). H- Main stem height; NL – number of leaves; LAI – leaf area index; RDM – root dry mass; SDM – shoot dry mass; TDM- total dry mass; and **, *Significant at 1% and 5% probability levels by F test.

Maximum H values observed in the present work were higher than found by Serrano et al., 2012 (ranged from 27.0 to 30.7 cm), which evaluated the effects of increasing doses of CRF 15-09-12 on black pepper plantlets cultivation, cultivars Cingapura, Iaçará, and Guajarina, using a commercial substrate. However, most of the maximum values of the growth traits (NL, SDM, RDM, and TDM) were lower than those founded by Serrano et al., 2012, mainly regarding cv. Guajarina, whose values were about 63% (SDM), 74% (RDM), and 66% (TDM) higher than observed in the present work. This may due to a relatively higher initial fertility level of substrate used by those authors, which has between 57% and 93% more N, K, Ca, and Mg than the substrate used in the present work. In addition, cv. Bragantina have less rhizogenic competence, comparing with cultivars Cingapura, Iaçará, and Guajarina (Freire et al., 2017; Secundino et al., 2019), which can represent a disadvantage to this cultivar, in terms of agronomical traits.

Maximum values of H and NL were higher than observed by Cruz et al., 2022 [ranged from 16.0 to 18.9 cm (H) and from 6.04 to 7.79 leaves per plant], who evaluated the effects of different substrates and irrigation levels on black pepper, cv. Bragantina, plantlets growth. These H and NL values were superior to those observed by Prasath et al. 2014 too [ranged from 6.8 to 20.8 cm (H) and from 2.5 to 4.5 leaves per plant]. Those authors have studied the influence of several substrates on growth traits of cultivars Panchami, Sreeka, IISR Sakthi, and IIRS Thevam in India.

Observed maximum SDM value in this work was inferior to founded by Cruz et al., 2022 (2.7 g plant^{-1}), while maximum LAI value was higher than observed by those authors for plants cultivated with a substrate composed by biosolid and crushed coconut fiber mixing - BC (1.3 m^2 m^{-2}), but was inferior to observed by those authors for plants cultivated with substrates composed of biosolid + granitic rock powder - BG (1.8 m^2 m^{-2}) and biosolid+granitic rock powder+ crushed coconut fiber - BCG (2.1 m^2 m^{-2}). In the same way, the observed maximum RDM value was inferior to obtained by Cruz et al., 2022 in plants cultivated with BG substrate (0.57 g plant^{-1}) and superior to the other evaluated substrates [0.23 g plant^{-1} (BC) and 0.45 g plant^{-1} (BCG)].

Black pepper plantlets with at least 30 cm of height and six leaves are preferable for commercial crops in Brazil (Secundino et al., 2019). Considering only these two traits, it would be sufficient to apply about 7.4 kg of CRF NPK 14-14-14 per m^{-3} of the substrate to obtain black pepper plantlets, *cv*. Bragantina, with commercial standard (Figure 2a and Figure 2b). But, as mainly H can be strongly affected by nitrogen and light availability (over stem growth, in case of low light conditions), it's recommended to consider TDM as a supplementary trait to define a plantlet commercial pattern (Secundino et al., 2019). Therefore, we recommend the 8.4 kg m^{-3} dose of CRF 14-14-14 for the production of black pepper plantlets, *cv*. Bragantina, when a substrate composed of clay soil and crushed coconut fiber is used.

This dose was greater than recommended by Serrano et al., 2012 for the black pepper plantlets, cultivars Guajarina (4.4 kg m^{-3}), Iaçará (6.4 kg m^{-3}), and Cingapura (5.3 kg m^{-3}), despite the concentrations of P and K in the CRF used by those authors were higher than those concentrations in the CRF used in the present work.

