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Production of San Marzano tomato seedlings submitted to mixed fertilizer rates and application forms

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ABSTRACT: The vigor of commercial tomato seedlings is associated with their nutrition. A well-developed seedling has a robust root system, a well-lignified stem and chlorophyll leaves which results in high yielding plants. The study was designed to evaluate rates and forms of application of mixed fertilizer (MF) in the production of San Marzano tomato seedlings. The experiment was carried out in a greenhouse in a 5 × 2 factorial scheme (0, 50, 100, 150, and 200 mg MF × solid and liquid forms). The experimental design was randomized blocks with four replications. The seedlings were evaluated at 26 days after sowing regarding the variables: stem diameter (SBD), number of leaves (NL), plant height (PH), root length (RSL), shoot dry matter (SDM), root dry matter (RDM), total dry matter (TDM), and Dickson quality index (DQI). The SBD, NL, PH, RSL, SDM, RDM, and TDM obtained the most satisfactory results with the rates: 115, 190, 148.83, 194.83, 162.50, 125, and 180 mg plant^{-1}, respectively, solid or liquid application is recommended. Considering the higher vigor of the plants with DQI of 0.0071, the rate of 125 mg plant^{-1} is indicated for solid or liquid application.

Key words: Dickson quality index; mineral nutrition; *Solanum lycopersicum*

Produção de mudas de tomateiro San Marzano submetidas a doses de fertilizante misto e formas de aplicação

RESUMO: O vigor de mudas comerciais de tomateiro está associado à sua nutrição. Uma muda bem desenvolvida apresenta sistema radicular robusto, caule bem lignificado e folhas clorofiladas o que resulta em plantas de alta produtividade. O estudo foi projetado para avaliar doses e formas de aplicação de fertilizante misto (FM) na produção de mudas de tomateiro San Marzano. O experimento foi conduzido em casa de vegetação em esquema fatorial 5 × 2 (0, 50, 100, 150 e 200 mg FM × sólido e líquido). O delineamento experimental foi o de blocos ao acaso com quatro repetições. As mudas foram avaliadas aos 26 dias após a semeadura quanto às variáveis: diâmetro do colo (DC), número de folhas (NF), altura de planta (AP), comprimento radicular (CR), matéria seca da parte aérea (MSPA), matéria seca radicular (MSR), matéria seca total (MST) e índice de qualidade de Dickson (IQD). A DC, NF, AP, CR, MSPA, MSR e MST obtiveram os resultados mais satisfatórios com as doses: 115, 190, 148,83, 194,83, 162,50, 125 e 180 mg planta^{-1}, respectivamente, sendo recomendável a aplicação sólida ou líquida. Considerando o maior vigor das plantas com IQD de 0,0071, a dose de 125 mg planta^{-1} é a indicada para aplicação sólida ou líquida.

Palavras-chave: índice de qualidade de Dickson; nutrição mineral; *Solanum lycopersicum*

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Introduction

Tomato (*Solanum lycopersicum* L.) is a indeterminate growing herbaceous solanaceous plant native to the Andean regions of Latin America and was domesticated in Mexico (Brandão Filho et al., 2018). In Brazil, it is the second most produced vegetable, reaching about 2 million tons and its sale value in the fields is 3.5 billion R$ year^{-1}, with the Northeast region responsible for 26% of the national table tomato production, including the Italian type (Boteon et al., 2020). The state of Sergipe was the 15st in the national ranking in tomato production with 7,530 tons produced in an area of 251 ha (IBGE, 2021). In order to reach a profitability of 16.3 thousand R$ ha^{-1}, the average cost of producing Brazilian table tomatoes is 125 thousand R$ ha^{-1}, in which the acquisition of seedlings corresponds to 4.4% of the expense (Deleo, 2021).

Success in tomato production depends on the production of quality seedlings. Vigorous tomato seedlings are produced from certified germplasm, with architectural uniformity, robust root system, lignified stem and well-chlorophylled leaves, free from pest insects and diseases (Filgueira, 2013). These results are a consequence of the investment, among other aspects, in the nutrition of plants during their production in greenhouses or similar (Santos et al., 2016). Adequate fertilization of seedlings optimizes photosynthesis, improving the physiological processes aimed at the synthesis of enzymes, hormones, vitamins, proteins, and carbohydrates (Taiz et al., 2017).

In the literature, results are found on the production of tomato seedlings as a function of organic and synthetic nutritional sources. The organic products tested in these studies were tanned bovine manure, poultry manure, manioc vines and castor pie (Costa et al., 2015; Gonçalves et al., 2018). Regarding mineral fertilizers, the researchers examined nutrient solutions based on N, P, K, Ca, Mg, S, B, Cu, Fe, Mo, Zn, and Mn (Santos et al., 2016) and evaluated rates of simple superphosphate in the production of tomato seedlings (Hoffman et al., 2017). In the case of mixed fertilizer, because it is affordable in the market and due to the scarcity of information on its effect on the production of tomato seedlings, the need to evaluate it arose.

