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Plant growth and micronutrient contents of yellow passion fruit subjected to organic fertilization

Ismael de Jesus Matos Viégas[1], Sávia Poliana da Silva[1], José Darlon Nascimento Alves[2*], Tayssa Menezes Franco[3], Ricardo Shigueru Okumura[4], Diocléa Almeida Seabra Silva[1], Carlos Valmison da Silva Araújo[5], Michel Sauma Filho[6], Heráclito Eugênio Oliveira da Conceição[6]

[1]Universidade Federal Rural da Amazônia, 68700-665, Capanema, Pará, Brazil
[2]Instituto Federal do Pará, 68250-000, Óbidos, Pará, Brazil
[3]Universidade Federal Rural da Amazônia, 66077-830, Belém, Pará, Brazil
[4]Universidade Federal Rural da Amazônia, 68515-000, Parauapebas, Pará, Brazil
[5]Universidade Federal de Viçosa, 36570-900, Viçosa, Minas Gerais, Brazil
[6]Universidade Federal Rural da Amazônia, 68650-000, Capitão Poço, Pará, Brazil

[*]Corresponding author: José Darlon Nascimento Alves ✉ | ORCID: 0000-0003-1290-5598

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Abstract: The utilization of organic fertilizers to enhance plant growth has witnessed a surge in recent years. This is attributed to the beneficial effects of organic matter on intensely cultivated soils, coupled with the high costs of mineral fertilizers for farmers. Here, we conducted an experiment to assess the impact of organic compound doses on the growth and nutritional status of passion fruit. The experiment was conducted in a greenhouse at the Universidade Federal Rural da Amazônia, in Belém, Pará State, Brazil. The experimental design was completely randomized with five treatments and four replications. Each experimental plot comprised a vase with a volume of 3.6 dm^3 of soil and a yellow passion fruit seedling (*Passiflora edulis* f. *flavicarpa Deg.*). Five rates of organic fertilizer (0%, 15%, 30%, 45%, and 60%) were tested out of the total volume of the substrate. The organic fertilizer (pH = 6.9, N = 15.2 g kg^{-1}, and C = 109.7 g kg^{-1}) was prepared by mixing 10% chicken manure, 20% duck manure, 15% cassava bark, 15% cassava leaf, 15% bean straw, 15% rice husk, and 10% corn cob. The optimal results of stem diameter, number of leaves, and total dry mass were achieved with a dose of 60% of the organic fertilizer at 97 days. The content and accumulation of micronutrients in the foliar tissue of yellow passion fruit plants followed the descending order: Fe>B>Mn>Zn>Cu. It is recommended a dose of 60% of organic fertilizer to be used for the production of yellow passion fruit seedlings in the edaphoclimatic conditions of the Brazilian eastern Amazon.

Keywords: *Passiflora edulis*, organic fertilization, mineral nutrition, plant growth.

Abbreviations: pH_hydrogenionic potential; N_nitrogen; C_carbon; Fe_iron; B_boron; Mn_manganese; Zn_zinc; Cu_copper; OM_organic matter; CEC_cation exchange capacity; Cl_chlorine; Na_sodium; DM_dry matter; P_phosphorus; K_potassium; Ca_calcium; Mg_magnesium; Al_aluminum; S_sulfur; H_hydrogen; OC_Organic carbon.