This fact may be due to the lower rhizogenic competence of cv. Bragantina (Freire et al., 2017; Secundino et al., 2019), as well as the higher initial fertility (mainly the levels of N, K, Ca, and Mg) of the substrate used by Serrano et al., 2012, compared with the substrate used in the present work. These factors can lead to a lower fertilizer demand since the absorption of nutrients by plants tends to be more efficient in some black peppers cultivars and the nutrient availability tends to be influenced by the initial levels in substrates, even when mineral fertilizer is used.

The presented results highlight the importance of prior knowledge on the chemical characteristics of a substrate for cultivation in pots, the cultivated variety, and the kind of fertilizer to define an adequate fertilization strategy, avoiding a unique formula for several conditions (Silber & Bar-Tal, 2019).

The AEs were 0.812 kg kg^{-1} (2.5 kg m^{-3}), 0.863 kg kg^{-1} (5.0 kg m^{-3}) and 0.462 kg kg^{-1} (10.0 kg m^{-3}). Those results have shown that the production gain due to the application of 5.0 kg m^{-3} of CRF, compared to 2.5 kg m^{-3}, was about 0.051 kg kg^{-1}. It is a very small value, considering the duplication of the CRF dose. The worst efficiency occurred when was applied 10 kg of CRF NPK 14-14-14 per m^{-3} of the substrate, indicating fertilization without benefits.

Chlorophyll contents were significantly influenced ($p<0.05$, F test) by CRF doses (Figure 3).

Chl_a, Chl_b, and Chl_{a+b} contents showed quadratic positive responses to increasing CRF doses, while the $Chl_{a/b}$ ratio showed a quadratic negative response to CRF doses. Maximum values of Chl_a, Chl_{a+b}, and Chl_b occurred under 7.2, 7.3, and 7.7 kg m^{-3} doses of CRF, respectively. But minimal Chl_a/Chl_b ratio occurred under the dose of 7.2 kg m^{-3}. (Figure 3).

The decreasing of Chl_a and Chl_b levels and consequently decrease of Chl_{a+b}, observed under CRF doses higher than 7.2 kg m^{-3} may be related to these pigments' dilution effect in the leaves, as results of the maximization of LAI and SDM values, mainly, in this nutritional condition (Figure 2). Cruz et al., 2022 observed the same effect in leaves of black pepper plantlets, when they tested different substrates and irrigation levels, as well as Valença et al. (2018) in lettuce seedlings, summited to different irrigation levels.

The increase in values of $Chl_{a/b}$ ratio generally is related to the increase of reaction centers, when superior plants grow under high luminous intensity conditions (Albanese et al., 2016). However, in the present work, it is unprovable that this condition has occurred, as seen in Figure 1.