The application of mixed fertilizer is commercially indicated to improve the development of tomato seedlings and is appropriate due to its formulation containing nitrogen, phosphorus, potassium, amino acid, humic acid, and auxin (Arébalo-Madrigal et al., 2019; Issa, 2021). These components have the function of improving the morphology and the dry matter production of tomato seedlings (Taiz et al., 2017). However, it is necessary to know the most appropriate rate and form of application to maximize producer gains and reduce production risks. Thereby, the objective of this study was to evaluate rates and forms of application of a mixed fertilizer available on the market in the production of San Marzano tomato seedlings.

Materials and Methods

Assembly and conduct of the experiment

The experiment was carried out in the state of Sergipe, Brazil (10° 9' 14'' S, 37° 8' 12'' W, and 231 m of altitude) with tropical savanna climate "Aw/As" (Alvares et al., 2013). The cultivar used was San Marzano, of the Italian type (Bezerra et al., 2018).

The experiment was carried out in a greenhouse in a 5 × 2 factorial scheme, with five rates of mixed fertilizer (0, 50, 100, 150, and 200 mg plant^{-1}) and two forms of application (solid and liquid). The experimental design was randomized blocks with four replications, totaling 36 plots with five plants in each plot. In the statistical evaluation all plants were considered.

The mixed fertilizer analyzed has in the physical-chemical composition N (7.0%), P_2O_5 (47.0%), K_2O (6.0%), L-amino acid (3.0%), humic acid (15.5%), auxin (0.03%), inert (21.47%), and pH 5.45, the latter information refers to the value recorded when one gram of the product is diluted in one liter of deionized water (Issa, 2021).

The seedlings were produced in 100 mL white polystyrene cups in a closed system, containing 70 g of substrate consisting of washed sand based on quartz and feldspar (65 g) and fine textured coconut fiber (5 g) (Oliveira et al., 2019). Sowing was carried out on April 14, 2021, placing three tomato seeds per cup, and six days after sowing, thinning was carried out, leaving the plant more vigorous.

On the eighth day, solid and liquid rates of fertilizer were applied to the plants according to the treatments. The solid rates were deposited on the substrate and then 5 mL of distilled water were applied to maintain moisture. In the case of liquid rates, the solid state fertilizer was diluted in the standard volume of 5 mL of distilled water, and applied to the treatments. Before application, the matter of each rate was measured in the laboratory using a properly leveled analytical precision balance.

During the experiment, distilled water was used in the water replacement of the substrate-plant system, keeping the substrate moisture at 70% of its maximum adsorption capacity based on the tests of the percentage of water retained in the substrate previously performed. In order to maintain the humidity, 20% of the cups of the sample universe were weighed daily, respecting the treatments, that is, randomly removing nine cups from each block.

Morphological evaluations, dry matter production, Dickson quality index, and Pearson correlation coefficient

On the 26th day, the number of leaves was counted, and the diameter of the stem was measured with a Messen® caliper. The root-substrate set was separated by washing the root system under running water. The plant height and the length of the root system (measured in the longitudinal position, from the stem base of the plant to the apex of the largest root, regardless of whether main or secondary) were then evaluated with a graduated ruler. After that, the cut was made, and the root system was separated from the shoot. Afterwards, the plants were placed in kraft paper bags and stored in an oven with forced air circulation at 65 °C for 72 hours (Barbosa et al., 2015).

As soon as they were removed from the greenhouse, a semi-analytical balance to determine the total weight obtained with the sum of those acquired in the dry matter of the shoot and root of each plant (Santos et al., 2016). Finally, the Dickson quality index was calculated (Dickson et al., 1960). This is a parameter applied in the selection of commercial seedlings for identifying the best morphological coherence and dry matter of the plants through the correlation of the stem base diameter, plant height, shoot dry matter, root dry matter and total dry matter (Santos et al., 2016). The higher the result of the indicator is, the more vigorous are the plants (Dickson et al., 1960). For this reason, in this study, the Dickson index was used to select the best rate to be used in the production of tomato seedlings, cultivar San Marzano. To calculate it, Equation 1 was used.

$$DQI = \frac{TDM}{\frac{PH}{SBD} + \frac{SDM}{RDM}} \quad (1)$$

where: DQI - Dickson quality index; TDM - total dry matter (g); PH - plant height (cm); SBD - stem base diameter (cm); SDM - shoot dry matter (g); and, RDM - root dry matter (g).

