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Fertirrigation with manganese in beet

Fertirrigação com manganês em beterraba

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ABSTRACT

No study has investigated the fertilization of beet with manganese (Mn) in the Brazilian semi-arid region. In this study, we evaluated the agronomic performance of manganese fertigated beet in Mossoró, Rio Grande do Norte. The experiments were conducted at Fazenda Experimental Rafael Fernandes in 2019 and 2021, and the study had a complete randomized block design with five treatments (0, 3, 6, 9, and 12 kg ha^{-1} Mn) and four replications. The Mn content increased in foliar diagnosis with fertilization. The accumulation of dry mass and the number of leaves did not differ significantly as a function of the dose. The highest total (21.59 t ha^{-1}) and commercial (20.55 t ha^{-1}) yields of tuberous roots were obtained with 6 kg ha^{-1} Mn. The adverse effects of excess Mn were expressed in the lower total and commercial productivity of beet fertilized with more than 6 kg ha^{-1} Mn. The accumulation of Mn in the tuberous roots was not affected by fertilization. In the leaves and the whole plant, the maximum accumulation occurred when 12 kg ha^{-1} Mn was applied. Although Mn did not influence the content of soluble solids, the pH of the tuberous roots of plants fertilized with 6 kg ha^{-1} Mn decreased, and the dose with the highest total and commercial productivity had a lower content of soluble sugars. Our findings suggest that treatment with 6 kg ha^{-1} Mn is optimum for the beet crop.

Index terms: *Beta vulgaris* L.; micronutrients; semi-arid.

RESUMO

Não há na literatura recomendações de adubação com manganês (Mn) para beterraba estabelecidas no semiárido brasileiro. Objetivou-se avaliar o desempenho agronômico de beterraba fertirrigada manganês em Mossoró, RN. Foram desenvolvidos experimentos na Fazenda Experimental Rafael Fernandes nos anos de 2019 e 2021, delineados em blocos casualizados completos com cinco tratamentos (0, 3,0, 6,0, 9,0 e 12,0 kg ha^{-1} de Mn) e quatro repetições. Houve aumento no teor de Mn na diagnose foliar com a adubação. O acúmulo de massa seca e o número de folhas não diferiram estatisticamente em função das doses. A maior produtividade total (21,59 t ha^{-1}) e comercial (20,55 t ha^{-1}) de raiz tuberosa foi obtida com 6,0 kg ha^{-1} de Mn. O efeito deletério do excesso de Mn foi expresso na menor produtividade total e comercial de beterraba adubada com mais que 6,0 kg ha^{-1} de Mn. O Mn acumulado na raiz tuberosa não foi influenciado pela adubação. Nas folhas e na planta inteira, o acúmulo máximo ocorreu na dose 12,0 kg ha^{-1} de Mn. O Mn não influenciou no conteúdo de sólidos solúveis, mas reduziu o pH e, a raiz tuberosa das plantas adubadas com 6,0 kg ha^{-1} de Mn, dose com maior produtividade total e comercial, tiveram menor teor de açúcares solúveis. Recomenda-se adubação com 6,0 kg ha^{-1} de Mn para a cultura da beterraba.

Palavras-chave: *Beta vulgaris* L.; micronutriente; semiárido.

INTRODUCTION

Beet (*Beta vulgaris* L.) is rich in nutrients and bioactive compounds (Abera, 2019; Chhikara et al., 2019; Kale et al., 2018) and is a part of the diet of the Brazilian population. According to Nizio-Łukaszewska and Gawęda (2016), beet is considered to be an accumulator of metals. El-Ashry, El-Bahr, and Gabr (2020) found that beet specifically accumulates high levels of manganese (Mn).

