REGULAR ARTICLE

Beta vulgaris production with micronutrient fertigation of seedlings

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Abstract

Adequate seedling nutrition is essential for beet production. This study evaluated the effects of applying boron, molybdenum, nitrogen and zinc to seedlings, considering agronomic characteristics and productivity. The experiment was carried out at the São Manuel Experimental Farm of the São Paulo State University, with a randomized block design, seven treatments (fertilizers) and five replicates: T1 - control (without application), T2 - Raiz® (4% N, 5% Mo), T3 - 'Raiz®+Zintrac®', T4 - Biotrac® (5.6% N, 2.3% K_2O, 1.1% B, 1,1% Zn), T5 - 'Biotrac®+Zintrac®', T6 - Zintrac® (1% N, 40% Zn) e T7 - 'Raiz®+Biotrac®'. Doses of 2.0 mL/L for Biotrac® and 0.5 mL/L for Raiz® and Zintrac® were used. The cultivar used was Betana from Feltrin Sementes®, sown in 200-cell trays. The applications took place 8 days after emergence. Evaluations at transplanting and at the end of the cycle included length, diameter, number of leaves and fresh and dry mass of seedlings and adult plants. Treatment T3 (Raiz® + Zintrac®) showed the highest fresh root mass (120 mg). The combination of Raiz® with Zintrac® and Biotrac® increased the number of leaves (3.6) and fresh root mass (20 mg) compared to the control. The application of Biotrac® alone (T4) resulted in the highest root yields (6.25 and 5.50 t/ha), the largest root diameter (19.68 cm) and the highest fresh leaf mass (125 mg). The Zintrac® (T6) treatment resulted in a higher fresh leaf mass (112.8 mg) than the control. However, the results were below commercial expectations.

Keywords

Beet; Boron; Molybdenum; Nitrogen; Zinc.

Introduction

Beet (*Beta vulgaris* L.), a species of the family Quenopodiaceae, originated in Europe and North Africa and is a crop adapted to temperate climates. It is grown for sugar production (sugar beet), forage, or as a food crop ("table" beet), and the lattest is the most widely grown in Brazil (Tivelli et al., 2011). The vegetable has several health benefits, such as the presence of bioactive compounds such as betalains, flavonoids, phenolic compounds and saponins, as well as several possibilities for its addition to food products, such as green juices, powders, cooked foods or fresh foods (Bangar et al., 2022).

In 2022, the global production of *Beta vulgaris* L. reached a production value of 14.24 million dollars, recovering from a decline since 2013 (FAO, 2022). The main beet-producing states in Brazil are Minas Gerais, São Paulo, Rio Grande do Sul and Paraná, accounting for 69% (65,357 thousand reais) of the country's production value (94,379 thousand reais). In 2017, the latest available data on the country's crop from the Brazilian Institute of Geography and Statistics (IBGE), 134,969 tons of the vegetable were produced in 24,870 farms (IBGE, 2017). In São Paulo, according to the Institute of Agricultural Economics (IEA, 2023), the production area of beets is 2,587 hectares with a production of 135,000 tons, exceeding the national production in 2017 and demonstrating the importance of the horticultural crop in the state.

Like other horticultural crops, beet is very demanding in terms of nutrients due to its rapid development, with a short vegetative cycle, intense dry matter production and large extraction and export of nutrients (Cardoso et al., 2017). Therefore, the plant's nutrition must be adequate from the seedling stage onwards. Among these, zinc (Zn), boron (B) and molybdenum (Mo) are considered to be important micronutrients in the vegetative development of beets. However, the effect of micronutrients on table beet production has been little studied and boron, molybdenum and zinc have been described as very important for good plant growth and development (Kirkby; Römheld, 2007).