Statistical analysis

The results were submitted to analysis of variance by the F test ($p \leq 0.05$), and when they were significant, the means of the fertilizer application forms were compared by the Tukey test and regression analysis was carried out for the rates with adjustment of the polynomial models, through the SISVAR software (Ferreira, 2019). Standard error bars of the sample mean were applied to all graphs for comparison between rates. Furthermore, in order to better understand the linear behavior of the dependent variables, two by two, within the limits of -1 to +1, Pearson determination principle (r) (Sousa, 2019) was used.

Results and Discussion

The interaction for the rates of mixed fertilizer versus the form of application was not significant for the variables evaluated. The form of application of the fertilizer was also not significant for all variables, indicating that the form of application of the product does not interfere with the vigor of San Marzano tomato seedlings. Significance was observed for fertilizer rates in stem diameter, number of leaves, plant height, root system length, root dry matter, shoot dry matter, total dry matter and Dickson quality index (Table 1). All variables fitted the quadratic model.

Stem base diameter, number of leaves, plant height, and root length

The maximum stem base diameter was 3.90 mm and occurred at a rate of 115 mg of fertilizer, with a gain of 0.50 mm in relation to the diameter of the control sample (Figure 1A) due to the supply of macronutrients (nitrogen, phosphorus, and potassium) through the fertilizer. The stem base diameter is one of the factors considered in the Dickson equation (Dickson et al., 1960), being determinant for the survival and development of the seedlings after the definitive planting because being well lignified and with a larger diameter, the stem of tomato seedlings drastically minimizes problems with damping off, besides optimizing the exchange of xylem sap and photo-assimilates between the root system and the aboveground part of the plants (Filgueira, 2013).

Based on the standard nutrient solution (100%), being: 184, 21, 248, 153, 43, 47.5, 0.31, 0.06, 4.5, 0.06, 0.4, and 0.4 mg L^{-1} of N, P, K, Ca, Mg, S, B, Cu, Fe, Mo, Zn, and Mn, respectively, Santos et al. (2016) also obtained a quadratic response to the increase in the concentration of nutrients in the solution for the highest result of the Santa Amélia and Santa Adélia cultivars with 2.37 and 3.49 mm in the concentration of 86 and 88%, both evaluated 30 days after sowing. In a study with the Santa Clara cultivar, Hoffman et al. (2017) obtained a positive linear response in the production of tomato seedlings, with the largest diameter of 2.65 mm at the 29th day after sowing in the application of 20 kg of single superphosphate.m^{-3} of Bioplant® substrate. Gonçalves et al. (2018), in the production of the Santa Cruz Kada cultivar, by

Table 1. Summary of analysis of variance related to stem base diameter (SBD, mm); number of leaves (NL); plant height (PH, cm); root system length (RSL, cm); shoot dry matter (SDM, g); root dry matter (RDM, g); total dry matter (TDM, g); and, Dickson quality index (DQI) in tomato seedlings, cultivar San Marzano, as a function of rates and forms of application of the mixed fertilizer.

Sources of variation	DF	Medium squares							
		SBD	NL	PH	RSL	SDM	RDM	TDM	DQI
Forms	1	0.003^{ns}	0.01^{ns}	1.46^{ns}	3.68^{ns}	0.0003^{ns}	0.0002^{ns}	0.001^{ns}	0.000001^{ns}
Rates	4	0.492^{**}	4.13^{**}	45.18^{**}	195.28^{**}	0.0608^{**}	0.0065^{**}	0.104^{**}	0.000024^{**}
F × R	4	0.056^{ns}	0.06^{ns}	5.24^{ns}	0.53^{ns}	0.0032^{ns}	0.0003^{ns}	0.005^{ns}	0.000002^{ns}
Block	3	0.079^{ns}	0.15^{ns}	39.23^{**}	12.85^{ns}	0.0010^{ns}	0.0002^{ns}	0.001^{ns}	0.000004^{ns}
Residue	27	0.041	0.10	4.71	7.55	0.0016	0.0003	0.003	0.000001
CV (%)		5.45	6.75	10.83	17.93	15.41	15.64	14.47	17.07

ns - Not significant; * and ** - Significant at 5% and 1% probability levels, respectively, by the F test; CV - Coefficient of variation; DF - Degrees of freedom.

increasing 25% of tanned bovine manure to the Plantmax HT® substrate, recorded a maximum stem base diameter of 2.87 mm at the 28th day after sowing. In comparison to the research results, the largest stem base diameter of the San Marzano cultivar (3.90 mm) was superior to all.