Introduction

Brazil is the world's largest producer of yellow passion fruit (*Passiflora edulis* f. *Flavicarpa Degener*), with an annual production of 697,859 tons and a productivity of 15.3 t ha^{-1}. The state of Pará is a major producer of yellow passion fruit in the northern region of Brazil, with an output of 15,155 tons. Nevertheless, its productivity remains below the national average (9.7 t ha^{-1}) (IBGE, 2023). One factor that contributes to this decline in productivity is the lack of information on effective crop management practices, including the optimal substrate for the species. This lack of knowledge results in the use of inferior substrates, which negatively impact the quality of seedlings.
The efficacy of organic fertilizers in the production of passion fruit seedlings has been the subject of several studies. These studies have employed a range of organic materials, including chicken manure, cattle manure, rice husks, vermiculite, and coconut fiber (Siqueira et al., 2020; Antunes et al., 2022; Silva et al., 2023). These fertilizers contain high organic matter (OM) contents, which favor the chemical, physical, and biological attributes of the soil (Aires et al., 2020). They also contribute to plant growth and reduce production costs (Silva et al., 2019; Antunes et al., 2022).
The incorporation of organic fertilizers into the formulation of substrates can serve as a soil conditioner, modifying its chemical, physical, and biological attributes. Organic fertilizers enhance soil biological activity by increasing the availability of macronutrients and micronutrients, as well as through improvements in aeration, infiltration, water retention, increased carbon storage, and cation exchange capacity (CEC) (Alves et al., 2020; Galvão et al., 2020; Wu et al., 2024). Studies conducted with organic fertilizers have demonstrated a positive effect on the development of papaya seedlings (Sousa et al., 2019), mangaba seedlings (Lima et al., 2020), forest species (Bastos et al., 2023; Barreto et al., 2023),

and *Passiflora edulis* seedlings (Silva et al., 2023). These studies have demonstrated the capacity of organic fertilizers to enhance the quality of seedlings (Antunes et al., 2022).

Despite the paucity of literature on the impact of organic fertilizers on the growth and nutritional status of yellow passion fruit, particularly with regard to the extraction and concentration of micronutrients in leaf tissue in the Amazon region, it is evident that further research is required. It is of paramount importance to conduct studies on the crop mineral nutrition, which will greatly contribute to the success of agricultural activity. This will provide a foundation for the recommendation of the substrate that provides the most optimal nutrient availability. According to Taiz et al. (2017) and Prado (2020), small amounts of micronutrients are required, yet they are essential for several physiological processes, such as photosynthesis, flowering, and fruit production.

Malavolta et al. (1997) report that passion fruit extracts micronutrients Fe>Zn>Mn>B>Cu in greater quantities. In contrast, Carvalho et al. (2001) observed that the nutrient content of leaf dry matter, which is related to maximum fruit productivity (43.5 t ha^{-1}), varied considerably over the course of the year, ranging from 16.9 to 28.9 g kg^{-1} of Cl, from 77 to 135 mg kg^{-1} of Fe, from 50.1 to 91.4 mg kg^{-1} of Mn, from 26.1 to 37.6 mg kg^{-1} of Zn, from 4.53 to 95.4 mg kg^{-1} of Cu, from 22.8 to 54.5 mg kg^{-1} of B, and from 0.96 to 2.31 g kg^{-1} of Na.

The present study evaluated the impact of organic fertilizer produced in the Brazilian eastern Amazon on the plant growth and nutritional status of micronutrients in yellow passion fruit.

Results and Discussion

Production characteristics

The quadratic models demonstrated the best fit for the variables of total dry mass (TDM) and stem diameter, whereas the number of leaves exhibited the best fit for the positive linear model (Fig. 1).

The optimal response for TDM (119.8 g), stem diameter (9.6 mm), and number of leaves (58 leaves $plant^{-1}$) was observed at doses of 60%, 40.4%, and 60%, respectively (Fig. 1). The absence of organic fertilizer resulted in reduced growth and development of yellow passion fruit plants. The control treatment exhibited the greatest degree of variation, with the best results observed at 74 g for TDM, 2.7 mm for stem diameter, and 38.6 leaves $plant^{-1}$ for the number of leaves (Fig. 1).