Zinc is a micronutrient involved in protein synthesis, enzymes, oxidation, and carbon metabolism in the plant (Castillo-González et al., 2018). However, exposure to different concentrations of the micronutrient varies, with increased plant growth observed in the case of beets (Gashash et al., 2022). Boron is important for sugar transport and carbohydrate accumulation in tissues, and sugar accumulation is favored by the presence of this micronutrient (Wimmer et al., 2015). Molybdenum is involved in the constitution of the enzyme nitrate reductase, which is responsible for biological

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nitrogen fixation in the plant (Mello; Mendonça, 2017). Among the macronutrients, nitrogen and potassium are the most accumulated by beets (Cardoso et al., 2017). Vasque et al. (2021), analyzing different nitrogen fertilizations by soil and foliar application of boron for the cultivar 'Early Wonder', observed a significant increase in plant growth, an increase in fresh and dry leaf mass. Oliveira et al. (2017), using fertilization composed of sulfur, zinc, boron and molybdenum, reported a significant increase in production compared to treatments without their application.

No studies were identified that investigated the foliar application of nitrogen and micronutrients at the early stage of seedling development in beet production. Therefore, the objective of this study was to evaluate the influence of foliar application of commercial products containing boron, molybdenum, nitrogen and zinc at the seedling stage on the production of 'Betana' beet.

Materials and methods

The work was carried out at the Experimental Farm of the School of Agriculture (FCA), in the municipality of São Manuel, of the São Paulo State University (UNESP), Botucatu Campus, São Paulo, Brazil, from May to October 2022. The geographical coordinates of the experimental site are 22°46'18.22" S, 48°34'12.28" O and an altitude of 740 m. Seven treatments were evaluated in a randomized block design with five replications. The treatments consisted of different fertilizers, as shown in Table 1.

The 'Betana' hybrid from Feltrin Sementes® was used, which has high vigor, excellent health and resistance to the main diseases such as cercosporiosis (*Cercospora beticola*), downy mildew (*Peronospora farinosa* f. sp. betae) and Beet necrotic yellow vein virus (BNYVV) (Feltrin, 2023). Seedlings were grown in 200-cell polypropylene trays containing commercial Carolina® substrate, with one seed per cell sown on June 22, 2022. Fertilizers were applied 8 days after emergence using a watering can with a volume of 1 L of solution per plot (200 seedlings). A dose of 2 mL per liter was used for the Biotrac® fertilizer and 0.5 mL per liter for the Raiz® and Zintrac® products.

Soil analysis revealed the characteristics shown in Table 2. The area was prepared by plowing and harrowing, and the 10.0 x 1.0 m beds were raised with a rotary tiller. Planting fertilizer was applied with 200 g of poultry manure and 200 g of granular NPK fertilizer formula 8-28-16 per m^2. The chemical analysis of the manure is shown in Table 3.

The seedlings were transplanted on August 1, 2022, at a spacing of 0.25 x 0.10 m, for a total area of 1 m^2 per plot with 40 plants. The usable area consisted of the two central rows of plants, excluding the two side rows and the first and last plants in each row, for a total area of 0.40 m^2. Two top dressings were applied throughout the cycle, at 16 and 31 days after transplanting, with poultry manure (100 g/m^2). Irrigation was performed daily by a microsprinkler system using a 120 L/h balloon microsprinkler for 20 minutes (40 L) at a rate of 3.18 mm. Spontaneous plants were managed manually. The characteristics assessed on the seedlings one day before planting were: shoot length, root length, shoot and root fresh mass and shoot and root dry mass.

Harvesting took place on October 26, 2022, and the following characteristics were evaluated: number of leaves per plant: this was done by counting all the leaves on the plant; height of the aerial part: the height was measured from the neck of the plant to the height of the highest leaf; root diameter: this was done using a caliper and expressed in cm; leaf and root fresh mass: this was done from the mass of the leaves and roots, separately, on a scale with a precision of 0.01 and the results were expressed in grams per plant; total productivity: this was estimated from the fresh mass per root by the estimated number of plants per ha (400,000 plants) and the results were expressed in t ha^{-1}; dry mass of leaves and roots: the leaves and roots were packed in paper bags and dried in an oven with forced air circulation at 70 °C until a constant mass was obtained and weighed on a scale with an accuracy of 0.01 g and the results were expressed in grams per plant.

The weather data were obtained from the meteorological system of the FCA and are shown in Table 4. The data was submitted to analysis of variance and the means were compared using the Tukey test at 5% probability, using the Sisvar software (Ferreira, 2011).