Mn is an essential heavy metal that promotes many physiological and metabolic functions in plants, such as the activation of enzymes, the transfer of electrons to photosystem II, protein synthesis, the metabolism of phenolic compounds, and cell elongation and division, by influencing the level of indole acetic acid (IAA) (Li et al., 2019; Wang et al., 2012). Excessive availability of Mn can disrupt photosynthesis and plant enzyme activity, causing

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deleterious effects on growth and yield (Fernando; Lynch, 2015; Li et al., 2019; Pittman, 2005). The deficiency of Mn can also damage plants (Schmidt; Jensen; Husted, 2016).

The recommended Mn content in beet is 70 – 200 mg kg^{-1} (Trani et al., 2018). Oliveira et al. (2018) found that the Mn content in semi-arid soils is suitable for agricultural production. They found an average Mn content of 55.42 mg dm^{-3} in the soil in the semi-arid region of Ceará. However, the exact requirements of the culture need to be determined under these conditions, since values below or above the extremes established by Trani et al. (2018) can lead to deficiency or toxicity respectively.

In the Brazilian semi-arid region, the yield of tuberous roots exceeds 20 t ha^{-1} (Batista et al., 2016; Silva et al., 2019). However, these values are below the average value recorded in Brazil, which varies between 30 and 50 t ha^{-1} (Trani et al., 2018).

The low yield of beet in the Brazilian semi-arid region might be due to the poor knowledge of crop management, specifically, nutrition. Hence, relying on the recommendations established in areas with different soil and climatic characteristics is necessary. However, this might not meet the actual requirements of the culture and, in turn, limit the yield and quality of the tuberous root.

In this study, we evaluated the agronomic performance of beet fertigated with manganese in Mossoró, RN.

MATERIAL AND METHODS

In June and September (2019) and July and October (2021), two experiments were conducted at the Rafael Fernandes Experimental Farm in the Universidade Federal Rural do Semi-Árido (UFERSA). The experiment was performed in the municipality of Mossoró, RN (5°6'37" S and 37°23'50" W). This region has a semi-arid climate, with an average temperature of 26.66 °C, relative humidity (RH) of 73.80%, and precipitation of 7.85 mm, in 2019 and 28.2 °C average temperature, 66.6% RH, and 0.3 mm of precipitation in 2021, during the months in which the experiments were conducted.

The soil in this area is classified as Argissolic red-yellow Latossolic (Empresa Brasileira de Pesquisa Agropecuária - Embrapa, 2018). The chemical characteristics were described after soil samples were collected at a depth of 0 to 20 cm and analyzed in the laboratory (Table 1). According to Trani et al. (2018), the concentration of Mn in the soil of the study area was medium in 2019 and high in 2021. The soil had a sandy texture.

The experiments were conducted using a complete randomized block design with five treatments and four replications. The treatments included 0, 3, 6, 9, and 12 kg ha^{-1} Mn, applied in the form of manganese sulfate. The total area of each plot was 4.5 m² (3.0 m × 1.5 m), and the useful area was 2.8 m^2. In both experiments, six rows of plants were spaced 0.25 m apart, and the plants were spaced 0.10 m apart. For delimiting the useful area, the lateral lines and a plan line at each end were not considered for the analysis.

The experiments were conducted in beds, fertilized in a foundation with 190 kg ha^{-1} P_2O_5, in the form of simple superphosphate, seven days before planting (Silva et al., 2019). Topdressing fertilization was performed with a split application by the fertigation of 120 kg ha^{-1} nitrogen and 180 kg ha^{-1} K_2O. Also, 13.7 kg ha^{-1} magnesium, 47.25 kg ha^{-1} calcium, and in 2021 only, 18.26 kg ha^{-1} sulfur were also applied to the top dressing. Urea, magnesium sulfate, calcium nitrate, potassium chloride, and potassium nitrate were used as nutritional sources. Organic fertilization was not conducted. Fertigation with Mn was started at 23 and 29 days after sowing (DAS) and completed at 70 and 76 DAS, respectively, in 2019 and 2021.