Regarding the number of leaves, a maximum of 5.46 leaves were found at the rate of 190 mg, with an average gain of 1.76 leaves compared to the control sample (Figure 1B). According to the studies of Taiz et al. (2017) the higher number of leaves in tomato plants is a result of the action of auxin in the process of cellular elongation, optimization of the totipotent of the cells of the conductive tissues and inhibition of ethylene gas which prevents leaf abscission. And also the effect of humic acid that accelerates the physiological activities of plants contributing to the internal energy flow and biomass gain of the shoot. In tomato seedlings, greater foliar development is desirable, as these are the organs responsible for the photochemical and biochemical processes that constitute photosynthesis (Peixoto, 2020).

Santos et al. (2016) also obtained a quadratic response, the seedlings had the highest number of leaves of 3.77, 3.75, and 5.21 for the cultivar Cereja Pendente Yubi, Santa Amélia and Santa Adélia, at concentrations of 80, 87 and 79%, respectively. Hoffman et al. (2017), with the Santa Clara cultivar, registered a positive linear response, verifying the highest number of leaves of 6.37 at the rate of 20 kg of single superphosphate m^{-3} of substrate. Gonçalves et al. (2018), in the production of tomato seedlings, cultivar Santa Cruz Kada, when adding tanned bovine manure at a concentration of 25% to the Plantmax HT® substrate, recorded the highest number of leaves of 7.00. In relation to the San Marzano cultivar (5.46 leaves), the seedlings of the cultivars Cereja Pendente Yubi, Santa Amélia and Santa Adélia had a lower number of leaves, however, the cultivars Santa Clara and Santa Cruz Kada had a higher number of leaves.

The cultivar San Marzano had a maximum plant height of 22.87 cm at a rate of 148.83 mg (Figure 1C), which was 6.49 cm higher than the control sample. This result is due to the balanced supplementation of tomato seedlings with auxin and nitrogen contained in the mixed fertilizer. Auxin together with other plant hormones, such as gibberellin, are responsible for cell expansion and elongation and division of meristematic tissue cells, respectively. And nitrogen, which in addition to composing the molecular structure of auxin is structuring amino acids and crucial in the composition of porphyrins found in chlorophyll molecules (Taiz et al., 2017; Peixoto, 2020). Seedlings with greater height, in this case, have consequently the lower risk of suffering damage in the critical period of the culture if there is competition with weeds within the level of economic damage.

Santos et al. (2016) obtained a quadratic response for the cultivars Cereja Pendente Yubi, Santa Amélia and Santa Adélia, with the highest result obtained for Santa Amélia

