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PERFORMANCE OF SOYBEAN AND CORN IN SANDY SOIL SUBJECTED TO INCREASING DOSES OF MICRONUTRIENTS

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ABSTRACT

At a global level, it is estimated that between 30% and 50% of agricultural production is influenced by the use of commercial fertilizers. The objective of this study was to evaluate the performance of soybean and corn subjected to doses of fertilizers containing multiple micronutrients. The experiment was conducted on the Água Limpa Araras property, in the 2022/2023 season. The experimental design adopted was randomized blocks, consisting of six treatments and four replicates, totaling 24 experimental units. Treatments were Fert Micro BR 12 fertilizer doses of: 0; 25; 50; 75; 100 and 125 kg ha^{-1}. Leaf B, Mn and Zn contents were within the range considered ideal for soybean and corn crops, except in the corn crop, where the leaf Mn content in the control treatment and at a dose of 25 kg ha^{-1}. Soybean and corn responded to the application of fertilizer containing multiple micronutrients. Soybean responded linearly with the increase in the dose of fertilizer containing multiple micronutrients, reaching a grain yield of 5,535 kg ha^{-1} with a dose of 125.0 kg ha^{-1}. For corn, the maximum estimated dose of fertilizer containing multiple micronutrients was 115.8 kg ha^{-1}, with grain yield of 12,454.48 kg ha^{-1}.

Palavras-chave:
Nutrição
Boro
Zinco
Manganês

DESEMPENHO DA SOJA E DO MILHO EM SOLO ARENOSO SUBMETIDOS A DOSES CRESCENTES DE MICRONUTRIENTES

RESUMO

A nível global, estima-se que entre 30% e 50% da produção agrícola seja influenciada pelo uso de fertilizantes comerciais. O objetivo desse trabalho, foi avaliar o desempenho da soja e do milho submetido a doses de fertilizantes contendo múltiplos micronutrientes. O experimento foi conduzido na propriedade Água Limpa Araras, na safra 2021/2022. O delineamento experimental adotado foi de blocos casualizados, constando de seis tratamentos apresentando e quatro repetições, totalizando 24 unidades experimentais. Os Tratamentos foram as doses do Fertilizante Fert Micro BR 12: 0; 25; 50; 75; 100 e 125 kg ha^{-1}. Os teores foliares de B, Mn e Zn estiverem dentro da faixa considerada ideal para as culturas de soja e milho, exceto na cultura do milho, onde o teor foliar de Mn no tratamento controle e na dose de 25 kg ha^{-1}. A soja e o milho responderam com a aplicação do fertilizante contendo múltiplos micronutrientes. A soja respondeu linearmente com o aumento da dose do fertilizante contendo múltiplos micronutrientes, chegando a uma produtividade de grãos de 5.535 kg ha^{-1} com a dose de 125,0 kg ha^{-1}. Para a cultura do milho a máxima dose estimada do fertilizante contendo múltiplos micronutrientes, foi de 115,8 kg ha^{-1}, com a produtividade de grãos de 12.454,48 kg ha^{-1}.

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INTRODUCTION

In the 2022/2023 season, corn was planted in an area of 22,267.4 thousand ha, with yield of 5,922.0 kg ha^{-1} and production of 131,865.9 thousand tons, indicating an increase of 16.6% compared to the previous season. Soybean, in the same season, was planted in an area of 44,075.6 thousand ha, with yield of 3,508.0 kg ha^{-1} and production of 154,617.4 thousand tons, indicating an increase of 23.2% compared to the previous season (Conab, 2023).

At global level, it is estimated that between 30% and 50% of agricultural production is influenced by the use of commercial fertilizers. Given the conditions of Brazilian soils, this estimate seems to be quite underestimated, since agriculture in soils not corrected for acidity often leads to low yields due to the scarce availability of most nutrients (Silva *et al*., 2021). Despite the gains obtained with the addition of fertilizers, much of these gains in crop yield is attributed solely to macronutrients; however, the addition of micronutrients is also necessary when the levels in the soil are considered low. Thus, crops that are produced on a large scale, intensively, such as soybean and corn, also need to be supplied with micronutrients to obtain good performance (Barbosa *et al*., 2016; Woli *et al*., 2019).