Table 1: Chemical characterization of the soil in the study areas at the Rafael Fernandes Experimental Farm.

2019															
pH	MO	B	Cu	Fe	Mn	Zn	P	K	Na	Ca	Mg	H+Al	SB	CEC	V
H_2O	g kg^{-1}	mg dm^{-3}								cmolc dm^{-3}					%
6.3	4.14	0.19	0.10	6.61	2.36	0.50	3.2	51.0	8.1	0.55	0.25	0.33	0.97	1.3	75
2021															
pH	MO	B	Cu	Fe	Mn	Zn	P	K	Na	Ca	Mg	H+Al	SB	CTC	V
H_2O	g kg^{-1}	mg dm^{-3}								cmolc dm^{-3}					%
5.2	14.87	0.77	0.33	163.03	15.8	0.64	1.9	39.1	2.3	0.66	0.08	0.20	0.84	3.69	23.04

MO: Organic matter; H+Al: Potential acidity; SB: Sum of bases: CEC: Cation exchange capacity; V: Base saturation.

From foundation fertilization to thinning, micro-sprinkler irrigation was performed. This system was later replaced by localized irrigation with self-compensating drippers at a flow rate of 1.5 L/h, spaced at 0.30 m. Three drip tapes were distributed in plots placed 0.50 m apart. The quantity of water used in irrigation was determined based on the evapotranspiration (ETc) of the crop.

Three beet glomeruli, cultivar Fortuna, were sown directly in the holes. At 20 DAS, thinning was performed, leaving only one plant per hole. During the crop cycle, manual weeding and chemical control were performed in the phytosanitary management of *Cercospora beticola*, *Conoderus scalaris*, *Liriomyza* ssp, *Fusarium* ssp., and *Macrophomina* spp.

We collected 20 completely expanded leaves at 55 DAS to quantify the nutrient content in the nutritional status diagnosis leaf (NSDL) (Malavolta; Vitti; Oliveira, 1997). The leaves were first washed thoroughly, and then, they were dried in a closed air circulation oven at 65 °C until a constant mass was obtained. The samples were ground in a Willey mill for further digestion. Then, sulfuric digestion and determination of the content of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and manganese were performed (Embrapa, 2009).

One day before harvesting, five plants were collected per plot and sent to the Plant Nutrition Laboratory at UFERSA. The height (cm) and number of leaves per plant were measured. The plants were divided into shoots and tuberous roots, and then, they were sanitized and dried at 65 °C in an oven to determine the dry mass in g/plant. The shoot dry mass (SDM), tuberous root (DMTR), and total dry mass (TDM) were quantified from the sum of SDM and DMTR.

After drying, the samples underwent sulfuric digestion, and the Mn content was quantified at the end of the cycle (Embrapa, 2009). With this data and the dry mass values, the accumulation of Mn in leaves, tuberous roots, and the total Mn content in beet were determined.

At 79 DAS, the plants were harvested. The tuberous root of beet was classified following the guidelines of Hortbrasil (2006). The roots that were below 50 mm in diameter, with serious defects and/or phytosanitary problems, were considered non-commercial; the rest were considered commercial. After classification, the commercial yield (CY), non-commercial yield (NCY), and total yield (TY) were quantified in tons per hectare.

The post-harvest quality attributes were determined based on the average values of 10 commercial tuberous roots per plot. After cleaning and processing the tuberous roots, the pH, soluble solids or SS (%), titratable acidity or TA (mEq 100 g^{-1}), and the SS/TA ratio (Pregnolatto; Pregnolatto, 1985) were evaluated. Total soluble sugars (%) or TSS were evaluated by the anthrone method (Yemn; Willis, 1954).

Analysis of variance (ANOVA) was performed to analyze the data by conducting the F test. When the ratio of the largest and smallest mean square of the residue was ≤ 4, the data were analyzed together (Ferreira, 2018). Regression analysis was performed for the dose of Mn, and the significant equation with the highest coefficient of determination was selected. The data were analyzed using the SISVAR v.5.3 software (Ferreira, 2019).

