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Área Agrícola

POULTRY MANURE INCREASES SOIL FERTILITY, GROWTH AND NUTRITIONAL STATUS OF YERBA MATE SEEDLINGS

EL ESTIÉRCOL DE AVES AUMENTA LA FERTILIDAD DEL SUELO, EL CRECIMIENTO Y EL ESTADO NUTRICIONAL DE LAS PLÁNTULAS DE YERBA MATE

Mônica Moreno Gabira • *monica.gabira@gmail.com*
Master in Forest Science. Federal University of Parana, Curitiba, Brazil.

Delmar Santin • *desantinflorestal@yahoo.com.br*
Doctorate in Soil and Plant Nutrition. Curitibanos, Brazil

Ivar Wendling • *ivar.wendling@embrapa.br*
Doctorate in Forest Science. National Centre of Forestry Research – Embrapa Forests, Colombo, Brazil.

Eliziane Luiza Benedetti • *eliziane.benedetti@ifsc.edu.br*
Doctorate in Soil and Plant Nutrition. Federal Institute of Education, Science and Technology of Santa Catarina, Curitibanos, Brasil.

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ABSTRACT

Contextualization: The use of organic fertilizers from agricultural industry residues is an alternative as a nutritional source in agroforestry cultures, mainly due to the slow release of nutrients. The leaf biomass production is essential for yerba mate production, which demands adequate nutritional management to maintain productivity and soil fertility.

Knowledge gap: Most yerba mate is produced with the use of mineral fertilizers, and there are no records of how organic fertilization with poultry manure could influence plants growth, nutritional status, and soil fertility.

Purpose: This study aimed to evaluate the influence of organic fertilization on soil fertility, growth, and nutritional status of yerba mate seedlings.

Methodology: Two clonal cultivars of yerba mate (BRS408 and BRS409) were subjected to three fertilization doses with poultry manure (0, 20, and 35 g dm^{-3}). The study was established in a factorial design, in a randomized block design with four replications. After 210 days, pH, organic matter content, availability of P, K, Ca, and Mg in the soil were analyzed. In addition, plants were evaluated in the same period for growth and leaf content of N, P, K, Ca, Mg, and S. Data were subjected to ANOVA and Tukey test for means comparison.

Results and conclusions: Organic fertilization positively influenced soil characteristics and yerba mate seedlings growth, with significant differences in the response of each clone. The use of 20 g dm^{-3} of poultry manure is recommended for yerba mate seedlings production.

Keywords: *Ilex paraguariensis;* organic fertilizer; plant nutrition; soil science

RESUMEN

Contextualización: El uso de fertilizantes orgánicos a partir de residuos de la industria agrícola es una alternativa como fuente nutricional en cultivos agroforestales, principalmente por la lenta liberación de nutrientes. La producción de biomasa foliar es muy importante para la producción de yerba mate, que demanda un adecuado manejo nutricional para mantener la productividad y la fertilidad del suelo.

Vacío de conocimiento: La mayor parte de la yerba mate se produce con el uso de fertilizantes minerales y no hay registros de cómo la fertilización orgánica con estiércol de aves de corral podría influir en el crecimiento de las plantas y el estado nutricional, así como en la fertilidad del suelo.