The lower responses in the growth and development of seedlings in the absence of organic fertilizer are related to the low natural fertility of Oxisols, which limit plant development (Gama et al., 2020) (Table 2). The utilization of organic fertilizers represents a more sustainable alternative for maintaining soil quality, as they contain essential nutrients for plant growth, such as N, P, K and micronutrients These nutrients are gradually made available to plants, thereby promoting a constant supply of nutrients necessary for the development of seedlings (Andrade et al., 2017). Furthermore, the application of organic fertilizers improves the soil cation exchange capacity (CEC), base saturation, and soil biological activity (Cavalcante et al., 2016).

Another crucial factor contributing to the positive response of seedlings under organic fertilization was the enhancement of soil physical quality. Organic fertilizers facilitate the expansion of the root system of seedlings by increasing soil porosity, thereby creating in a larger contact area between the root system and the soil. Furthermore, the increase in microporosity enhances water retention in the soil, enabling a higher rate of water and nutrient absorption by the seedlings.

In their respective studies, Cavalcante et al. (2016) and Paixão et al. (2021) evaluated the use of substrates composed of different organic animal and vegetable fertilizers in the production of yellow passion fruit seedlings. Their findings indicated a positive effect on plant growth, dry matter production, number of leaves, and stem diameter in treatments with rabbit composite + soil, goat composite + soil, and soil + coffee peel.

Micronutrient content in yellow passion leaves

The concentration of micronutrients Fe, Mn, and Zn in the leaves was best described by positive quadratic models, while a negative linear model provided a better fit for micronutrient Cu (Fig. 2).

The lowest Fe concentration was equivalent to 39.14 mg kg^{-1} of leaf, representing an estimated percentage of 42%. Conversely, the percentages of 0, 15, 30, 45, and 60% yielded Fe contents equivalent to 228.9, 149.3, 117.61, 54.7, 40.1, and 73.8 mg kg^{-1} of leaf, respectively. With regard to the micronutrient Mn, a concentration of 26.3 mg kg^{-1} was observed, representing an estimated percentage of 31.8% (Fig. 2).

Higher levels of Fe and Mn were observed in the substrates without the application of organic fertilizer. This may be attributed to the naturally high levels of Fe and Mn in Amazonian soils, which are a consequence of the low pH. These micronutrients are essential for several vital plant processes, such as the electron transport chain in photosynthesis. However, high levels of these micronutrients cause toxicity to plants (Marschner, 2022).

The lowest concentration of Zn observed in the leaf was 13.48 mg kg^{-1}, which was equivalent to 27% of organic fertilizer. The highest concentration was observed in the 60% treatment, with 16.19 mg kg^{-1}. For copper (Cu), there was an increase in Cu concentration as the percentage of organic fertilizer increased, with the lowest concentration (1.37 mg kg^{-1}) observed in the 60% treatment (Fig. 2).

In general, the use of organic fertilizers has been shown to enable adequate levels of micronutrients for the development of seedlings. This is due to the promotion of a better balance of nutrients in the soil, which has been attributed to an increase in soil pH (Novais et al., 2007). Additionally, the use of organic fertilizers has been demonstrated to promote a reduction in Fe availability due to a reduction in solubility (Raij, 2019). Furthermore, the increase in the OM content reduces the availability of Cu, Zn, and Mn (Malavolta, 2006).

Micronutrients accumulation in yellow passion leaves

The accumulation of micronutrients in yellow passion fruit leaves followed the following decreasing order: Fe>B>Mn>Zn>Cu. The micronutrients were described by quadratic models, with iron, zinc and manganese fitted to the positive quadratic regression model, while boron and copper were better described by the negative quadratic model (Fig. 3).

The lowest observed Fe accumulation was 2,125.9 µg kg^{-1} with an estimated dose of 34% and the accumulation achieved with the application of treatments was 3,488.9, 2,810.1, 2,557.5, 2,147.3, 2,258.1, and 2,889.9 µg kg^{-1} with 0, 10, 15, 30, 45 and 60%, respectively (Fig. 3). The reduction in accumulation is associated with the elevated pH of the soil (Prado, 2020). Additionally, there may have been a reduction in its absorption, due to the higher levels of K, Ca, and Mg in the substrate (Malavolta, 2006).