Recent studies have reported a positive response of soybean yield (Johnson *et al*., 2023; Santos *et al*., 2023) and corn yield (Moraes Gatti *et al*., 2023, Ratke *et al*., 2023) to micronutrients. However, the response of soybean yield to micronutrients was not consistent across several studies, mainly due to different environmental conditions, such as soil type, soil organic matter (SOM), moisture, and temperature (Thapa *et al*., 2021). Despite low nutrient removal, ranging from 39 to 245 g ha^{-1}, the use of micronutrients in corn crop can be quite significant (Woli *et al*., 2019). In this same crop, the use of fertilizers containing several micronutrients promoted yield gains of up to 24% when compared to the control treatment (Dourado Neto *et al*., 2015).

Under tropical climate conditions in weathered soils, where high doses of limestone are added, especially on the surface, there may be an increase in surface pH, reducing the availability of micronutrients. In addition, leaching of more mobile micronutrients into the soil, such as B, can occur, especially in sandy soils, being more intense in regions with high rainfall, so it is important to add fertilizers containing micronutrients (Tomicioli *et al*., 2020). Therefore, the objective of this study was to evaluate the performance of soybean and corn subjected to doses of fertilizer containing multiple micronutrients.

MATERIAL AND METHODS

The experiment was carried out at the Água Limpa Farm, located at coordinates 17°20’48.1” S, 52°02’56.73” W. The region has an average annual temperature of approximately 24.2 ºC and average rainfall of 1,400 mm. The prevailing climate is hot, semi-humid and notably seasonal, with rainy summer and dry winter, being classified as “Aw”, according to Köppen’s classification. During the experiment, temperature and rainfall were monitored, and the results are presented in Figure 1.

The soil of the experimental area was classified as *Neossolo Quartzarênico órtico* (Quartzipsamment) (Santos *et al*., 2018), and contains 140 g kg^{-1} of clay, 100 g kg^{-1} of silt and 760 g kg^{-1} of sand in the 0-0.20 m layer. The experimental area has been managed in a no-tillage system and cultivated with soybean crop in the summer season and corn or sorghum crop in the winter season since 2010.

For the selection of the experimental area to conduct the study, several soil analyses were previously assessed, and a plot in which the micronutrients boron, manganese and zinc were classified with low content (Sousa & Lobato, 2004) was selected, according to the chemical attributes in Table 1.

Soybean crop was planted on November 8, 2022, with a spacing of 0.45 m between rows and harvested in March 2023. For the soybean crop, 270 kg ha^{-1} of the fertilizer 07-36-06 +9% of S were applied in all plots. Corn crop was planted on December 20, 2022, with a spacing of 0.9 m between rows and harvested at the end of April 2023. 300 kg ha^{-1} of Monoammonium Phosphate (MAP) fertilizer were applied to the corn crop at planting,

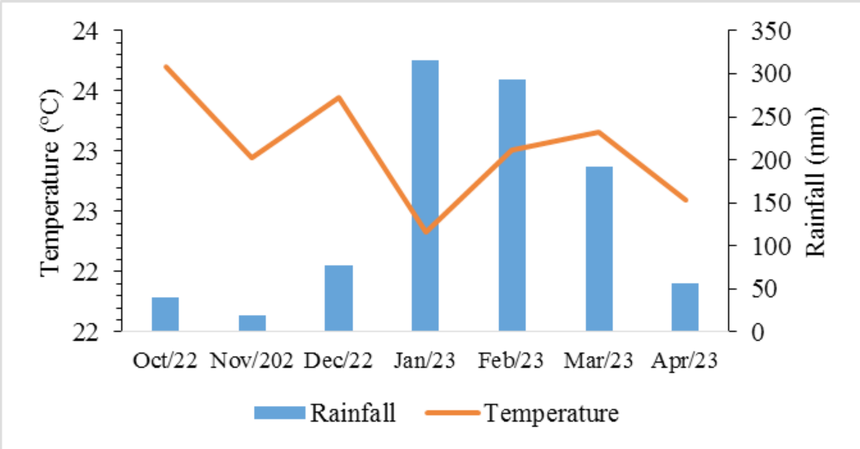

Figure 1. Distribution of accumulated annual rainfall (mm) and average temperature (°C) during the experimental period

Table 1. Basic chemical characterization of the experimental area, in the 0-0.2 m layer

pH	OM	P	K	Ca	Mg	Al	H+Al	B	Cu	Mn	Zn
	-- g dm^{-3}--	--- mg dm^{-3} ---		-------------- mmol$_c$ dm^{-3} ------------				---------- mg dm^{-3} ---------			
3.9	13.4	1.1	110	0.24	0.21	1.9	8.3	0.18	0.2	0.42	0.5

as well as 150 kg ha^{-1} of Potassium Chloride (KCl) when the plants were in the V6 vegetative stage together with 200 kg ha^{-1} of ammonium sulfate fertilizer. In the V10 stage, 150 kg ha^{-1} of urea and 200 kg ha^{-1} of 20-00-20 fertilizer were applied.