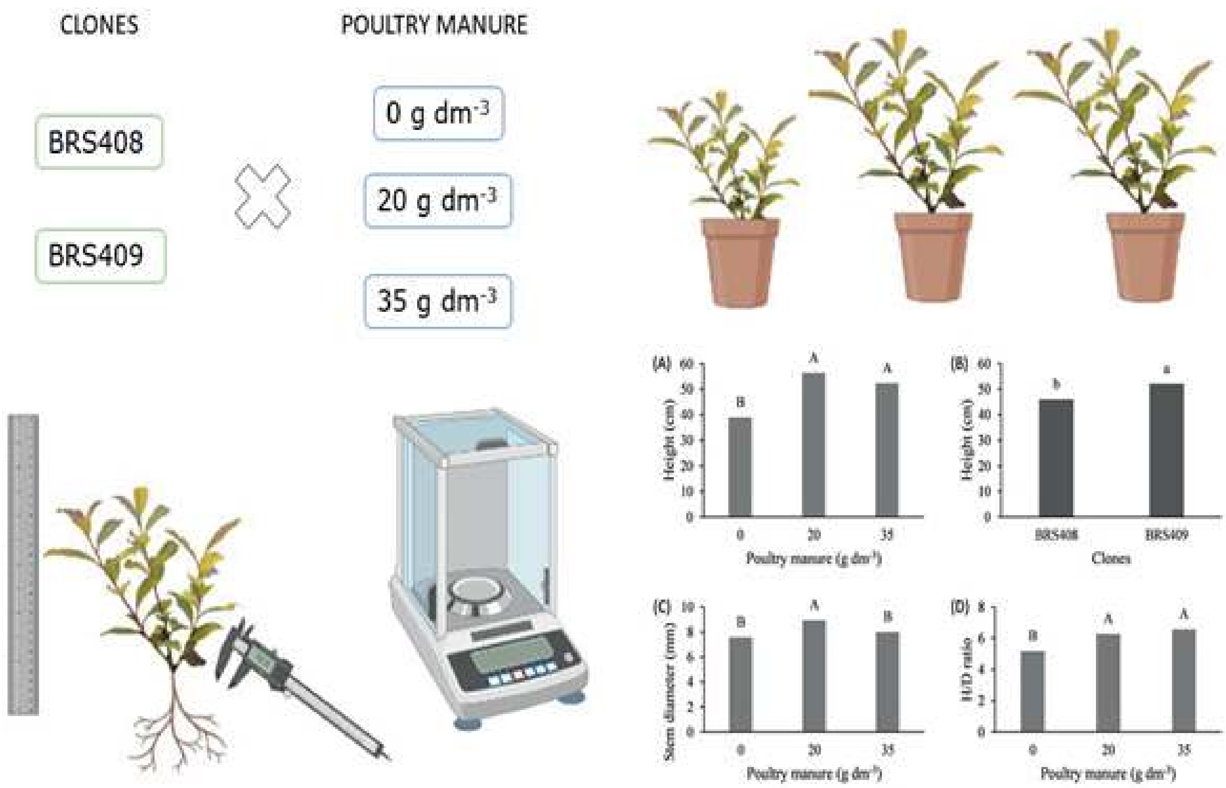
Propósito del estudio: Este estudio tuvo como objetivo evaluar la influencia de la fertilización orgánica en la fertilidad del suelo, el crecimiento y el estado nutricional de las plántulas de yerba mate.

Metodología: Dos cultivares clonales de yerba mate (BRS408 y BRS409) fueron sometidos a tres dosis de fertilización con estiércol de aves (0, 20 y 35 g dm^{-3}). El estudio se estableció en un diseño factorial, en un diseño de bloques al azar con cuatro repeticiones. Después de 210 días se evaluó el pH, el contenido de materia orgánica, la disponibilidad de P, K, Ca y Mg en el suelo. Las plantas se evaluaron en el mismo período para determinar el crecimiento y el contenido de hojas de N, P, K, Ca, Mg y S. Los datos se sometieron a ANOVA y prueba de Tukey para la comparación de medias.

Resultados y conclusiones: La fertilización orgánica influyó positivamente en las características del suelo y el crecimiento de las plántulas de yerba mate, con diferencias significativas en la respuesta de cada clon. Se recomienda el uso de 20 g dm^{-3} de estiércol de ave para la producción de plántulas de yerba mate.

Palabras clave: *Ilex paraguariensis;* fertilizante orgánico; nutrición vegetal; ciencia del suelo

GRAPHIC SUMMARY



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1. INTRODUCTION

Among the inputs used in plant production, substrates and fertilizers are the most important and are a significant part of production costs. Therefore, the increase in cost, high demand, and possible scarcity of inputs for agricultural production are relevant factors in searching for new alternative materials (Higashikawa et al., 2016). In addition, there is interest for such inputs to come from renewable sources, aiming to develop sustainable practices in agricultural production.

The intensive production of animals in Brazil is an industry that generates high amounts of waste (Yaldız et al., 2019). When disposed of inappropriately, these residues impact negatively in a social, economic, and, above all, environmental level. The use of agricultural residues as organic fertilizers has been increasingly frequent, mainly due to the availability and diversity of sources. These materials generally have a high concentration of nutrients; however, they require attention to the occurrence of heavy metals, which can be highly harmful to both the culture and the environment (Ghori et al., 2019). Poultry manure is a residue known for its high phosphorus content, and it has strong effects on soil microbial communities. The increase in poultry products demand has led to an excessive deposition of this residue in several countries.

Studies indicate the possibility of using these materials as components of substrates and fertilizers for several species (Mažeika et al., 2020; Yaldız et al., 2019). However, the excessive application of organic fertilizers can be highly harmful to crops and cause environmental damage through soil and water contamination by heavy metals and pathogens. The diverse and highly variable composition of residues and the risks of its inappropriate use indicate the need for studies on dosages and effectiveness of these products as inputs for plant production. There

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is a lack of research focusing on developing more sustainable and economically viable agricultural practices (Higashikawa et al., 2016).

Yerba mate (*Ilex paraguariensis* A. St-Hil.) is a tree species, naturally occurring in southern Brazil, Argentina, and Paraguay (Carvalho, 2003), where it is widely consumed as beverages. In Brazil, the species is cultivated on small properties and represents an important part of rural families' income. The great diversity of products from yerba mate has significantly increased the demand for raw material; however, the sector has faced a reduction in the productivity of plantations, mainly due to nutritional deficits (Santin et al., 2017). Furthermore, plantings carried out without genetic selection criteria for seedling production negatively affect the establishment of plantations and, consequently, productivity (Wendling & Brondani, 2015). These problems can be avoided, in part, by using vegetatively propagated seedlings with genetically superior material of known provenance and by maintaining adequate plant nutrition (Wendling & Santin, 2015).