RESULTS AND DISCUSSION

The dose of Mn had an isolated effect on the contents of Mg and Mn in the nutritional status diagnosis leaf (NSDL). The increase in the dose of Mn applied via fertigation linearly reduced the Mg content in the foliar diagnosis, with a minimum of 2.77 g kg^{-1} at 12 kg ha^{-1} Mn (Figure 1A) and increased the Mn content to 314.06 mg kg^{-1} (Figure 1B). The levels of N, P, K, and Ca were not affected by fertilization with Mn.

Fertilization with Mn can cause Mg deficiency in the beet plant. The absorption of Mg has an antagonistic relationship with Mn (Farzadfar; Zarinkamar; Hojati, 2017), and the competition between cations can cause Mg deficiency (Gransee; Führs, 2013). The estimated Mg content in NSDL after fertilization using 6 kg ha^{-1} Mn (2.99 g kg^{-1}) was below 3.0 g kg^{-1}, the minimum dose that is considered ideal for beet in a range that has a maximum of 8.0 g kg^{-1} (Trani et al., 2018).

Fertilization above 0.2 kg ha^{-1} Mn increased the manganese content to higher than 200 mg kg^{-1} in the beet NSDL, which was toxic to the plant. The adequate content of manganese in the beet NSDL is 70 to 200 mg kg^{-1} (Trani et al., 2018). Compared to the content of Mn in the NSDL in the treatment without Mn fertilization, the concentrations of Mn in the soils after treatment in 2019 and 2021 were considered to be medium and high, respectively (Trani et al., 2018), and the applied doses were within the desirable range for beet.

Manganese is a heavy metal that has phytotoxic effects in excess. It affects photosynthesis and enzymatic activity, causing deleterious effects on growth and production (Li et al., 2019). Oxidative stress is another problem caused by excess Mn (Oliveira; Andrade, 2021). Under such stressful situations, plants exhibit adaptations such as the activation of the antioxidant system and the regulation of Mn uptake and homeostasis (Li et al., 2019) to minimize damage.

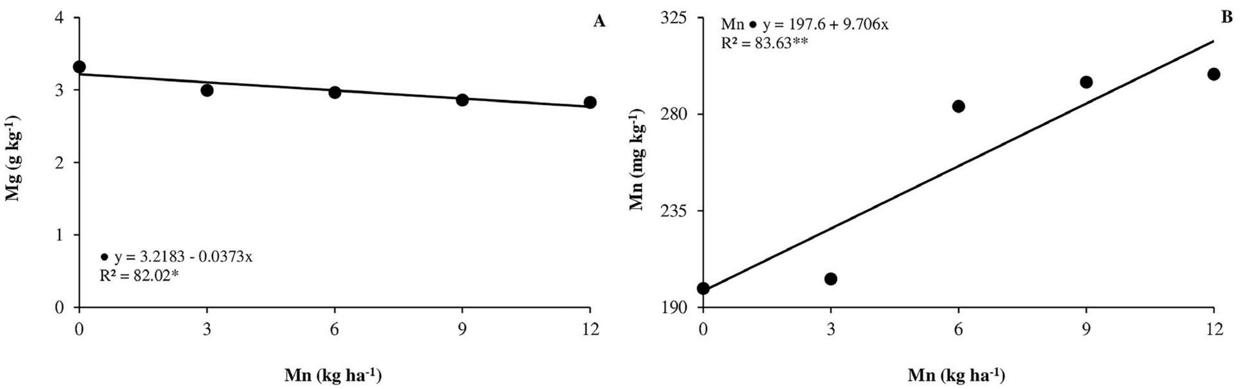

Figure 1: Contents of magnesium (A) and manganese (B) in the nutritional status diagnostic leaf (NSDL) of beet fertilized with Mn; the data presented are the average of two years (2019 and 2021), in Mossoró, RN.