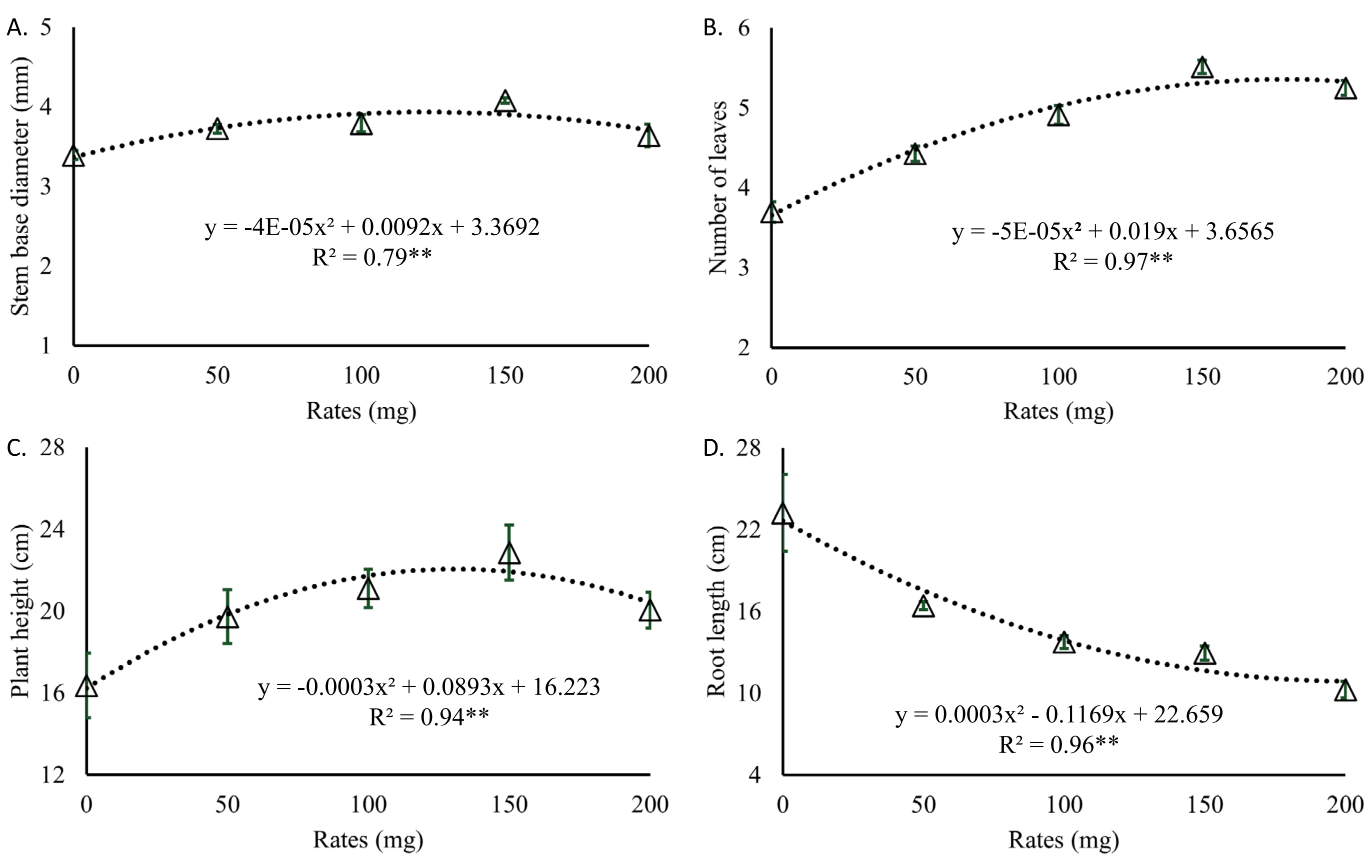

Figure 1. Stem base diameter (A), number of leaves (B), plant height (C), and root length (D) in tomato seedlings, cultivar San Marzano, as a function of mixed fertilizer rates.

with 10.88 cm when using the nutrient concentration at 86%. Hoffman et al. (2017) also found a quadratic behavior for plant height, with the highest estimated value of 15.41 cm (Santa Clara cultivar) obtained with a rate of 15.76 kg of single superphosphate m^{-3} of substrate. In the case of the Santa Cruz Kada cultivar, Gonçalves et al. (2018), by increasing 25% of tanned bovine manure to the Plantmax HT® substrate, found the highest plant height of 13.8 cm. In comparison with the height of 22.87 cm of the San Marzano cultivar, all the other results of the mentioned cultivars were inferior.

In the length of the root system, a negative quadratic adjustment was observed in relation to the increase in fertilizer rates (Figure 1D). The smallest root length (11.27 cm) occurred at the rate of 194.83 mg, which was 48.49% lower than the length of the control sample (23.24 cm). However, in this situation, the smallest root lengths showed greater root system matter, which is desired for tomato seedlings. Variations in root length with increasing rates of fertilizer may have occurred due to increased salinity in the substrate.

Maia Junior et al. (2020) observed this fact when they submitted tomato seedlings, cultivar IPA 6 Caline, to salinity condition (4.5 dS m^{-1}), in which they recorded a reduction of 87% in the length of the root system compared to the control treatment (Maia Junior et al., 2020). Santos et al. (2016) obtained a decreasing linear response for the cultivars Cereja Pendente Yubi and Santa Amélia, with the smallest lengths of the root system being recorded at the maximum concentration of 125% for the two cultivars, 4.14 and 3.83 cm, respectively. In the case of the Santa Adélia cultivar, the response was quadratic, with the smallest result of 4.23 cm at a concentration of 125%. In comparison to these results, the length of the root system of the San Marzano cultivar (11.27 cm) was superior to all.

Shoot dry matter, root dry matter, and total dry matter

The highest production of shoot dry matter (0.338 g) occurred at the rate of 162.50 mg, which means that there was a gain of 58.58% compared to the control sample matter (Figure 2A). Considering the fact that the work was carried out in a region with a tropical “Aw/As” savanna climate (Alvares et al., 2013), the significant gain of shoot dry matter was only possible due to the action of the potassium present in the fertilizer, because, in an adequate quantity in the tomato seedlings, this macronutrient enabled a greater tolerance of the plants to abiotic stress suffered because of thermal oscillation or drastic variation in relative humidity (Filgueira, 2013; Peixoto, 2020), through the adequate regulation of the ostioles of the stomata, avoiding the loss of water by excessive transpiration and improving the assimilation efficiency of glucose and cellulose (Taiz et al., 2017; Prado, 2020).