It is known that the export of nutrients from commercial yerba mate plantations is high, but there are still few producers willing to invest in mineral fertilizers, making this a promising market for organic fertilization, such as the waste from the poultry industry (Santin et al., 2016). However, few studies have developed aiming to use use of this fertilization for the yerba mate culture. Thus, this study aimed to evaluate the soil fertility, growth, and nutritional status of yerba mate clones submitted to organic fertilization.

2. MATERIALS AND METHODS

The yerba mate seedlings were produced by mini cutting by Embrapa Florestas, according to Wendling & Brondani (2015), from the clonal cultivars BRS408 and BRS409. The experiment was established in a greenhouse at the Federal Institute of Education, Science, and Technology of Santa Catarina, in Canoinhas, SC (26° 10' S and 23° 50' W, 765 m). The region's climate is Cfb-type (Alvares et al., 2013), with an average annual temperature between 15 and 17 ºC.

From soil analysis [4.80 % organic matter (OM), 25 % clay, 5.2 pHH_2O; Calcium (Ca), Magnesium (Mg), and Aluminium (Al), respectively, of 5.50, 1.16, and 1.59 $cmol_c$ dm^{-3}; phosphorus (P) and potassium (K), respectively, of 1.4 and 172 mg dm^{-3}] and the concentration of nutrients in poultry manure [Nitrogen (N): 1.56 %, phosphorus pentoxide (P_2O_5): 6.59 %, potassium oxide (K_2O): 2.51 %, Ca: 1.37 %, and Mg: 0.85 %], we defined doses as D1 - control, D2 - recommended dose (20 g dm^{-3}), and D3 - dose 75 % above the recommended dose (35 g dm^{-3}) to supply P for the planting phase following the recommendation for fertilization for yerba mate (Wendling & Santin, 2015). Fertilization occurred in two equal applications. The first was homogenized to the soil at seedling planting, and the second was fertilized superficially after three months.

Seven months after experiment establishment, we evaluated height (H), stem diameter (D), leaves fresh weight (LFW), branches fresh weight (BFB), and shoots fresh weight (SFW). After drying in an oven at 65 °C, total dy weight was determined. We obtained total fresh wight (TFW), and H/D and LFW/BFW ratios from these data. Subsequently, leaves were ground in a Wiley mill, and the content of N (Bremner, 1996), P (Braga & Defelipo, 1974), K, Ca, Mg (Tedesco et al., 1995), and S (Alvarez et al., 2001) were determined. After removing the plants, soil was dried and sieved in a 2 mm mesh; this material was used to determine pH, OM, P, K, Ca, Mg and Al, according to the methodology described by Embrapa (1997).

Statistical analysis

Treatments were arranged in a randomized block design, with 4 replications. Each experimental unit consisted of five pots with 2.5 dm^3 of soil and one plant per pot. Treatments were arranged in a 3 x 2 factorial scheme (3 doses of organic fertilization x 2 clones). Data of poultry manure characteristics were submitted to one-way analysis of variance and data of plant analysis were subjected to a two-way analysis of variance. When we obtained significant effects of the treatments, means were compared by the Tukey test at a 5 % probability level. We used the R software (R Core Team, 2020) to perform statistical analysis and the Excel software for figures.

3. RESULTS AND DISCUSSION

Fertilization with poultry manure positively affected all variables (Figure 1) in the soil used as a substrate for yerba mate seedlings production. The availability of P and K, as well as pH and base saturation, increased significantly with the application of poultry manure to the soil. Organic matter and Ca content also increased at the dose of 20 g dm^{-3} of poultry manure. In general, we obtained positive results concerning soil characteristics after adding poultry manure.