The design adopted was randomized blocks, consisting of six treatments and four replicates, totaling 24 experimental units. Each experimental unit was composed of 6 rows of each crop (soybean and corn) spaced 0.45 m apart for soybean and 0.9 m apart for corn, with 5 m in length. Treatments were the following doses of Fert Micro BR 12 fertilizer: 0, 25, 50, 75, 100 and 125 kg ha^{-1}. The fertilizer containing the micronutrients was applied immediately after planting the soybean and corn crops. The fertilizer used (Fert Micro BR) has in its composition 1.8% boron (B), 2% manganese (Mn) and 9% zinc (Zn).

Micronutrient contents were evaluated in soybean and corn crops. For this evaluation, a total of 10 leaves were collected from the soybean crop, randomly distributed in each experimental unit, consisting of the 3rd leaf from the apex of the main stem in the flowering period. For the collection of leaves in the corn crop, 10 leaves randomly distributed in each experimental unit were collected from the basal third of the plant at 60 days after planting (Teixeira *et al.*, 2017).

To calculate the yield of soybean and corn crops, plants were collected from two central rows of each plot with two meters in length, threshed to harvest the grains, and grain weight was measured on a precision scale and extrapolated to one hectare, with moisture content corrected to 13%.

For the comparison of the Fert Micro BR 12 fertilizer doses, the data were subjected to analysis of variance and, when significant, polynomial regression analysis was adopted. A biplot graph was constructed to assess the overall variability of the experiment and the trends of the multivariate analysis. Correlation analysis was also performed between the variables obtained in this study. The analyses were performed using the Rbio® program with the interface of the R program (Bhering, 2017).

RESULTS AND DISCUSSION

Leaf B and Zn contents were influenced by fertilization containing multiple micronutrients in the soybean crop (Figures 2A and 2E). However, in the corn crop, fertilization influenced only leaf Mn content (Figure 2D). Leaf B contents in soybean increased with the increase in the dose of multi-nutrient fertilizer, and the dose of 120 kg ha^{-1} promoted a 65% increase in leaf B content compared to the control treatment (Figure 1A). Leaf B content in soybean, in the treatment with application of 25 kg ha^{-1} of multi-nutrient fertilizer, was slightly below the critical range for the soybean crop, which is 21 to 55 mg kg^{-1}, whereas the other treatments were within the range considered adequate.

Boron is one of the micronutrients that limit the yield of many crops under Brazilian soil conditions. This element participates in functions related to plant rooting to grain filling, generating high crop responsiveness in soils with medium and low levels (Tomicioli *et al*., 2020). Therefore, the supply of this element can favor the performance of crops. This occurs because in sandy soils associated with environments with high rainfall at certain times of the year, such as those located in the Cerrado biome, its leaching can be favored, with the potential to cause a possible deficiency of this micronutrient in plants (Prado, 2010).

Increase in the doses of multi-nutrient fertilizer did not allow an increase in the leaf Mn content in soybean leaves (Figure 1C). Leaf Mn contents in all treatments in the soybean crop were within the range considered ideal, which is between 21 and 100 mg kg^{-1} (Sousa and Lobato, 2004). Leaf Mn content in the corn crop obtained the maximum increase with the 120 kg ha^{-1} dose of multi-nutrient