Table 1. Characterization of the seven treatments used in the beet production experiment with seedling fertigation

Treatment	Product	Chemical composition
T1	Control	without application
T2	Raiz®	(4% N, 5% Mo)
T3	Raiz® + Zintrac®	(4% N, 5% Mo) + (1% N, 40% Zn)
T4	Biotrac®	(5.6% N, 2.3% K_2O, 1.1% B, 1.1% Zn)
T5	Biotrac® + Zintrac®	(5.6% N, 2.3% K_2O, 1.1% B, 1.1% Zn) + (1% N, 40% Zn)
T6	Zintrac®	(1% N, 40% Zn)
T7	Raiz® + Biotrac®	(4% N, 5% Mo) + (5.6% N, 2.3% K_2O, 1.1% B, 1.1% Zn)

Table 2. Soil analysis of the experiment area

pH	Organic Matter	P_{resin}	K	Ca	Mg	Base Saturation	CTC	V%
5.8	9.5 g/dm^3	62 mg/dm^3	1.4 $mmol_c/dm^3$	54.5 $mmol_c/dm^3$	12.0 $mmol_c/dm^3$	80.5 $mmol_c/dm^3$	93.0 $mmol_c/dm^3$	84%

Table 3. Chemical analysis of poultry manure used as organic fertilizer

Organic Matter	P_2O_5	K_2O	S	Ca	Mg	Cu	Fe	Mn	Zn
1.15%	1.30%	1.57%	0.20%	1.14%	0.47%	150 mg/kg^{-1}	9790 mg/kg^{-1}	324 mg/kg^{-1}	137 mg/kg^{-1}

Table 4. Climatic data during the experiment period

Month	Average Temperature (ºC)	Relative Humidity (%)	Total Rainfall (mm)
August	18.90 ºC	65.51%	40.38 mm
September	19.04 ºC	72.40%	79.25 mm
October	22.56 ºC	73.40%	129.54 mm

Results and discussion

According to the analysis of variance and Tukey's test (5%), differences were observed among the fertilizers used for all characteristics evaluated in the seedlings (Table 5). Treatment 'T3' (Root® + Zintrac®) produced the highest number of leaves with an average of 4.0 leaves per seedling, about 42% and 24% more leaves than treatments 'T2' (Root®) and 'T6' (Zintrac®), respectively, but only 5.3% higher than the control (T1) without difference (Table 5). The fertilizer 'Raiz®' (T2) gave the lowest number of leaves, 2.3 leaves, which was even lower than the control treatment (no application).

For the length of the aerial part of the seedling, the treatment 'T7' (Root® + Biotrac®) had the highest value, with an average length of 7.83 cm, not different from the treatments 'T6' (Zintrac®) and 'T1' (control) (Table 5). On the other hand, the 'Raiz®' fertilizer (T2) had the shortest length, with an average of 4.06 cm, which was lower than the other fertilizers and the control. In the control treatment, the seedlings had the longest roots, greater than all the other treatments (Table 5).

The highest root fresh mass values were observed in treatments 'T7' (Root® + Biotrac®) and 'T3' (Root® + Zintrac®) with average values of 120 and 100 mg per plant, respectively, while 'T6' (Zintrac®) provided the lowest fresh mass (40 mg per plant) (Table 5). However, for root dry mass, all fertilizers were inferior to the control (Table 5). For fresh and dry leaf mass, no differences were observed between the control and treatments 'T7' (Root® + Biotrac®) and 'T3' (Root® + Zintrac®), while 'T4' (Biotrac®) and 'T2' (Root®) had lower fresh leaf mass.

At the end of the cycle, there were no differences among treatments for the number of leaves and the length of the aerial part (Table 6). However, for fresh and dry leaves mass, treatment 'T4' (Biotrac®) had higher values than treatment 'T3' (Raiz® + Zintrac®), as well as for root diameter. For fresh leaves mass and yield, treatments 'T4' (Biotrac®) and 'T5' (Biotrac® + Zintrac®) showed the highest values, higher than the control (Table 6). The observed yields were 68.92% and 48.65% higher than the control for treatments 'T4' (Biotrac®) and 'T5' (Biotrac® + Zintrac®), respectively, showing the advantage of these treatments for beet production.