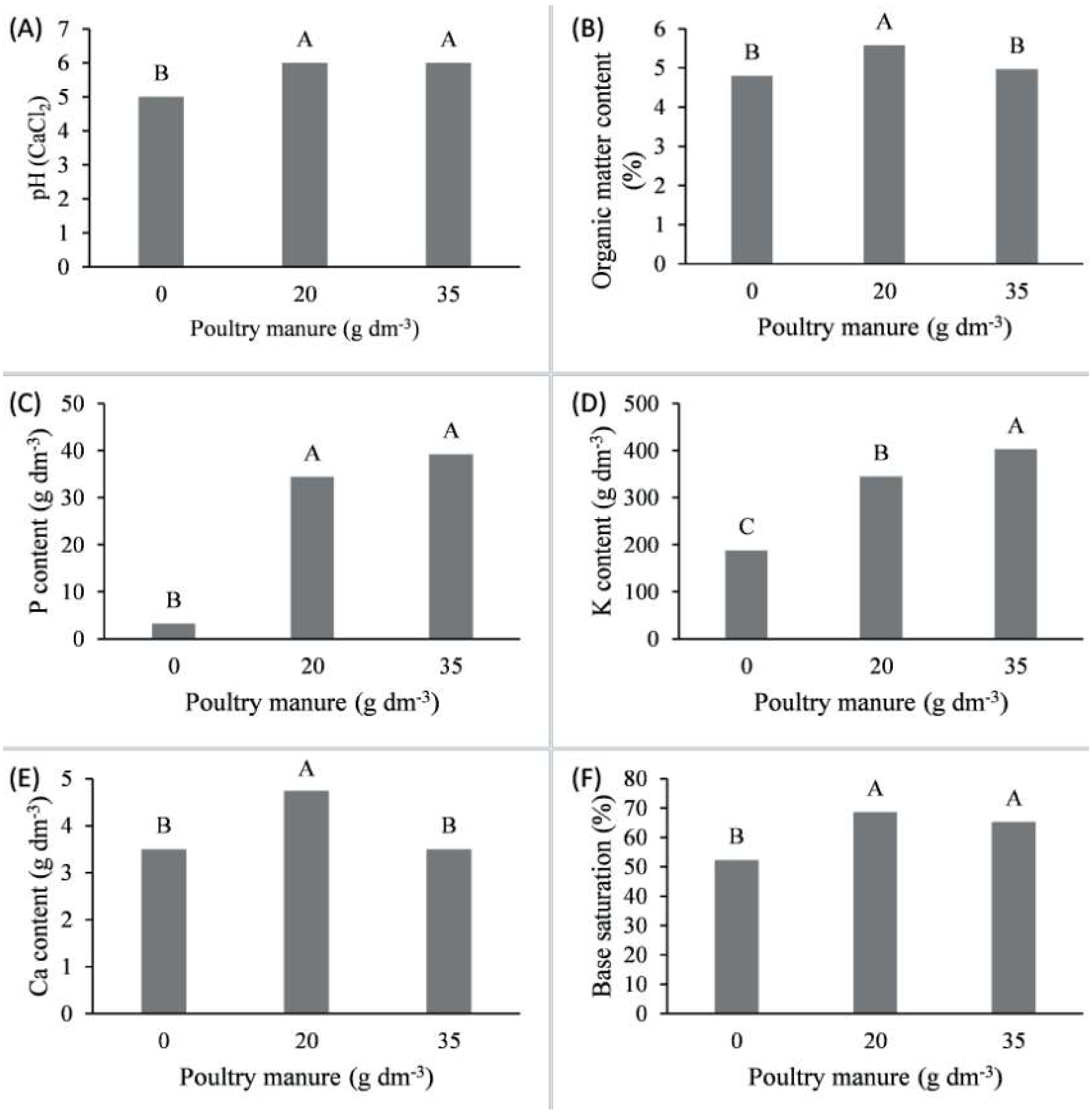

Figure 1. pH (A), organic matter content (B); P content (C), K content (D), Ca content (E), and base saturation (F) of soil used as substrate for *I. paraguariensis* seedlings production. Same capital letters do not differ by the Tukey test at 5 % probability.

Source: *Authors.*

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There is a close relationship between fertility and soil carbon content (Nguyen & Wang, 2016), directly affecting plant growth. In this experiment, there was a significant increase in soil organic matter after adding poultry manure, indicating the possibility of recovering its fertility. In addition to the chemical characteristics evaluated in this study, adding poultry manure to agricultural soil also increases soil aggregation, hydraulic conductivity, porosity, and base saturation (Cayci et al., 2017).

One of the main characteristics of organo-mineral fertilizers is the slow availability of nutrients, which allows for greater use by plants and reduction of losses through leaching (Mažeika et al., 2020). We observed that the availability of nutrients by poultry manure was adequate to the needs of the plants, ensuring the growth and maintenance in a container until the moment of planting. One of the main factors for increasing nutrient availability is maintaining the pH close to 6.5, enabling greater nutrient availability for plants; however, as yerba mate occurs naturally in acidic soils, the ideal is to keep the Ca availability below 6.5 cmolc dm^{-3} (Wendling & Santin, 2015). This condition requires a pH below the optimal availability of nutrients in the soil, as observed in this study.

As a result of changes in the soil, there was an influence of poultry manure on yerba mate seedlings' growth (Figure 2), but without interaction between the factors for these variables. The addition of 20 g dm^{-3} of poultry manure provided positive results for both height and stem diameter of seedlings, although there was no significant difference for height in the treatment with the application of 35 g dm^{-3} of poultry manure. The difference between clones was observed only for height, with clone BRS409 being 6.02 cm larger than clone BRS408 (Figure 2B). Stem diameter varied between 7,58 and 8,95 cm, with the highest value in plants grown with the addition of 20 g dm^{-3} of poultry manure.