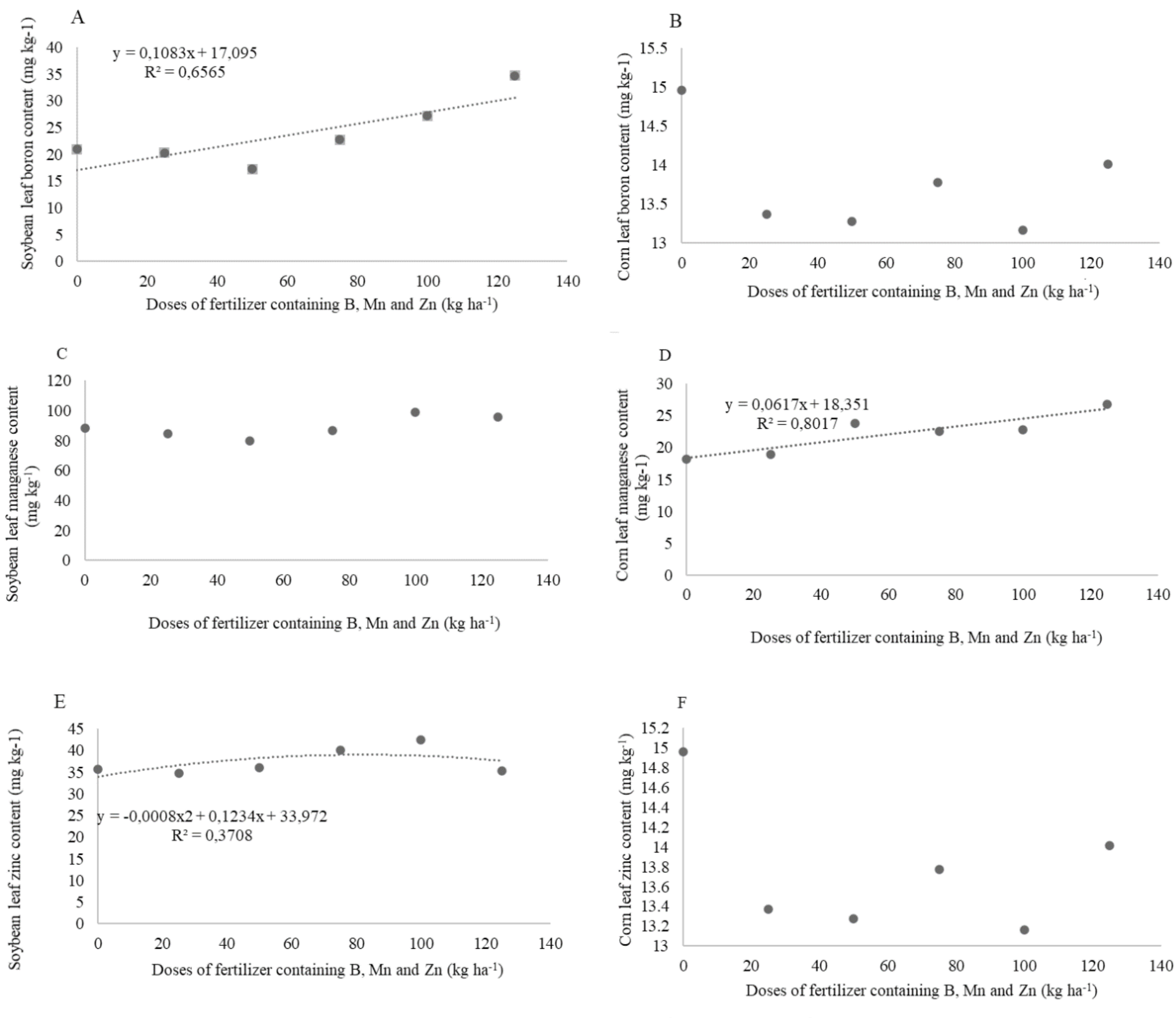

Figure 2. Leaf boron, manganese and zinc contents in soybean and corn crops grown in *Neossolo Quartzarênico* (Quartzipsamment) in the 2022-2023 crop year

fertilizer, being 48% higher than the value observed in the control (Figure 1D).

In the corn crop from the dose of 50 kg ha^{-1} of multi-nutrient fertilizer, the Mn contents were within the range considered ideal, which is from 20 to 100 100 mg kg^{-1} (Sousa and Lobato, 2004). In the control treatment, as well as at the lowest dose of multi-nutrient fertilizer (25 kg ha^{-1}), leaf Mn contents were lower than 20 mg kg^{-1}. In a study evaluating the accumulation of nutrients in 1960- and 2000-era corn hybrids, Woli *et al*. (2019) found leaf Mn content of 3.5 mg kg^{-1} at the R5 stage. In this study, the Mn contents in the leaf tissues of the corn crop ranged from 18.1 to 26.8 mg kg^{-1} among the treatments, and these values were much higher than those found by Woli *et al*. (2019). In view of the above, it can be seen that, despite being required in small quantities, the micronutrient Mn is of great importance for crops in general, as it participates in vital processes for them (Silva & Berti, 2022).