Analyzing Table 5, the product Raiz® together with Zintrac® resulted the highest fresh mass for the root in the seedlings (120 mg); and together with Biotrac® for the number of leaves (3.8) and the fresh mass of the root (100 mg). For the adult plant (Table 6), we can see that the Biotrac® product, alone or together with Zintrac®, continues to provide better characteristics than the control for root diameter (19.68 and 19.13 cm) and fresh leaves mass (40.7 and 38.2 mg).

The highest fresh and dry mass of leaves and roots with the Biotrac® product can be attributed to the presence of nitrogen (5.6%) and potassium (2.3% K_2O) in its composition, since these nutrients (N and K) are the most required by beet plants (Grangeiro et al., 2007; Cardoso et al., 2017). In addition to being essential for osmotic regulation and the photosynthetic process, potassium is closely related to the transport of sugars from the leaves to the roots, the main reserve organ of beets (Barlóg et al., 2018). As observed in the work of Füllgrabe et al. (2022), the higher the dose of potassium applied via foliar or soil application, the higher the concentration found in the leaves. As a result, photosynthetic activity and sugar transport increased, as did water potential and cell turgor, the latter being an essential requirement for high plant growth rate (Füllgrabe et al., 2022).

The same result was obtained by Alves et al. (2008) when analyzing nitrogen and potassium deficiency, where the authors observed a reduction in the dry matter of the whole plant, although in their work the nitrogen deficiency also reduced the number of leaves and plant height, unlike the data obtained in the present work. Oliveira et al. (2017) also observed that when fertilized with different doses of nitrogen, there was an increase in content of the nutrient in the leaves and roots. In addition, according to the same author, the addition of nutrients such as sulfur (S), zinc (Zn), boron (B), and molybdenum (Mo) along with nitrogen had a significant effect on the accumulation of nitrogen in leaves and roots, as well as on the mass of fresh and dry matter in leaves and roots. If we compare the results obtained in this study, we can see that the presence of these nutrients in the Biotrac® and "Biotrac® + Zintrac®" products had high values, although they were similar to the control value. However, if we compare the results obtained in this study with those of Vasque et al. (2021) for one of the main beet varieties, "Early Wonder", the analyzed characteristics are much lower than expected, which requires further studies on dosages and application times for the Betana hybrid.

On the other hand, the presence of zinc and boron in Biotrac® (1.1% of each micronutrient) may also have contributed to obtaining better characteristics in beets. Elmasry and Al-Maracy (2023), when evaluating the application of boron together with different doses of nitrogen in beets after 70 and 100 days of germination, obtained greater diameters and yields with the application of boron. Compared to the data obtained in this study, we observed that the presence of boron had a great influence on root diameter and yield, which corroborates our data. Prado et al. (2013) observed a progressive increase in beet dry matter with foliar boron application.

Carmona et al. (2020) observed an increase in fresh mass of beet roots when 10 mg L^{-1} zinc was applied by seed. Zhao et al. (2024) obtained an 11.3% increase in leaf dry mass when applying different doses of Zn. If we compare these data with those of the present study, for treatments T5 and T6 containing Zn, there was an increase of 53.5% and 54.4%, respectively, compared to the control. Costa et al. (2023), when evaluating the application of Zn at 23, 29, 70 and 76 days after germination, obtained an increase in plant mass and number of leaves, which was not observed in this study. These studies show that zinc is an essential micronutrient for plants because it is required catalytically and structurally by several enzymes. In addition, it is a precursor of AIA (indol acetic acid), participates in auxin production, acts in protein synthesis, carbohydrate metabolism, and chlorophyll biosynthesis (Broadley et al., 2012).

However, if we analyze the equivalence table of the Companhia de Entrepostos e Armazéns de São Paulo (CEAGESP, 2024) for root diameter, the results obtained are classified with the wholesale market denomination "1A", in the third lowest evaluation class "C", below what is expected for the market. Considering the importance of a balanced fertilization, with an adequate supply of macro- and micronutrients, and based on the results obtained, it can be concluded that the application of fertilizers containing nitrogen, potassium, boron and zinc to the beet crop can make a positive contribution to obtaining better agronomic characteristics as well as higher productivity.