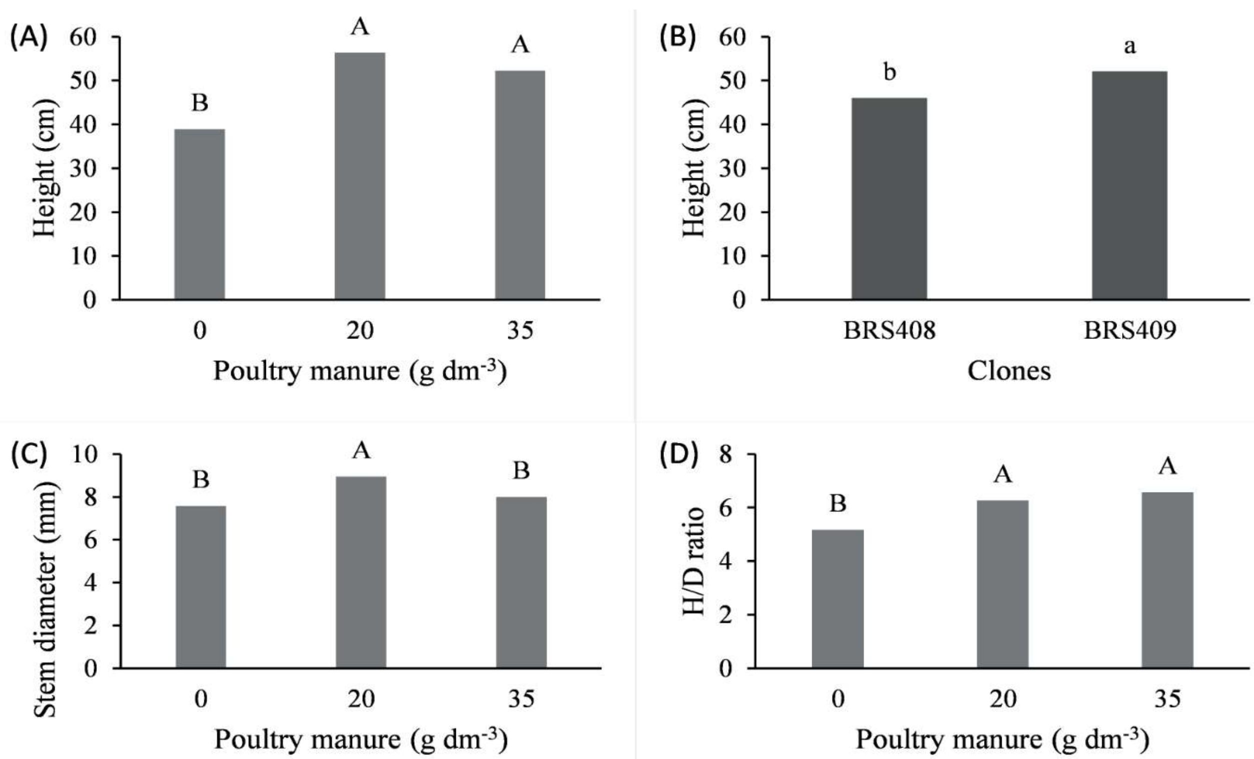

Figure 2. Height (A and B), stem diameter (C), and H/D ratio (D) of *Ilex paraguariensis* seedlings 210 days after planting. Capital letters in poultry manure doses and small letters in clones do not differ by the Tukey test at 5 % probability.

Source: *Authors.*

Plants submitted to treatment with the addition of 20 g dm^{-3} of poultry manure showed better results for fresh biomass and dry biomass, similar in some cases to plants with the addition of 35 g dm^{-3} of poultry manure (Figure 3A to D). Only LFW, BFW, and TFW presented interaction between the factors used in this experiment. Clone BRS409 presented better results than BRS408 in treatments in which poultry manure was added, with no difference for total dry biomass (Figure 3C). There were significant differences for the LFB/BFB ratio for the fertilization rates and the clones, although there was no interaction between factors (Figure 3E and F).