Leaf Zn content in soybean obtained the maximum increase with the estimated dose of 77.00 kg ha^{-1} of multi-nutrient fertilizer, leading to the maximum leaf accumulation of 38.73 mg kg^{-1} of Zn. These maximum values of leaf Zn content (38.73 mg kg^{-1}), observed in our study, are close to the contents found in a study in the Paraná state, Brazil, where the average leaf Zn content was 37.4 mg kg^{-1} for the soybean crop. In a *Latossolo* (Oxisol) in the Cerrado, Zn content in soybean leaves decreased with the increase in the doses of fertilizer containing micronutrients (6.8% Mn, 3.9% Zn, 2.1% Fe, 1.2% and 1.1% B), as reported by Barbosa *et al*. (2016), differing from the results found in the present study. Leaf Zn contents in soybean crop ranged from 35 to 42 mg kg^{-1}, being within the range considered ideal, which is 20 to 50 mg kg^{-1} (Sousa and Lobato, 2004).

In the corn crop there were no significant differences between the doses of multi-nutrient fertilizer for leaf Zn accumulation. In this study, leaf Zn contents in the corn crop ranged from 13.1 to 14.9 mg kg^{-1}. In a study evaluating the accumulation of nutrients in 1960- and 2000-era corn hybrids, Woli *et al*. (2019) found that in whole corn plants, Zn contents reach the highest accumulation at the R5 development stage, ranging between 263 and 366 g Zn ha^{-1}. These same authors reported that, in grains, the greatest accumulation occurs when hybrids reach the R5 development stage, with accumulation ranging between 178 and 230 g Zn ha^{-1}.

The increases in soybean yield, as well as in the leaf B content, obtained in the present study, may be related to the various functions performed by this element in legumes. In common bean and soybean plants, low availability of B may affect the cell wall of the nodules present in the roots, allowing the entry of oxygen into the nodules, reducing the process of biological nitrogen fixation. Therefore, supplying B to plants is extremely important, especially in Cerrado soils with low availability of this micronutrient (Tomicioli *et al*., 2020). On the other hand, when clayey soils contain adequate levels of this micronutrient, foliar application of B in soybean crop at the phenological stages R3 and R5.1 leads to no significant results (Bruns *et al*., 2017).

Soybean grain yield increased with increasing dose of multi-nutrient fertilizer (Figure 3A). Grain yield in the control treatment was 4670.9 kg ha^{-1}, while in the treatment with the dose of 120.0 kg ha^{-1} of multi-nutrient fertilizer, a grain yield of 5535.9 kg ha^{-1} was reached, which led to an increase of approximately 19%. In the corn crop, the maximum estimated dose for grain yield was 115.8 kg ha^{-1} of multi-nutrient fertilizer, which led to maximum grain yield of 12616.7 kg ha^{-1} (Figure 3B).

The maximum estimated dose of 115.8 kg ha^{-1} of multi-nutrient fertilizer promoted an increase of 12% in corn grain yield. Different results were reported in a study with 40 sites in Iowa, evaluating foliar application of the same micronutrients evaluated in our study, in which Enderson *et al*. (2015) found that foliar application of B, Mn and Zn increased their contents in the leaf and trifoliate leaf; however, there was no effect of the application on soybean grain yield. Results similar to those found here were verified in a *Latossolo* (Oxisol) of the Cerrado under field