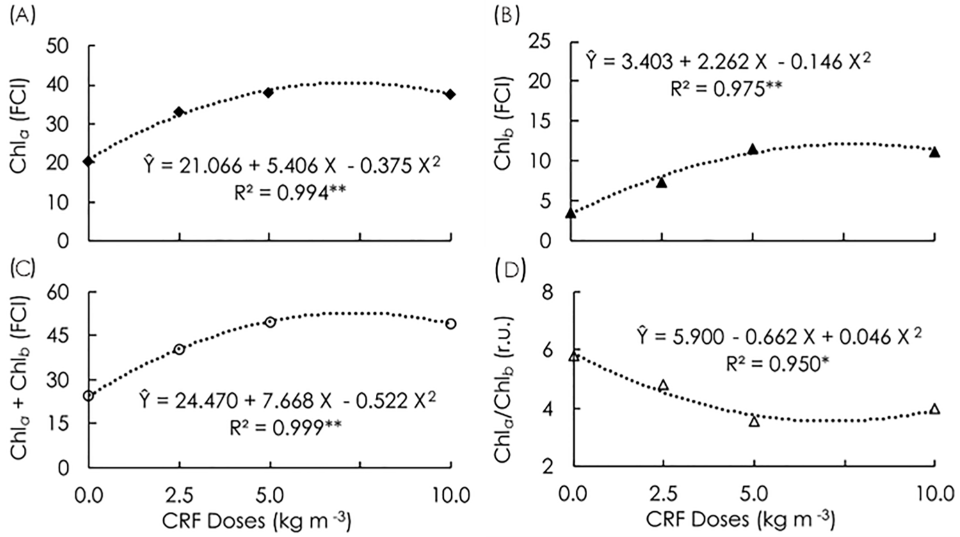

Figure 3. Chlorophyll *a* (Chl_a), chlorophyll *b* (Chl_b) and total chlorophyll (Chl_{a+b}) content and $Chl_{a/b}$ ratio of black pepper plantlets, *cv*. Bragantina, at 120 days after transplanting, as a function of doses of controlled-release fertilizer (CRF). FCI – Falker chlorophyll index; r.u. – Relative unit; and **, * - significant model at 1% and 5% probability levels by F test.

On the other hand, Mg^{2+} ions are present in porphyrin-type ring structures of chlorophyll molecules (Taiz et al., 2017). It's acceptable that there was an increase in Mg bioavailability, as the doses of CRF increased since this fertilizer has about 3.674 grams of Mg per kg of CRF in composition. Thus, larger values of $Chl_{a/b}$ ratio were observed when lower CRF doses were applied (Figure 3D), which may be due to prioritization of Chl_a synthesis over the Chl_b under reduced availability of Mg. This may favor the maintenance of the electron transport in the photosystems, since, although both chlorophylls are involved in light energy capture, only Chl_a is essential for energy transformation in the photosystem's reaction centers (Meneses-Lazo et al., 2020).

These results are in line with Meneses-Lazo et al., 2020, who observed an increase in the levels of Chl_a, Chl_b, and Chl_{a+b}, as well as a reduction in the values of $Chl_{a/b}$ ratio in Habanero pepper (*Capsicum chinense* Jacq.), according to increasing the concentration of Mg in nutrient solutions. In addition, the negative correlation observed in this work between Mg content in plants and $Chl_{a/b}$ ratio (Figure 4) can indicate the same type of relationship between the availability of Mg^{2+} in the substrate and the prioritization of Chl_a synthesis, to the detriment of Chl_b, as prior discussed.

This theory, however, is not valid for CRF doses greater than 7.2 g kg^{-1}, since there may have been increasing Mg availability, however, this does not represent a decrease of $Chl_{a/b}$ ratio (Figure 3D). In that case, it may have been the dilution effect of nitrogen concentration in leaves, as the $Chl_{a/b}$ ratio can be considered an indicator of N content in leaves (Kitajima & Hogan, 2003). There are reports about the strong influence of mineral fertilization on chlorophyll content in black pepper plants (Ann, 2012).

In present work was observed a process of acidification of the substrates with increasing CRF doses. The final substrate pH values were: 5.6 (0.0 kg m^{-3}), 4.71 (2.5 kg m^{-3}), 4.56 (5.0 kg m^{-3}) and 4.27 (10.0 kg m^{-3}). This process can be explained by the nitrification of NH_4^+ present in the Ammonium Nitrate (Dal Molin et al., 2020) that constituted the CRF. The substrate acidification in the cultivation of *Cornus sericea*, *Weigela florida*, *Salix purpurea*, *Hydrangea paniculata*, *Hibiscus syriacus* and *Spiraea japonica* in containers by the application of CRF was also observed by Agro and Zheng (2014).

Lima et al. (2010) founded a strong pH influence on soil chemical characteristics of a black pepper crop in the state of Espírito Santo. Those authors observed spatial dependence between the soil attributes pH and P, K, Al, and H+Al levels. However, in the present work, the pH reduction under the highest dose of CRF may have had a negative influence on plant growth (Figure 2), due to the probable reduction in the bioavailability of nutrients under the resulting low pH value.

The results reinforce the importance of considering both plant characteristics (Freire et al., 2017; Secundino et al., 2014) and substrate types (Cruz et al., 2022; Secundino et al., 2019) to produce black pepper plantlets, adopting a rational mineral fertilization strategy, which certainly will avoid unnecessary spending of money on fertilizers and time.