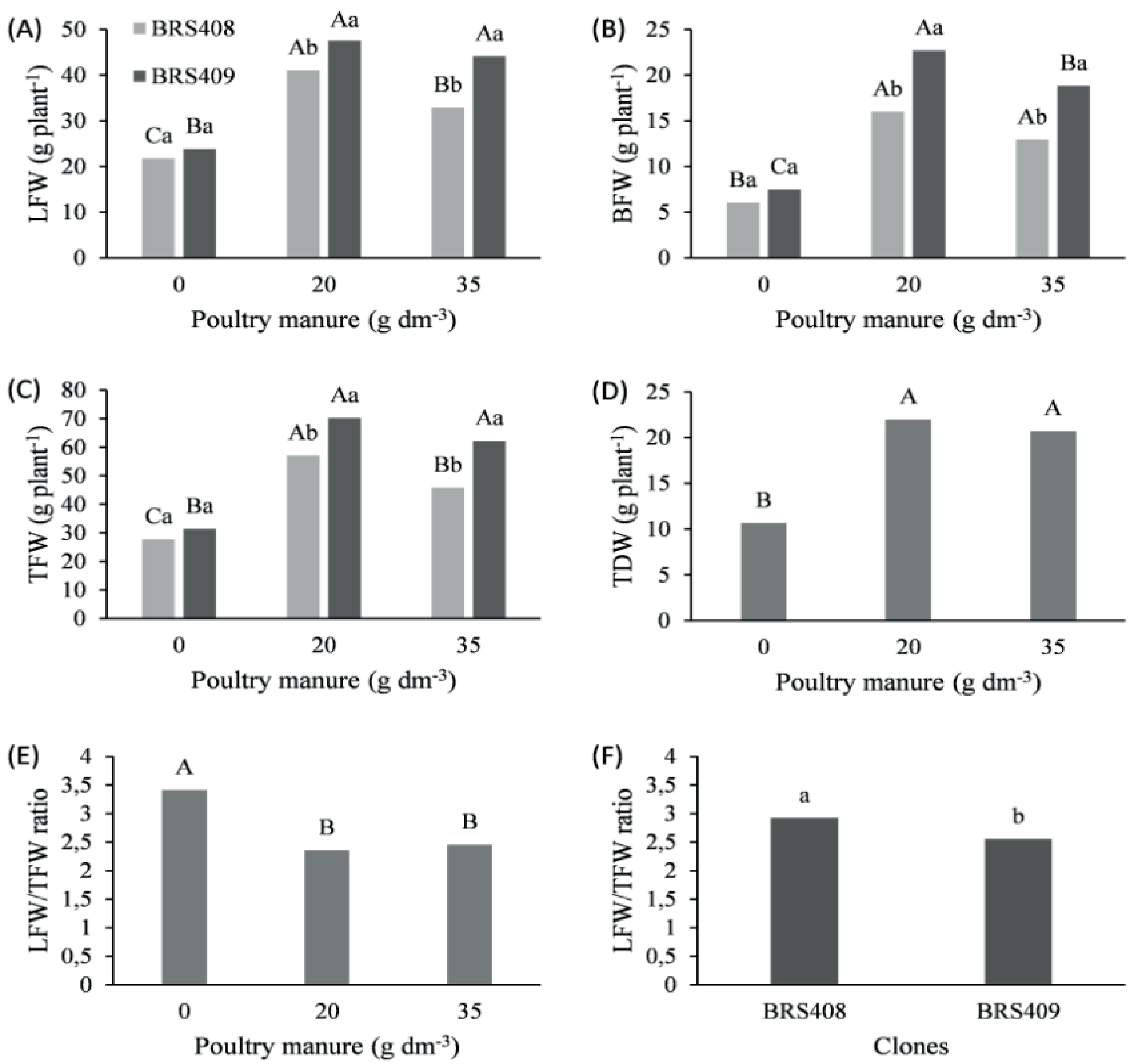

Figure 3. Leaf fresh weight (LFW) (A), branch fresh weight (BFW) (B), total fresh weight (TFW) (C), total dry weight (TDW) (D), and LFW/TFW ratio (E and F) of *Ilex paraguariensis* seedlings 210 days after planting. Same capital letters for poultry manure and same small letters for clones do not differ by the Tukey test at 5 % probability.