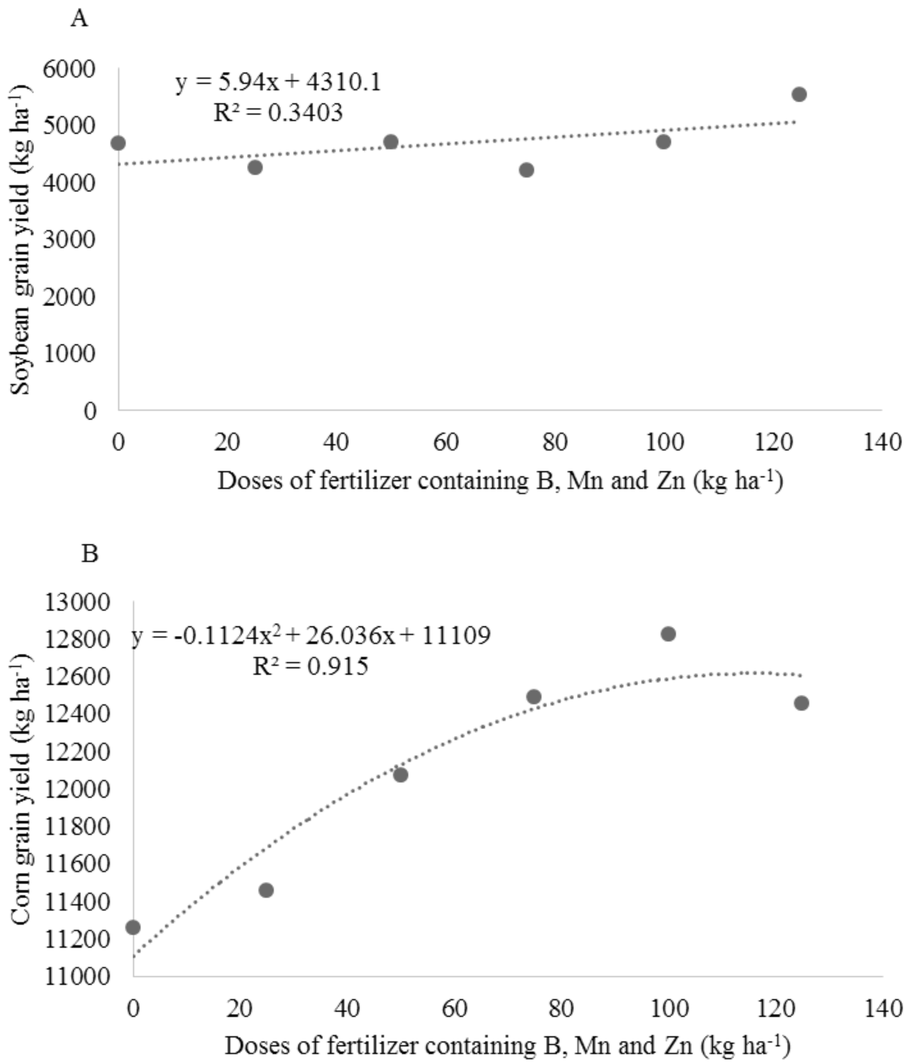

Figure 3. Grain yield of soybean and corn crops grown in *Neossolo Quartzarênico* (Quartzipsamment) in the 2022-2023 crop year

conditions, in which the authors used different doses of fertilizers containing micronutrients (6.8% Mn, 3.9% Zn, 2.1% Fe, 1.2% and 1.1% B) and observed an increase in soybean grain yield from 33.6% to 79.7% compared to the control with the dose of 133 kg ha_{-1} applied to the soil (Barbosa *et al*., 2016). In the corn crop, the use of micronutrients (Cu: 0.07; Mn: 1.2% and Zn: 7%) in seed treatment with the dose of 600 ml ha_{-1} promoted an increase of 24% compared to the control treatment, leading to grain yield of 6,949 kg ha_{-1} (Dourado Neto *et al*., 2015), corroborating the results found in the present study.

Micronutrients are essential elements used by plants in small amounts. For soybean crop, the amount of micronutrients absorbed is often less than 2.0 kg ha^{-1} (Thapa *et al*., 2021). In corn crop, removal rates vary within the range of 39 to 245 g ha_{-1} for micronutrients (Woli *et al*., 2019). Therefore, applications even at low doses per hectare can cause significant effects on soybean and corn yield (Dourado Neto *et al*., 2015; Barbosa *et al*., 2016).

A network of comparisons was performed using Pearson's correlation to visualize all the traits measured in this study simultaneously for soybean and corn crops (Figure 4). Positive correlations were expressed in green lines, negative correlations were expressed in red lines, and the intensity of the correlation is proportional to the thickness of the lines.