In present work, therefore, was evident the impact of mineral fertilization using CRF on morphological and chlorophyll traits of black pepper plantlets, *cv.* Bragantina, in different magnitudes.

Conclusions

To produce plantlets of black pepper, cv. Bragantina, using soil and crushed coconut fiber mixing substrate, it's recommended to apply 8.4 kg of controlled-release fertilizer 14N-14P-14K (CRF) per cubic meter of substrate.

To obtain maximum values of morphological traits of plantlets of black pepper, *cv.* Bragantina, it's necessary to apply higher CRF doses than those demanded to obtain maximum chlorophyll indices in these plants.

References

Achilea, O., Rottenberg, O., Thomas, M. 2010. Using controlled-release fertilizers for perennials increases productivity while reducing fertilizer application rates. *Acta Hoerticulturae* 868: 255-260.

Agro, E., Zheng, Y. 2014. Controlled-release Fertilizer application rates for container nursery crop production in Southwestern Ontario, Canada. *HortScience* 49: 1414-1423.

Albanese, P., Manfredi, M., Meneghesso, A., Marengo, E., Saracco, G., Barber, J., Morosinotto, T., Pagliano, C. 2016. Dynamic reorganization of photosystem II supercomplexes in response to variations in light intensities. *Biochimica et biophysica acta* 1857: 1651-1660.

Ann, Y.C. 2012. Impact of different fertilization methods on the soil, yeld and growth performance of Black Pepper (*Piper nigrum* L.). *Malaysian Journal of Soil Science* 16: 71-87.

Baligar, V.C., Fageria, N.K., He, Z.L. 2001. Nutrient use efficiency in plants. *Communications in Soil Science and Plant Analysis* 32: 7-8.

Bataglia, O.C., Gallo, J.R., Cardoso, M. 1976. The influence of applications of fertilizer on foliar concentrations of nutrients of black pepper. *Bragantia* 35: 405-411.

Bezerra, A.C.M., Valença, D.C., Carvalho, D.F., Pinho, C.F., Reinert, F., Gomes, D.P., Gabetto, F.P., Azevedo, R.A., Masseroni, D., Medici, L.O. *2019*. Automation of lettuce seedlings irrigation with sensors deployed in the substrate or at the atmosphere. *Scientia Agricola* 76: 179-189.

Cabreira, G.V., Leles, P.S.S., Alonso, J.M., Abreu, A.H.M., Junior, J.C.A., Vieira, A.V.G., Lopes, N.F. 2019. Fertilization and containers in the seedlings production and post-planting survival of *Schizolobium parahyba*. *Ciência Florestal* 29: 1644-1657.

Chatzistathis, T., Papadakis, I.E., Papaioannou, A., Giannakoula, A. 2020. Comparative study effects between manure application and a controlled-release fertilizer on the growth, nutrient uptake, photosystem II activity and photosynthetic rate of *Olea europaea* L. (cv. 'Koroneiki'). *Scientia Horticulturae* 264: 1-9.

Cruz, E.S., Medici, L.O., Leles, P.S.S., Ambrozim, C.S., Souza, W.L., Carvalho, D.F. 2022. Growth of black pepper plantlets under different substrates and irrigation levels. *Scientia Agricola* 79: e20200094.

Dal Molin, S.J., Ernani, P.R., Gerber, J.M. 2020. Soil acidification and nitrogen release following application of nitrogen fertilizers. Communications in Soil Science and Plant Analysis 51: 2551-2558.

FAO. Food and Agriculture Organization of the United Nations. 2019. http://www.fao.org/faostat/en/#home<Acesso em 20 Nov. 2019>

Ferreira, D.F. 2011. SISVAR: a computer statistical analysis system. *Ciência e Agrotecnologia* 35: 1039-1042.