Table 5. Mean values of number of leaves (NL), Aerial Part Length (APL), root length (RL), fresh and dry mass of leaves and roots of beet seedlings as a function of fertilizer application, Botucatu, UNESP, 2024.

Treatments	NL	APL (cm)	RL (cm)	Fresh mass (mg)		Dry Mass (mg)	
				Root	Leaves	Root	Leaves
Control (T1)	3.80 ab*	6.86 ab	12.56 a	87 ab	370 a	30 a	53 a
Raiz® (T2)	2.30 c	4.06 c	7.80 b	83 ab	190 c	10 c	20 b
Raiz® + Zintrac® (T3)	4.00 a	5.89 b	8.39 b	120 a	320 abc	20 b	33 ab
Biotrac® (T4)	2.70 bc	6.16 b	8.53 b	57 bc	190 c	13 c	13 b
Biotrac® + Zintrac® (T5)	3.80 ab	5.64 b	7.85 b	60 bc	260 abc	20 b	23 b
Zintrac® (T6)	3.00 abc	6.58 ab	6.26 b	40 c	230 bc	20 b	30 b
Raiz® + Biotrac® (T7)	3.60 ab	7.83 a	8.09 b	100 a	350 ab	20 b	37 ab
CV (%)	12.3	8.0	12.2	17.1	16.9	11.5	22.4
Overall Average	3.3	6.14	8.50	70	270	10	30
DMS	1.20	1.40	2.97	30	13	6	20

*Means followed by the same letter in the columns are not different at 5% probability by Tukey's test.

Table 6. Mean values of number of leaves (NL), aerial part length (APL), root diameter (RD), productivity (PR), fresh and dry mass of leaves and roots of beet as a function of fertilizer used in seedling production, Botucatu, UNESP, 2024.

Treatments	NL	APL (cm)	RD (cm)	PR (t/ha^{-1})	Fresh mass (mg)		Dry mass (mg)	
					Root	Leaves	Root	Leaves
Controle (T1)	12.38 a	22.13 a	17.63 ab	3.70 bc	32.7 ab	75.0 bc	3.4 ab	11.4 ab
Raiz® (T2)	12.00 a	23.04 a	17.25 ab	3.30 bc	26.0 ab	67.3 bc	2.9 ab	11.7 ab
Raiz® + Zintrac® (T3)	12.00 a	19.50 a	14.94 b	2.70 c	20.8 b	55.7 c	2.5 b	10.7 b
Biotrac® (T4)	13.88 a	24.96 a	19.68 a	6.25 a	40.7 a	127.5 a	4.7 a	16.0 ab
Biotrac® + Zintrac® (T5)	14.25 a	24.08 a	19.13 ab	5.50 a	38.2 ab	112.8 a	4.1 ab	17.5 a
Zintrac® (T6)	14.13 a	24.76 a	19.19 ab	4.80 ab	37.3 ab	98.0 ab	4.4 ab	17.6 a
Raiz® + Biotrac® (T7)	13.75 a	22.81 a	17.13 ab	3.30 bc	36.8 ab	67.0bc	3.4 ab	10.4 b
CV (%)	8.6	12.5	10.7	18.7	24.9	18.7	24.6	20.6
Média geral	13.19	23.03	17.84	4.22	33.2	86.2	3.6	13.6
DMS	2.66	6.73	4.45	1.84	19.34	37.75	2.09	6.57

*Means followed by the same letter in the columns are not different at 5% probability by Tukey's test.

Conclusions

The supply of micronutrients, such as boron, zinc, and molybdenum, has important functions in the plant. The greater their presence in the plant, the greater the desired trait for the market. However, even with the increase in characteristics described, when analyzed from the point of view of sales in the main warehouse of São Paulo, CEAGESP, the characteristics of the Betana hybrid are far below commercial expectations, requiring further studies on the practical application periods of the products for this variety.

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