Source: *Authors*

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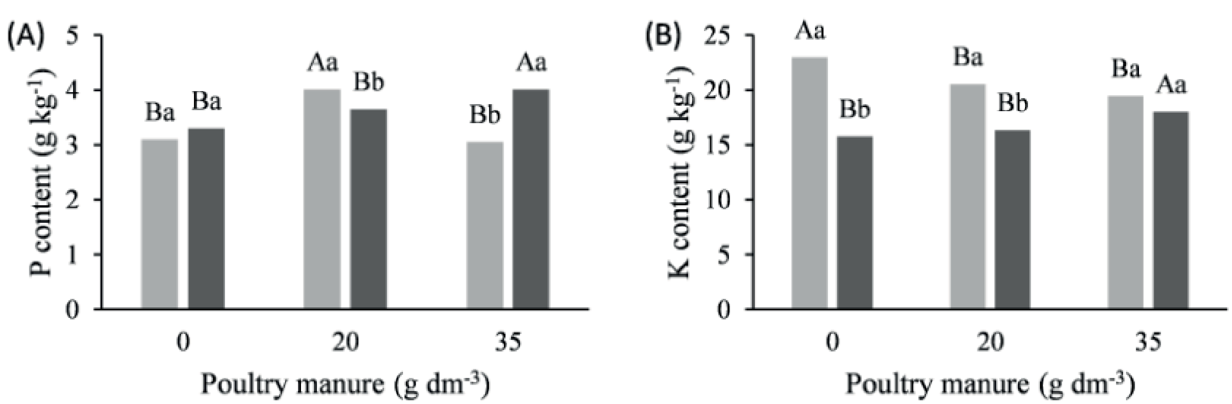
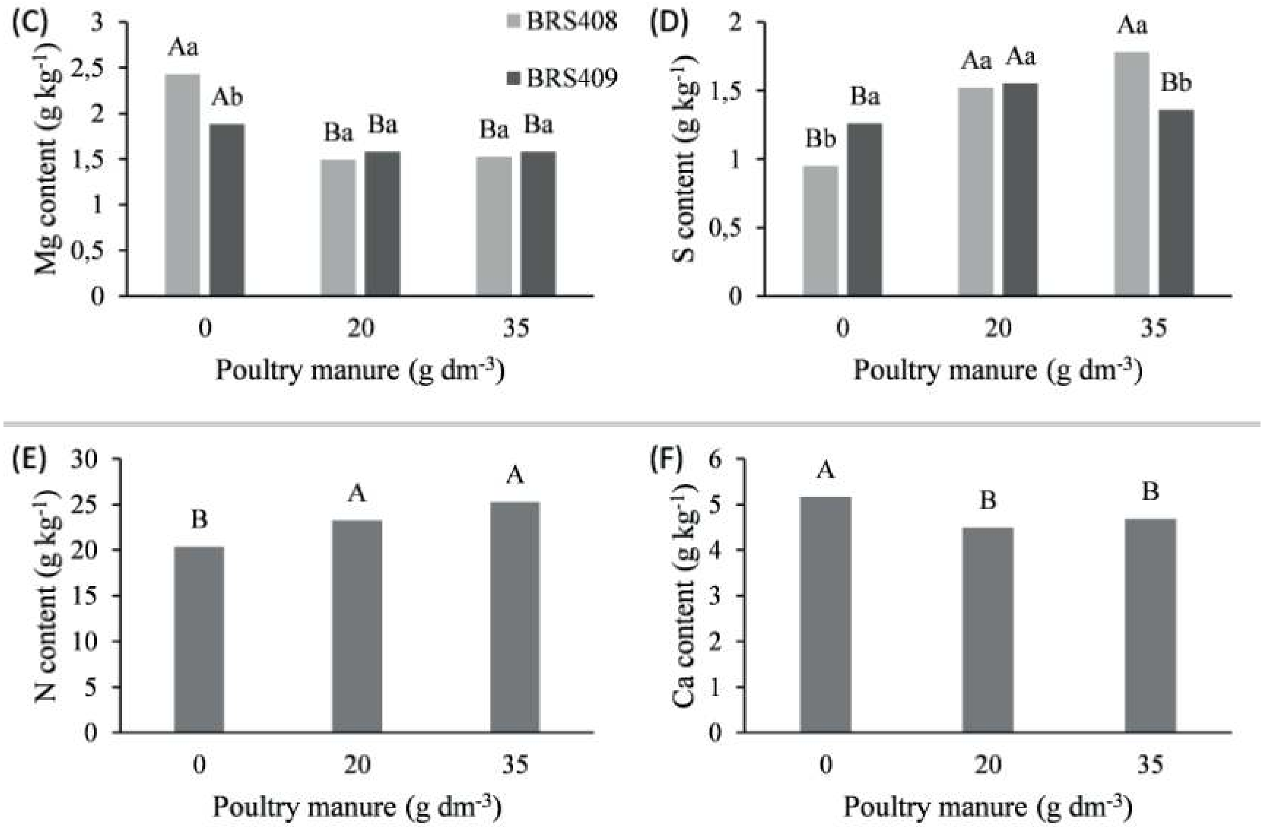
Although yerba mate occurs naturally in acidic and low fertility soils (Carvalho, 2003), several studies have shown its remarkable capacity to respond positively in increasing growth or productivity in soils with greater fertility (Barbosa et al., 2018; Santin et al., 2016, 2017). In addition to aspects related to absorption, it is important to understand how fertilizers influence crop quality, in addition to the ideal amount for nutrients best use (Mažeika et al., 2020). In this experiment, we observed that adding 20 g dm-3 poultry manure provided greater seedling growth, indicating a point of maximum utilization of nutrients by plants and differences between genetic materials. Thus, the addition of organic fertilizer is a viable alternative for field planting and seedling production.