Santos et al. (2016) found a quadratic response for the cultivars studied, with the highest results of 0.65 g (Santa Amélia), 0.70 g (Cereja Pendente Yubi) and 0.96 g (Santa Adélia) in nutrient concentrations of 79, 81, and 86%, respectively. Hoffman et al. (2017) also obtained a quadratic response for the shoot dry matter of tomato seedlings of the cultivar Santa Clara, which recorded the highest result of 0.11 g as a function of the rate of 14.83 kg of simple superphosphate m^{-3} of Bioplant® substrate. The shoot dry matter of the cultivar San Marzano (0.338 g) was lower than the results of the cultivars Santa Amélia, Cereja Pendente Yuri, and Santa Adélia, however it was higher than the value of the cultivar Santa Clara.

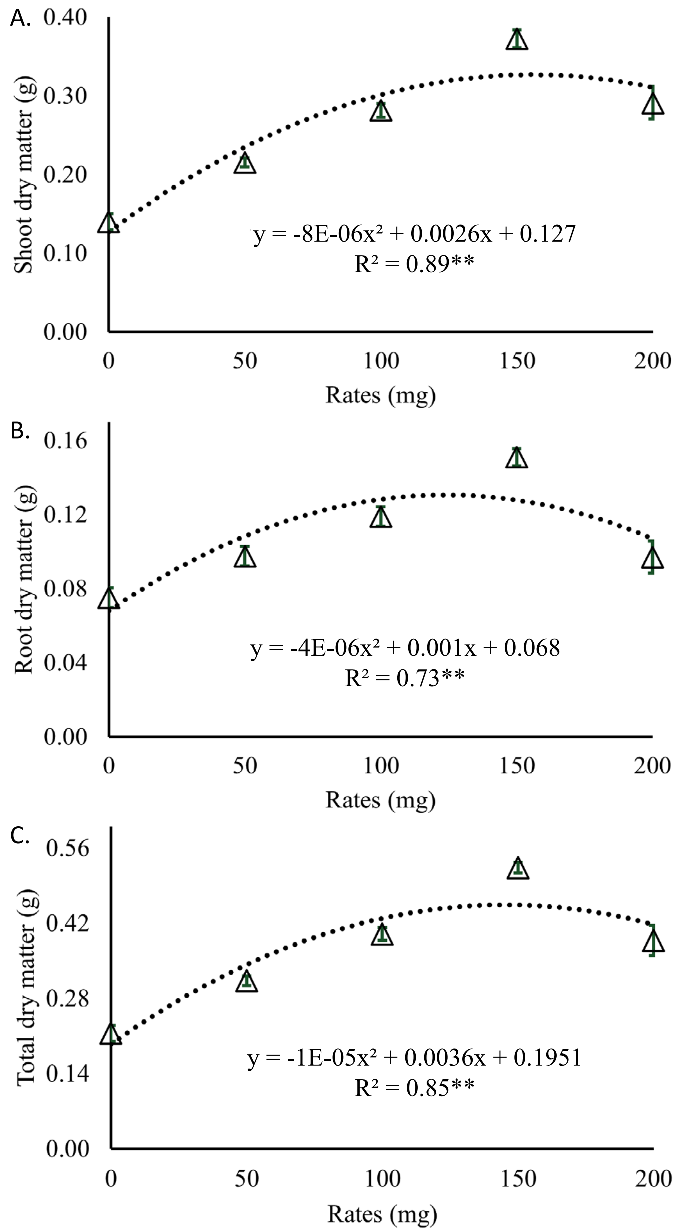

Figure 2. Shoot dry matter (A), root dry matter (B), and total dry matter (C) in tomato seedlings, cultivar San Marzano, as a function of mixed fertilizer rates.

The highest root dry matter (0.130 g) was observed at rate of 125 mg. In this case, an increase of 42.31% of root dry matter was observed in relation to the control (Figure 2B). The main responsible for the increase in root dry matter in relation to the control sample was the phosphorus contained in the mixed fertilizer. Considering the absorption march of tomato (Furlani et al., 2017), it is recommended to apply the mixed fertilizer in the crop establishment stage, starting at emergence until the first 26 days of cultivation (Filgueira, 2013). Of the total phosphorus absorbed, 75% is stored in the vacuole of the cells in the form of orthophosphate, being easily released due to its great mobility to perform physiological activities such as the production of adenosine triphosphate molecules, deoxyribonucleic acid and ribonucleic acid responsible for the formation of carbohydrates, proteins and fibers (Taiz et al., 2017; Prado, 2020).