Boron (B) exhibited greater accumulation with an estimated dose of 70.9%, resulting in 1,872.6 µg kg^{-1} (Fig. 3). This response is attributed to the fact that organic matter represents the primary source of B available to plants (Prado, 2020). Another crucial factor is the soil pH, which should be

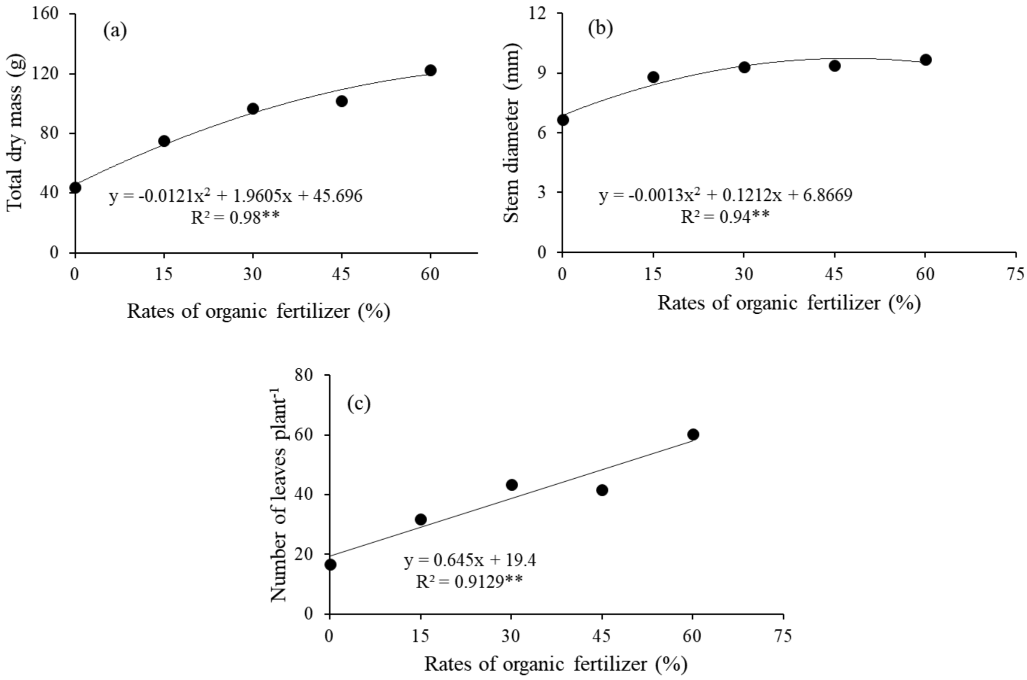

Figure 1. Total dry mass (a), stem diameter (b), and number of leaves per plant (c) of yellow passion fruit submitted to varying rates of organic fertilizer in a greenhouse at 97 days after sowing.

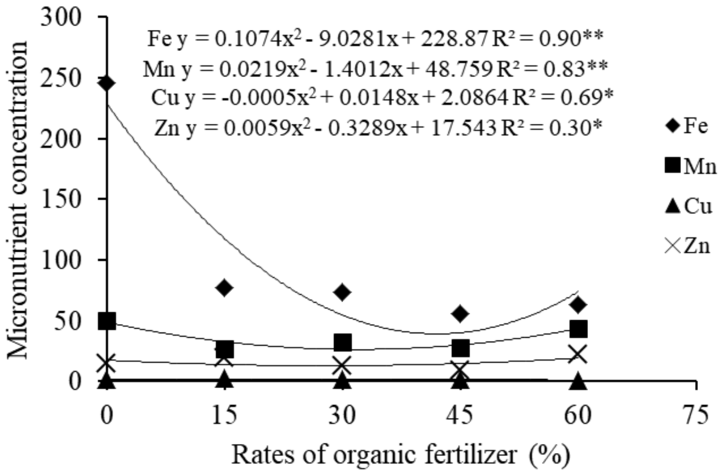

Figure 2. Concentrations of micronutrients (mg kg^{-1}) in leaves of the yellow passion fruit subjected to varying rates of organic fertilizer in a greenhouse at 97 days after sowing.