The average content of nutrients in the nutritional status diagnosis leaf among the experiments showed a significant difference in N, P, K, and Mn (Table 2). A higher content of P and K occurred in 2019 because the study area was cultivated in the previous years, and the soil was treated with phosphate and potassium fertilizers. The high N content in 2021 occurred because the soil in the area had never been cultivated. The dose of Mn was higher in the soil in the second experiment (Table 1).

In 2021, the average levels of N, P, K, and Mg in the leaf were within the ideal range for beet, according to Trani et al. (2018). For the Ca content in 2019 and 2021, the average was below 25 g kg^{-1}, while for Mn, the values were above 200 mg kg^{-1} (Trani et al., 2018) (Table 2).

Table 2: Average content of N, P, K, Ca, Mg, and Mn in the diagnosis leaf of the nutritional status of fertilized beet B in the years 2019 and 2021, in Mossoró, RN.

Ano	N	P	K	Ca	Mg	Mn
	g kg^{-1}					mg kg^{-1}
2019	29.7b	6.4a	55.7a	4.2a	2.9a	217.3b
2021	43.1a	3.7b	39.5b	4.2a	3.1a	294.8a

N: Nitrogen; P: Phosphor; K: Potassium; Ca: Calcium; Mg: Magnesium; Mn: Manganese. *Significant to 5% of probability (p < 0,05).

In 2019, the maximum height of the plants (26.16 cm) was recorded after fertilization with 5.6 kg ha^{-1} Mn. In 2021, the equations for the effect of the dose of Mn on plant height were not adjusted. The average height of the plants in 2021 was 30.44 cm (Figure 2).

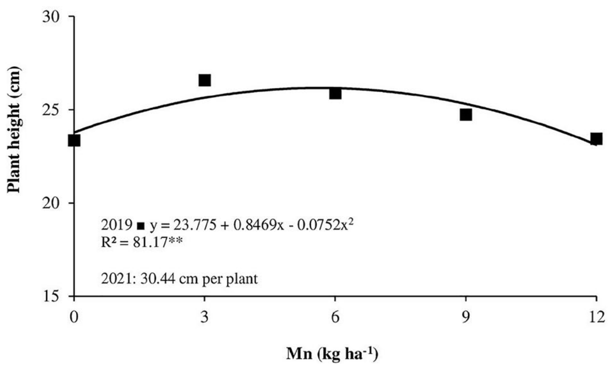

Figure 2: Height of beet plant fertilized with Mn in the years 2019 and 2021, in Mossoró, RN.

The increase in shoot dry mass, tuberous root, and total dry mass were not affected by Mn. The highest averages of SDM, DMTR, and TDM occurred in 2021, as shown in Table 3.

The commercial tuberous root and total beet yield increased after manganese was applied. The highest CY of beet (20.55 t ha^{-1}) was recorded at 6.0 kg ha^{-1} Mn. At the same dose, the maximum total yield of 21.59 t ha^{-1} was obtained (Figure 3). The application of Mn did not affect the yield of non-commercial tuberous roots.

The TY and CY were higher in 2021 than in 2019. The highest average of NCY occurred in 2019 (Table 3). The difference in the total and commercial yield of tuberous roots between the experiments was associated with the loss of plants due to phytosanitary problems that occurred in 2019.

Table 3: Average dry mass, yield, and Mn accumulation in beet plants fertilized with Mn in the years 2019 and 2021, in Mossoró, RN.

Ano	SDM	DMTR	TDM	TY	CY	NCY	MnTR
		g/plant			t ha^{-1}		mg/plant
2019	3.59b	6.60b	10.19b	8.74b	7.35b	1.39a	0.50b
2021	4.16a	14.76a	18.92a	32.55a	31.72a	0.83b	1.18a

SDM: Shoot dry mass; DMTR: Dry mass tuberous root; TDM: Total dry mass; TY: Total yield; CY: Commercial yield; NCY: Non-comercial yield; MnTR: Manganese Tuberous root. *Significant to 5% of probability (p < 0,05).