Santos et al. (2016) obtained a quadratic response in the three cultivars, with the highest values of 0.44 g (Cereja Pendente Yubi), 0.29 g (Santa Adélia), and 0.19 g (Santa Amélia), in nutrient concentrations at 74, 79, and 75%, respectively. Hoffman et al. (2017) found that the quadratic model also had the best fit, with an estimated maximum value of 0.025 g of Santa Clara cultivar, in the application of a rate of 15.0 kg of single superphosphate m^{-3} of Bioplant® substrate. In the case of Gonçalves et al. (2018), by adding 25% of tanned bovine manure to the Plantmax HT® substrate in the production of tomato seedlings (cultivar Santa Cruz Kada), they obtained the highest root dry matter of 0.08 g. In comparison with the cultivars evaluated by Santos et al. (2016), the root dry matter of San Marzano cultivar was lower, however, it was higher than the results of Hoffman et al. (2017) and Gonçalves et al. (2018).

Regarding the variable total dry matter, the highest result (0.519 g) was at the rate of 180 mg, which had a gain of 58.57% in relation to the control sample (0.215 g) (Figure 2C). This greater dry matter gain of tomato seedlings compared to the control was possible due to the integration of the components of the mixed fertilizer: nitrogen, phosphorus, potassium, auxin, L-amino acids, and humic acids, the latter two being responsible for the gain in efficiency of seedlings in transporting and storing nutrients (Prado, 2020; Dunoyer et al, 2022), consequently, it improved the process of mitosis, enzyme synthesis and protein formation of plants (Taiz et al., 2017).

Santos et al. (2016) also obtained a quadratic response in the three cultivars, with the highest results of 1.12 g (Santa Adélia) and 0.83 g (Santa Amélia) in the nutrient concentration at 78%, and 0.91 g (Yubi Pending Cherry) at 79% concentration. In the case of Gonçalves et al. (2018), when adding 25% of tanned bovine manure to the Plantmax HT® substrate in the production of tomato seedlings, cultivar Santa Cruz Kada, obtained the highest result of total dry matter of 0.47 g. Regarding the total dry matter of the cultivars Santa Adélia, Santa Amélia, and Cereja Pendente Yubi, the cultivar San Marzano obtained a lower result, however, its value was higher when compared to the cultivar Santa Cruz Kada result. The efficiency of the seedlings in accumulating biomass is an indication of the productive potential of the plants in the reproductive adult phase, considering that the most vigorous tomato seedlings will have a better capacity to reach the peak of productivity of oleracea fruits.

Dickson quality index and Pearson correlation coefficients

The highest value of Dickson quality index (0.0071) was at the rate of 125 mg (Figure 3A), which is 39.44% higher than the control sample (0.0043). This fact validates the expressive gain of biomass by tomato plants, through the relationship of total dry matter, plant height, stem diameter, dry matter of the aerial part, and dry matter of the root that obtained, respectively, gains of 58.57, 39.62, 14.71, 58.58, and 42.31% in relation to the control (zero rate), due to the application of the rates of the mixed fertilizer. Tomato seedlings with greater vigor grow and develop better, are more tolerant to biotic and abiotic stresses during the biological cycle and in the reproductive adult phase reach maximum fruit productivity (Prado, 2020; Issa, 2021; Dunoyer et al., 2022). Therefore, the DQI of 0.0071 confirms that the use of mixed fertilizer at a rate of 125 mg per plant, solid or liquid, improved the vigor of tomato seedlings, cultivar San Marzano.

In the quality evaluation of tomato seedlings in the cultivar Santa Clara, 29 days after sowing, (Hoffman et al., 2017) in which simple superphosphate was used as a nutritional source, a quadratic response for the Dickson quality index was obtained, observing the highest value of 0.0018 in the application of 12.5 kg of single superphosphate m^{-3} of substrate. In this case, the result of the San Marzano