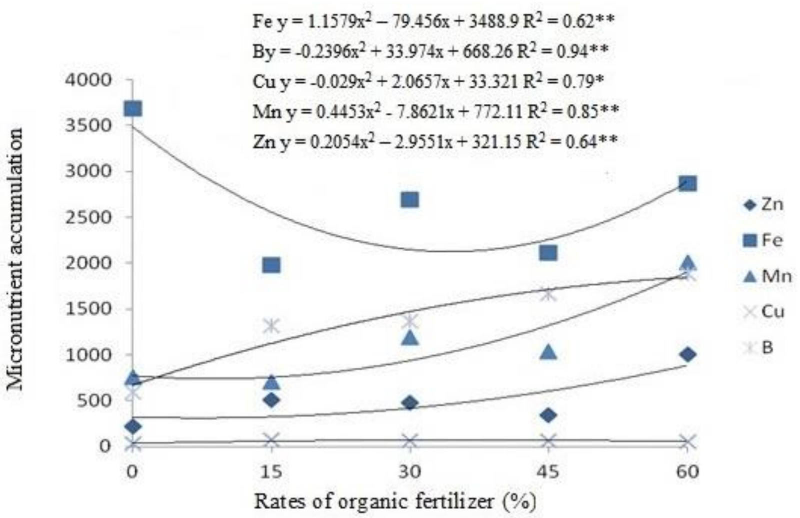

Figure 3. Accumulation of micronutrients in leaves (μg kg^{-1}) of the yellow passion fruit subjected to varying rates of organic fertilizer in a greenhouse at 97 days after sowing.

Table 1. Particle size analysis of the soil used in the experiment.

Depth (cm)	Granulometry (g kg^{-1})		
	Sand	Silt	Clay
0-20	817.0	103	80

Table 2. Chemical analysis of the soil employed in the experiment.

pH	P	K	Fe	B	Mn	Zn	Cu	Ca	S	Na	Mg	H + Al	N total	V
H_2O	mg dm^{-3}							cmol$_c$dm^{-3}					(%)	
6.2	1.0	43.0	34.6	0.4	16.8	1.5	2.0	2.7	4.8	0.1	0.9	2.6	0.1	59.3

between 5.0 and 7.0, as observed in the present research. This pH range facilitates greater B availability through adsorption reactions in the soil (Novais et al., 2007). Therefore, the quantification of B in leaves is of paramount importance, as B is a fundamental micronutrient for essential biological processes, including cell division, plasma membrane formation, root growth, sugar transport, and nucleic acid synthesis (Silva-Matos et al., 2015; Kerbauy, 2019; Marschner, 2022).

The highest accumulation of Cu was 70.1 μg kg^{-1}, with an estimated dose of 35.6%. The accumulation achieved with the application of treatments was 33.3, 51.1, 57.8, 69.19, 67 .5, 52.8 μg kg^{-1}, with 0, 10, 15, 30, 45 and 60%, respectively (Fig. 3). The reduction in the Cu availability in the largest quantity of organic fertilizer may have occurred due to its high interaction with organic compounds in the soil, forming stable complexes (Raij, 2019).

The lowest accumulation of micronutrient Mn was observed with the estimated dose of 8.8%, reaching the equivalent of 734.4 μg kg^{-1}, the other percentages of organic fertilizer tested provided accumulations of 772.1, 738.0, 754 .4, 937.0, 1,320.0, 1,903.5 μg kg^{-1} with 0, 10, 15, 30, 45 and 60% respectively. The lowest accumulation of micronutrient Zn was observed with the estimated dose of 23.2%, reaching an equivalent of 362.9 μg kg^{-1}. The other percentages of organic fertilizer tested provided accumulations of 312.14, 323.04, 417.4, 604.1, 883.29 μg kg^{-1} with 0, 10, 15, 30, 45 and 60%, respectively (Fig. 3). The highest accumulation of Zn in the highest doses of organic fertilizer may have been the result of an increase in pH, which can enhance the availability of Zn due to the decomposition of organic matter by soil biota (Malavolta, 2006).