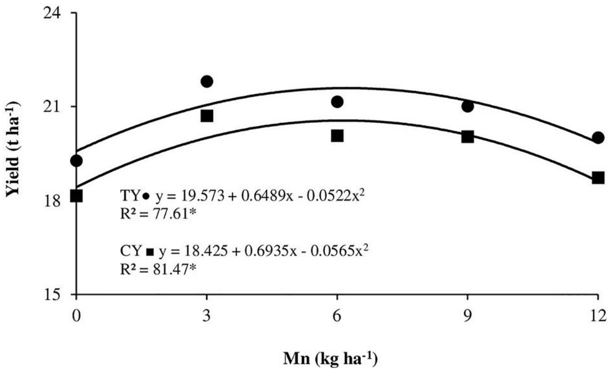

Figure 3: Total yield (TY) and commercial yield (CY) of the tuberous roots of beet fertilized with Mn; data shown are the average of the years 2019 and 2021, in Mossoró, RN.

The maximum commercial yield (20.55 t ha^{-1}) after fertilization with Mn was close to (20.58 t ha^{-1}) the yield achieved by Batista et al. (2016) and lower (25 t ha^{-1}) than that obtained by Silva et al. (2019). The authors obtained these results in experiments conducted on the same farm.

The Mn doses and years of experimental conduction showed an interaction effect on the total accumulation of manganese in beet and leaves. In both cases, only the equations for the Mn dose obtained in 2021 were adjusted, with an estimated maximum of 10.66 and 11.92 mg/plant in the leaves and the whole plant, respectively, after 12.0 kg ha^{-1} Mn was applied (Figure 4). The manganese accumulated in the tuberous roots differed significantly only when the average accumulation between years was compared (Table 3).

A greater content of Mn accumulated in the leaves than in the tuberous root of the beet plants. This result suggested low mobility and lesser redistribution of Mn in the plant. A low Mn content in other organs compared to that in the leaves occurred due to the low concentration of manganese in the phloem exudate and its weak movement in the phloem vessels (Tkachenko; Kosavera; Frontasyeva, 2021). The accumulation of Mn was greater in 2021 because of the greater availability of manganese in the soil in that year (Table 1) and the greater dry mass of beet (Table 3).

Fertilization with Mn decreased the pH of the tuberous roots, making them more acidic. The pH was 5.88 in the control treatment but 5.59 in plants fertigated with 12 kg ha^{-1} Mn (Figure 5A). The average pH content between the experiments was significantly different ($p < 0.05$), with a higher average in 2019 (5.99) than in 2021 (5.48).

In the analysis of soluble sugars, a quadratic adjustment was made to the equations for the dose of Mn applied. The maximum TSS content (9.27%) was obtained when 12 kg ha^{-1} Mn was applied. However, at