Considering that the best seedling growth occurred with the addition of 20 g dm^{-3} of poultry manure (Figure 2), at this dose, the availability in the soil of P_2O_5 (34.3 mg dm^{-3}), K2O (345 mg dm^{-3}), and Ca (4.7 mg dm^{-3}) is considered, respectively, very high, very high and high level (SBCS, 2017). This result indicates that yerba mate is a much more nutritionally demanding crop than was postulated until recently. Nutrient availability in the soil promotes a positive effect on biomass accumulation in yerba mate seedlings, and each nutrient behaves in a specific way (Santin et al., 2008). The increase in biomass in plants produced in soil fertilized with poultry manure has already been observed by other authors (Mažeika et al., 2020); these fertilizers promote an increase in crop productivity similar to that provided by mineral fertilizers, which was observed with the increase in LFW in both clones (Figure 3A).

In an experiment with yerba mate seedlings submitted to NPK fertilization, Santin et al. (2008) observed that the species respond positively to the addition of P in height and diameter, as observed in our results. However, this aspect may also be influenced by plants genetic characteristics, considering that the clones used in this study responded differently ways for the height variable. These are the morphological variables most used in determining the quality of seedlings due to their ease of measurement and their non-destructive characteristic (Ivetić et al., 2016). Furthermore, these are considered the best morphological characteristics to predict survival and initial growth in the field, mainly because they are correlated with the size of root system, biomass accumulation, and competitive advantage with other vegetation (Grossnickle & MacDonald, 2018).

Leaf contents of P, K, Mg, and S showed an interaction between clone and poultry manure dose (Figure 4), indicating that, in addition to the applied fertilizer doses, there is an influence of the genetic factor on nutrient accumulation in the plants. N and Ca contents altered only as a function of fertilizer doses, increasing N contents as the poultry manure dose increased and the Ca contents decreased.





F**igure 4.** P content (A), K content (B), Mg content (C), S content (D), N content (E), and Ca content (F) in *Ilex paraguariensis* seedlings 210 days after planting. Same capital letters for poultry manure and same small letters for clones do not differ by the Tukey test at 5 % probability.

Source: *Authors*

Studies using different doses of P and K in the production of yerba mate seedlings indicate that the addition of these nutrients positively influences all plant growth variables (Santin et al., 2017). In the present study, we obtained a significant seedling growth with poultry manure, mainly composed of P and K (6.59 % of P_2O_5 and 2.51 % of K_2O). P is the most present macronutrient in poultry manure composition, and it was the one with the highest leaf content compared to what is commonly found in yerba mate. Leaf content of 1.2 to 1.6 g kg^{-1} of P is considered adequate for yerba mate (Santin et al., 2017). At the best growth dose, BRS408 presented 4.0 g kg^{-1} of P (Figure 4A). Mg can explain this high foliar P content in plants in poultry manure, which has a synergistic effect on P absorption, functioning as a carrier and acting directly on ATP synthesis through photosynthesis.

The foliar P content (Figure 4A) was above what commonly occurs in mate seedlings; On the other hand, the foliar Mg content at the recommended dose (around 1.5 g kg^{-1}) is below the 4.7 g kg^{-1} indicated as ideal (Santin et al., 2013). However, the foliar content of the other nutrients is higher than those observed in other studies evaluating the influence of soil attributes on yerba mate elemental composition in the field without fertilizers (Toppel et al., 2018). It indicates the capacity of yerba mate to absorb and accumulate nutrients according to their availability in the soil, which was more significant for P, possibly due to the high concentration of these nutrients in the poultry manure. We also observed differences in nutrient content between the clones evaluated, which may be related to absorption patterns or differences in soil exploration by the root system. The reduction in Mg, S, and Ca content, mainly in clone BRS409, may be related to a nutrient dilution effect in the greater volume of fresh weight obtained for treatments or by the greater efficiency of this cultivar in converting nutrients into biomass (Schmitt et al., 2018).

The results obtained in this study indicate the potential use of organic fertilizers in the

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production of yerba mate seedlings, which has already been the focus of studies with other species of commercial interest (Cayci et al., 2017; Higashikawa et al., 2016; Nguyen & Wang, 2016; Yaldız et al., 2019). Based on these results, it will be possible to establish alternative nutritional management plans, enabling new studies on species response to other organic fertilizers from regional agricultural residues.

CONCLUSIONS

The addition of poultry manure promotes an increase in soil fertility to produce yerba mate seedlings. The species respond positively to adding 20 g dm^{-3} of poultry manure to the soil for seedling production, increasing growth and quality.

AUTHOR'S CONTRIBUTION

Mônica Moreno Gabira: Research, data analysis, writing, original draft and editing.
Delmar Santin: Research, conceptualization, review and editing.
Ivar Wendling : Conceptualization, review and edition.
Eliziane Luiza Benedetti: Resource acquisition, project manager, supervision, conceptualization, review and editing.

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Conflicto de intereses
Los autores declaran no tener ningún conflicto de intereses.