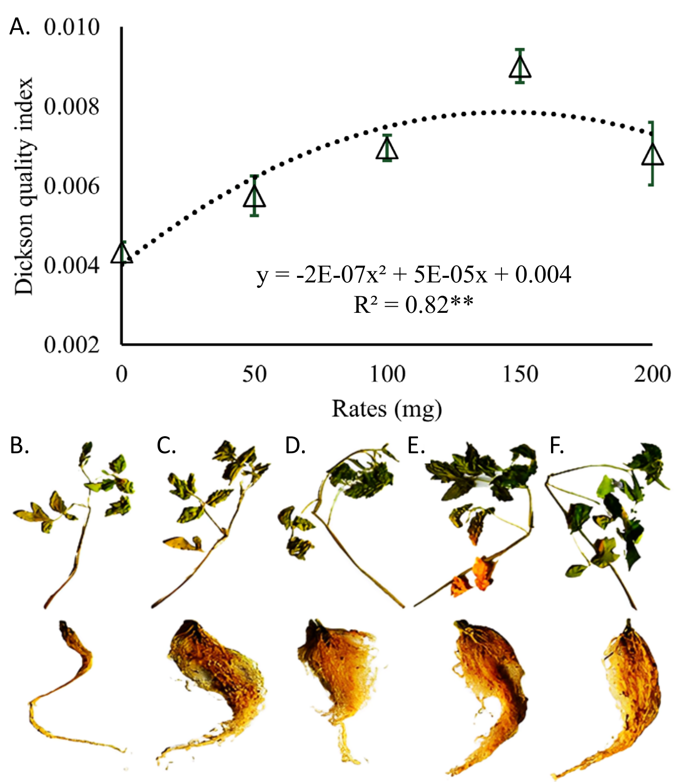

Figure 3. Dickson quality index in tomato seedlings, cultivar San Marzano, as a function of mixed fertilizer rates (A) and Shoot part and dehydrated root system of tomato plants submitted to mixed fertilizer rates (mg): 0 (B), 50 (C), 100 (D), 150 (E), and 200 (F).

cultivar was 74.65% higher than the result of the Santa Clara cultivar (Figure 3B, C, D, E, and F).

In the evaluation of seedling development of cherry tomato cultivars (Pêra Amarela, Pêra Vermelha, and Carolina), on the 28th day after sowing, (Costa et al., 2015) the highest index of 0.0069 was reached by using cassava branch and tanned bovine manure as sources of nutrients in the proportion of 1/1, in which the biggest highlight was the cultivar Carolina, which had a lower performance (2.82%) when compared to the cultivar San Marzano.

The positive correlations (r) with the highest affinity occurred between shoot dry matter and total dry matter (0.99**), shoot dry matter and Dickson quality index (0.99**), stem diameter and root dry matter (0.98**), and between number of leaves and shoot dry matter (0.98**), with emphasis on the interaction between the total dry matter and the Dickson quality index, which obtained a perfect correlation (r = 1**), that is, the two variables reached a totally proportional linear growth (Table 2).

In the negative correlations (r), all were associated with the length of the root system, which was the only one among the analyzed variables to present a negative quadratic adjustment in relation to the increase of rates of the mixed fertilizer, with the greatest equidistance between the length of the root system with the number of leaves (-0.93*).

Therefore, based on obtained results in this work, further scientific research could be carried out to obtain data on the seedlings index after definitive planting and to quantify and qualify the productivity and physicochemical characteristics on San Marzano tomato fruit seedlings, according to appropriate rate found in this study.

Table 2. Pearson correlation coefficients (r) between the variables stem base diameter (SBD), number of leaves (NL), plant height (PH), root system length (RSL), shoot dry matter (SDM), root dry matter (RDM), total dry matter (TDM), and Dickson quality index (DQI).

	SBD	NL	PH	RSL	SDM	RDM	TDM	DQI
SBD	1	0.82^{ns}	0.97^{**}	-0.64^{ns}	0.91^{*}	0.98^{**}	0.94^{*}	0.95^{*}
NL		1	0.92^{*}	-0.93^{*}	0.98^{**}	0.81^{ns}	0.95^{*}	0.94^{*}
PH			1	-0.81^{ns}	0.96^{*}	0.94^{*}	0.97^{**}	0.97^{**}
RSL				1	-0.85^{ns}	-0.59^{ns}	-0.80^{ns}	-0.78^{ns}
SDM					1	0.92^{*}	0.99^{**}	0.99^{**}
RDM						1	0.95^{*}	0.96^{**}
TDM							1	1^{**}
DQI								1

ns - Not significant; * and ** - Significant at 5% and 1% probability levels, respectively.

Conclusions

To meet specific needs in the improvement of morphological structures and dry matter of the cultivar San Marzano, the following rates are indicated to the producer: 115, 190, 148.83, 194.83, 162.50, 125, and 180 mg plant^{-1}, which can be applied solid or liquid, referring to SBD, NL, PH, RSL, SDM, RDM, and TDM, respectively.

Overall, the mixed fertilization of 125 mg plant^{-1}, solid or liquid, is recommended to seedling growers, cultivar San Marzano, who wish to improve plant vigor based on the highest Dickson quality index of 0.0071.

Compliance with Ethical Standards

Author contributions: Conceptualization: JAMS, TMA, TBG; Data curation: JAMS; Formal analysis: JAMS, TMA; Funding acquisition: JAMS; Investigation: JAMS; Methodology: TMA, TBG; Project administration: JAMS, TMA; Resources: JAMS, TMA; Software: JAMS, TMA, TBG; Supervision: JAMS, TMA, TBG; Validation: JAMS, TMA, TBG; Visualization: JAMS, TBG; Writing – original draft: JAMS, TMA, TBG; Writing – review & editing: JAMS, TMA, TBG.

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