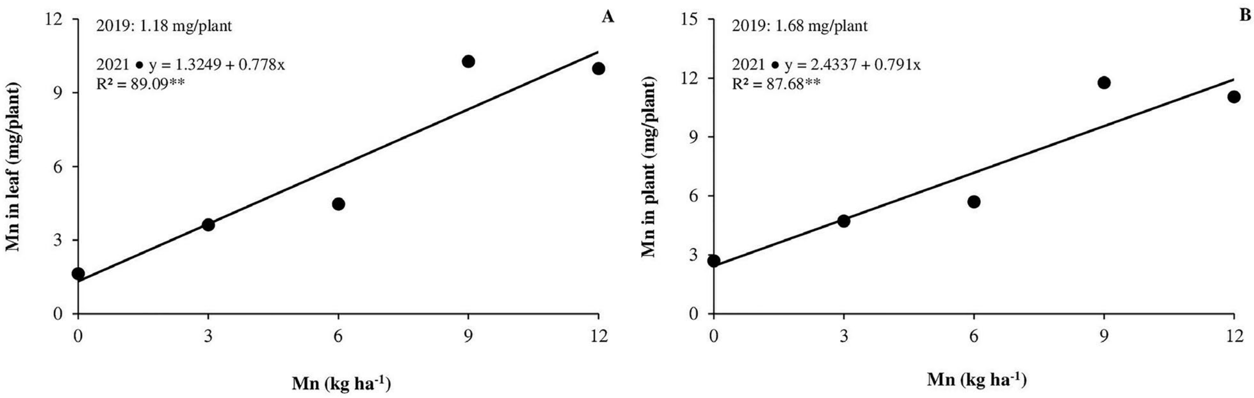

Figure 4: Accumulation of Mn in leaves (A) and tuberous roots (B) of beet fertilized with Mn in 2019 and 2021, in Mossoró, RN.