Despite the increased absorption of micronutrients, no symptoms of toxicity were identified in the yellow passion fruit seedlings. This allowed to confirm that the levels were within acceptable levels for the crop.

Materials and Methods

Study site

The experiment was conducted in a greenhouse at the Federal Rural University of Amazonia in the municipality of Belém, Pará State, Brazil (geographical coordinates 01°26’00” S and 48°26’00” W). According to Köppen classification, the climate is Af type, which is defined as a rainy equatorial region, hot and humid conditions, with an average annual rainfall of between 2500 and 3000 mm. This climate is characterized by the absence of dry periods or with a maximum of one to two dry months (Alvares et al., 2013). The mean annual air temperature is 27 to 30°C, with minor fluctuations of 1 to 3°C throughout the year (Bastos et al., 2002). The air temperature within the greenhouse ranged from 26 to 35°C. The luminous intensity inside and outside the greenhouse during the experimental period was 321 and 694 lux, respectively, as measured with a digital luximeter (Instrutherm, model LD-206).

Plant materials

To conduct the experiment, yellow passion fruit seeds (*Passiflora edulis* f. *flavicarpa Degener*) Redondo Amarelo cultivar, were utilized, selected from an orchard managed by a rural producer in the Tracateua Community, in the municipality of Moju, State Pará, Brazil. The seeds were sown in polyethylene trays using a commercial vermiculite substrate. Following germination, thinning was performed, leaving one seedling per cell. Subsequently, the seedlings were transplanted into the container containing the substrate and organic fertilizers.

Soil sampling and analysis

The organic fertilizers were incorporated into the soil in volumetric proportions, classified as Yellow Latosol (Santos, 2018) and Oxisols (Soil Survey Staff, 2014), with a sandy texture. The soil was collected from an arable layer (0-20 cm) in an area of secondary vegetation, in the municipality of Moju, Pará State, Brazil, for soil chemical and physical characterization.

The pipette method was employed to determine the clay, silt and, and sand-size fractions. The extractors utilized in the chemical analysis of soil samples were as follows: P, Na, K, Fe, Zn, Mn, and Cu (Mehlich 1); Ca, Mg, and Al (KCl 1 mol L^{-1}); H + Al (0.5 mol L^{-1} calcium acetate, pH 7.0); B (hot water); S (monocalcium phosphate). The concentration of organic carbon (OC) was determined by the Walkley-Black method, in accordance with the methodology described by Donagema et al. (2011). The results of the granulometric and chemical analyses are presented in Tables 1 and 2, respectively.

The chemical properties of the organic waste were found to be pH = 6.9, N = 15.2 g kg^{-1}, and C = 109.7 g kg^{-1}. Further information is presented in Table 3.

The organic fertilizer was created by combining chicken manure (10%), duck manure (20%), cassava peel (15%), cassava leaf (15%), bean straw (15%), rice husk (15%), and corn cob (10%) in 130-day composting process.

Experiment setup

Each experimental plot consisted of a single pot (3.6 dm^3) containing a single plant of yellow passion fruit. The soil moisture was maintained between 60% and 80% of the total soil porosity, using demineralized water, while the control was carried out by weighing the pots.