Freire, R.R., Schmildt, E.R., Lopes, J.C., Chagas, K., Marques, H.I.P., Filho, J.C., Oliveira, J.P.B., Otoni, W.C., Alexandre, R.S. 2017. Rooting responses of black pepper (*Piper nigrum* cv. Bragantina) as affected by chemical, physical and microbiological properties of substrates and auxin. Australian Journal of Crop Science 11: 126-133.

IBGE. Instituto Brasileiro de Geografia e Estatística. 2021. https://sidra.ibge.gov.br/tabela/6588<Acesso em 10 Abril 2021>

Kitajima, K., Hogan, K.P. 2003. Increases of chlorophyll *a/b* ratios during acclimation of tropical woody seedlings to nitrogen limitation and high light. *Plant, Cell and Environment* 26: 857-865.

Lima, J.S.S., Oliveira, R.B., Rocha, W., Oliveira, P.C., Quartezani, W.Z. 2010. Análise espacial de atributos químicos do solo e da produção da cultura pimenta-do-reino (*Piper nigrum* L.). *IDESIA* 28: 31-39.

Menegathi, R.D., Souza, A.G., Bianchi, V.J. 2020. Different environments and doses of controlled-release fertilizer in peach rootstocks production. *Advances in Horticultural Science* 34: 157–166.

Meneses-Lazo, R., Garruña, R., Echevarría-Machado, I., Alvarado-Lópes, C., Villanueva-Couoh, E., García-Maldonado, J.Q., Cristóbal-Alejo, J. 2020. Growth, chlorophyll fluorescence and gas Exchange of Pepper (*Capsicum chinense* Jacq.) plants in response to uptake and partioning of nutrients. *Chilean Journal of Agricultural Research* 80: 585-597.

Prasath, D., Vinitha, K.B., Srinivasan, V., Kandiannan, K., Anandaraj, M. 2014. Standardization of soil-less nursery mixture for black pepper (*Piper nigrum* L) multiplication using plug-trays. *Journal of Spices and Aromatic Crops* 23: 1-9.

Prezotti, L.C., Gomes, J.A., Dadalto, G.G., Oliveira, J.A. (eds.). 2007. *Manual de recomendação de calagem e adubação para o Estado do Espírito Santo*. SEEA/Incaper/CEDAGRO, Vitória. 305 p.

Secundino, W., Alexandre, R.S., Schimildt, E.R., Schimildt, O., Magevski, G.C., Martins, J.P.R. 2014. Rhizogenic behavior of black pepper cultivars to indole-3-butyric acid. *Acta Scientiarum* 36: 355-364.

Secundino, W., Alexandre, R.S., Schimildt, E.R., Schimildt, O., Chagas, K., Marques, H.I.P. 2019. Substrates on the cuttings rooting of black pepper genotypes. *Comunicata Scientiae* 9: 621-628.

Serrano, L.A.L., Marinato, F.A., Magiero, M., Sturm, G.M. 2012. Produção de mudas de pimenteira-do-reino em substrato comercial fertilizado com adubo de liberação lenta. *Revista Ceres* 59: 512-517.

Silber, A., Bar-Tal, A. 2017. Nutrition of substrate-grown plants. In: Raviv, M., Lieth, J.H., Bar-Tal, A. (eds.). *Soilless Culture: Theory and Practice*. Academic Press, London, UK. p. 197–257.

Sousa, W.L., Cruz, E.S., Medici, L.O., Salvador, C.A., Carvalho, D.F. 2020. Avaliação de um acionador automático para irrigação em substratos agrícolas com diferentes características de retenção de água. *Brazilian Journal of Animal and Environmental Research* 3: 3944-3956.

Taiz, L., Zeiger, E., Moller, I.M., Murphy, A. 2017. *Fisiologia e desenvolvimento vegetal.* Artmed, Porto Alegre, Brazil, 888p.

Valença, D.C., Carvalho, D.F., Reinert, F., Azevedo, R.A., Pinho, C.F., Medici, L.O. 2018. Automatically controlled deficit irrigation of lettuce in “organic potponics”. *Scientia Agricola* 75: 52-59.

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