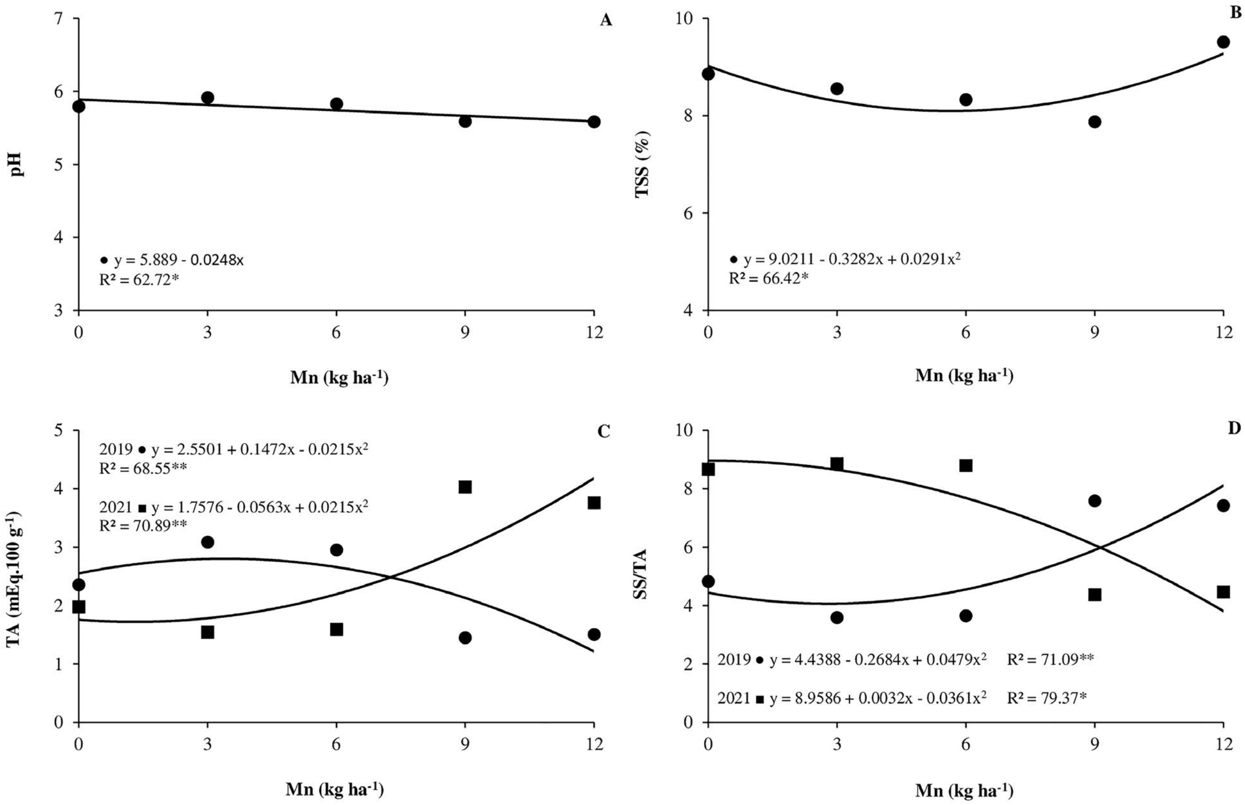

Figure 5: Quality attributes, pH (A), total soluble sugars – TSS (B), titratable acidity – TA (C), and the ratio of soluble solids to titratable acidity– SS/TA (D) of the tuberous roots of beet fertilized with Mn.

6.0 kg ha^{-1} Mn, the highest total and commercial yields were obtained, and the content of total soluble sugars was 8.1%, which was lower than the maximum TSS (9.27%), and the TSS recorded in the control treatment (9.02%) (Figure 5B). The mean TSS values in 2019 (8.90%) and 2021 (8.34%) did not differ significantly from each other ($p < 0.05$).

There was an interaction effect of the Mn dose and the year of the experiment on titratable acidity. In 2019, fertilization with 12 kg ha^{-1} Mn led to lower acidity (1.21 mEq 100 g^{-1}). At 6 kg ha^{-1} Mn, TY and CY were higher, and the tuberous root was more acidic (2.65 mEq 100 g^{-1}) than the control treatment (2.55 mEq 100 g^{-1}). In 2021, the TA obtained after applying 6.0 kg ha^{-1} Mn (2.19 mEq 100 g^{-1}) was also higher than that in the control treatment (1.75 mEq 100 g^{-1}), whereas the highest TA (4.17 mEq 100 g^{-1}) was recorded when the highest dose of Mn was applied (Figure 5C).

There was also an interaction effect of the factors on the SS/TA ratio. In 2019, the SS/TA ratio at 6.0 kg ha^{-1} Mn (4.55) was higher than the ratio in the control treatment (4.43). The highest SS/TA ratio in 2019 was recorded after 12.0 kg ha^{-1} Mn was applied (8.11). In 2021, the SS/TA ratio was lower (8.94) after 6 kg ha^{-1} Mn was applied than the ratio in the control treatment (8.95).

The SS/TA ratio is a quality indicator; it indicates that a food has a milder flavor when the SS content is higher than the TA content. By comparing the treatment with 6.0 kg ha^{-1} Mn (higher TY and CY) to the treatment without fertilization, we inferred that, in 2019, this quality improved in the presence of Mn, while in 2021, the quality decreased.

The initial Mn content in the soil in 2019 and 2021 probably influenced the TA and, consequently, the SS/TA ratio. There was also an interaction effect of the Mn dose and the year of experiment on soluble solids; however, no adjustments to the equations were made. The average SS content in 2019 among treatments was 10.91%, while in 2021, it was 15.63%.

CONCLUSIONS

The recommended Mn dose for beet cultivation was 6.0 kg ha^{-1}. Fertilization with Mn did not affect the yield of non-commercial tuberous roots. Fertilization with Mn did not affect its accumulation in the tuberous roots of beet. In leaves, the accumulation of Mn increased with an increase in the dose of Mn applied, which indicated that the leaves of beet could act as an accumulator of Mn. At 6.0 kg ha^{-1} Mn, the acidity increased, and the TSS decreased in the tuberous roots of beet.

AUTHOR CONTRIBUTION

Conceptual Idea: Costa, R. M. C.; Grangeiro, L. C.; Methodology design: Costa, R. M. C.; Grangeiro, L. C.; Data collection: Costa, R. C. C. Morais, E. G.; Oliveira, R. R. T.; Silva, I. B. M.; Data analysis and interpretation: Costa, R. M. C.; Grangeiro, L. C.; Cortez. J. W. M.; and Writing and editing: Costa, R. M. C.; Grangeiro, L. C.

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