Determination of plant growth and production parameters

At 97 days after sowing, plant growth was assessed. This included the measurement of stem diameter (mm), the number of leaves, and the total dry mass (g). The stem diameter was determined at 2 cm above the soil surface using a digital caliper (Alhrout, 2017). The total dry mass of the yellow passion plant was obtained by summing the weight of the stem, leaves, and roots. All leaves measuring 2 cm in length were considered to count the number of leaves. The stem, leaves, and roots were placed separately in paper bags and oven dried with forced air circulation at 60°C until

Table 3. Analysis of the organic waste in a composting process of 130 days.

Organic waste	N	P	K	Ca	Mg	S
	g kg^{-1}					
Organic fertilizer	9.1	12.6	6.3	52.1	3.6	7.2
Duck manure	20.8	19.0	10.9	51.2	7.0	10.2
Chicken manure	27.3	21.4	27.9	43.5	8.2	11.7
Cassava peel	10.3	0.6	7.3	5.0	0.9	2.3
Cassava leaf	36.6	2.0	12.2	12.0	4.4	15.3
Bean straw	13.4	1.0	12.8	4.2	4.7	2.6
Rice husk	6.4	1.5	4.6	2.7	0.8	2.3
Corn cob	7.4	0.3	3.4	0.5	0.5	1.5
Organic waste	**Zn**	**Fe**	**Mn**	**Cu**	**B**	
	mg kg^{-1}					
Organic fertilizer	164.0	2546.0	139.0	241.0	19.3	
Duck manure	295.0	4012.0	340.5	42.3	39.2	
Chicken manure	607.0	15457.0	684.0	297.1	20.9	
Cassava peel	22.8	4639.5	82.6	8.8	30.8	
Cassava leaf	61.5	120.8	52.8	6.5	52.6	
Bean straw	20.0	313.3	42.0	5.1	61.8	
Rice husk	34.9	6209.0	145.7	9.7	14.2	
Corn cob	40.4	189.1	19.9	2.4	19.5	

reaching a constant mass to obtain the plant dry mass (Sá et al., 2017). Afterward, the dried samples were ground in a Wiley mill (20-mesh size).

Plant material analysis

Following milling, the samples were submitted to the Laboratory of Mineral Nutrition of Plants at the Federal University of Viçosa (Minas Gerais State, Brazil) for the determination of micronutrient contents (B, Cu, Fe, Mn, and Zn) in the leaves of yellow passion fruit (Malavolta, 2006).

The dry and ground plant material was submitted to nitroperchloric digestion and quantified by atomic absorption spectrophotometry to determine the contents of Fe, Mn, Zn, and Cu. Boron was analyzed after dry digestion (calcination in a muffle furnace at 550°C) and determined by colorimetry using the Azometrine-H method.

The accumulation of micronutrients (μg $leaf^{-1}$) was calculated using the following equation:

$$\text{Accumulation}=\frac{[\text{Dry Matter (mg)}\times\text{Nutrient Content (mg kg}^{-1})]}{100} \quad (1)$$

Experimental design and statistical analysis

The experimental design was a completely randomized design with five treatments, with organic fertilizer at rates of 0%, 15% (525 g), 30% (1050 g), 45% (1575 g), and 60% (2100 g) of substrate volume (Oliveira et al., 2004), with four replicates.

The experimental results were subjected to analysis of variance (F test, $p<0.05$). When the means were found to be statistically significant, regression models were constructed and the models with the highest coefficient of determination (R^2) for the organic fertilizer rates were selected using the Assistat software (Silva & Azevedo, 2016).

Conclusion

The application of organic fertilizer to yellow passion fruit seedlings has been demonstrated to promote improvements growth and development. These improvements have been observed at a dose of 60% of organic fertilizer.

The absorption of iron (Fe), boron (B), manganese (Mn), zinc (Zn), and copper (Cu) varies depending on the concentration of organic fertilizer. The sequence of accumulation of micronutrients by yellow passion fruit leaves is Fe>B>Mn>Zn>Cu.

A dose of 60% of organic fertilizer is recommended for the production of yellow passion fruit seedlings in the edaphoclimatic conditions of the Brazilian eastern Amazon.

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