There are groups of positive values, with a

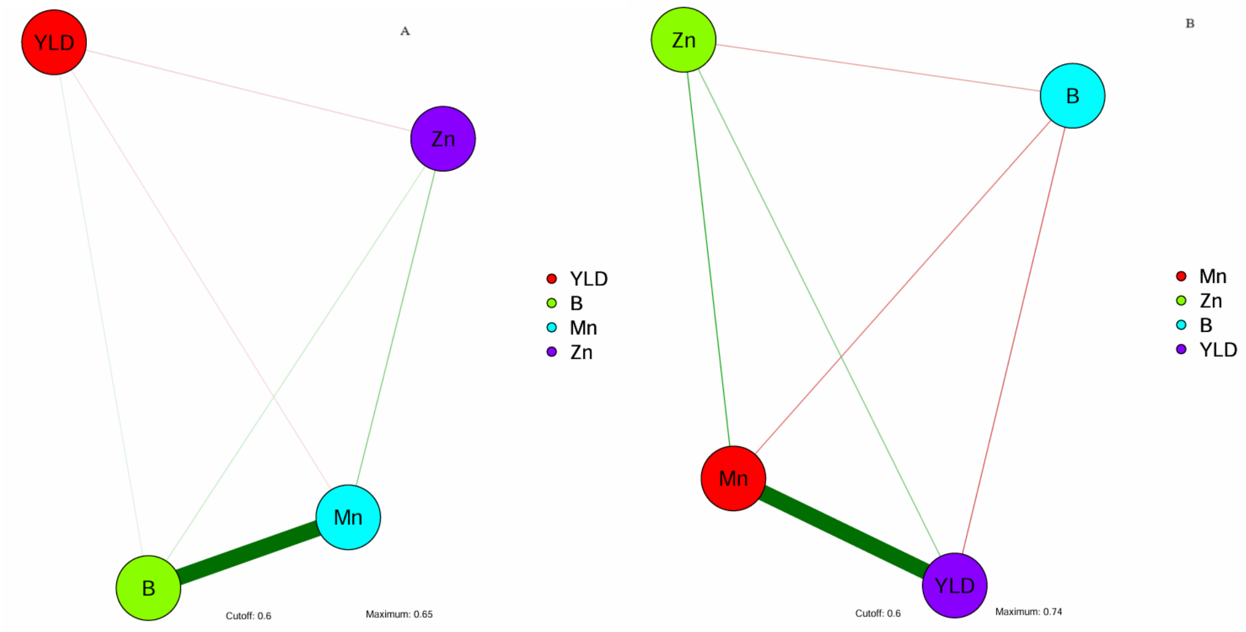

Figure 4. Network of correlations between yield, boron (B), manganese (Mn) and Zinc (Zn), in soybean (A) and corn (B) crops, cultivated in *Neossolo Quartzarênico* (Quartzipsamment) in the 2022-2023 crop year

high correlation between the variables analyzed (Figures 4A and 4B). For the soybean crop, there was a high correlation between leaf B and Mn contents; however, the other variables analyzed for the soybean crop showed a low correlation. For the corn crop, there was a high correlation between grain yield and leaf Mn content, reaching a correlation coefficient of 0.92. Such high correlation coefficient of Mn with corn grain yield may be related to the increase in the absorption of other nutrients such as Mg, Zn and Fe (Fageria, 2002). There was also a moderate positive correlation between leaf Zn content and yield, with a correlation coefficient of 0.51. In the corn crop, there was also a high negative correlation between B contents and Zn and Mn contents. The interactions of Zn, Mn and Cu with macro and micronutrients are synergistic, antagonistic or have no effects, depending on the species and nutrients of the crop (Fageria, 2002). Therefore, the increased concentration of a micronutrient used in the multi-nutrient fertilizer may have inhibited the absorption of others.

Analyses of canonical variables were performed to assess the contribution of each variable (Figures 5A and 5B). Therefore, the accumulations of variances in the first two variables corresponded to 96% and 87%, respectively, for soybean and corn crops, being higher than the recommended minimum of 80% (Mingoti, 2005). Thus, the canonical variables in this study can be used for an accurate interpretation.

The eigenvectors presented in Figure 5A show that soybean yield was close to the highest leaf B contents and to the treatment using the dose of 125 kg ha^{-1} of multi-nutrient fertilizer. The treatment with a dose of 100 kg ha^{-1} of multi-nutrient fertilizer was close to the leaf Mn and Zn contents in the soybean crop (Figure 5A). The doses of 0, 25, 50 and 75 kg ha^{-1} of multi-nutrient fertilizer were close to one another and were not close to any variable analyzed in this study. The eigenvectors presented in Figure 5B show that, for the corn crop, grain yield was close to the dose of 100 kg ha^{-1} of multi-nutrient fertilizer. Leaf Mn contents were close to the dose of 125 kg ha^{-1} of multi-nutrient fertilizer. Leaf B contents were close to the control treatment. Leaf Zn contents were close to the doses of 25 and 50 kg ha^{-1} of multi-nutrient fertilizer.

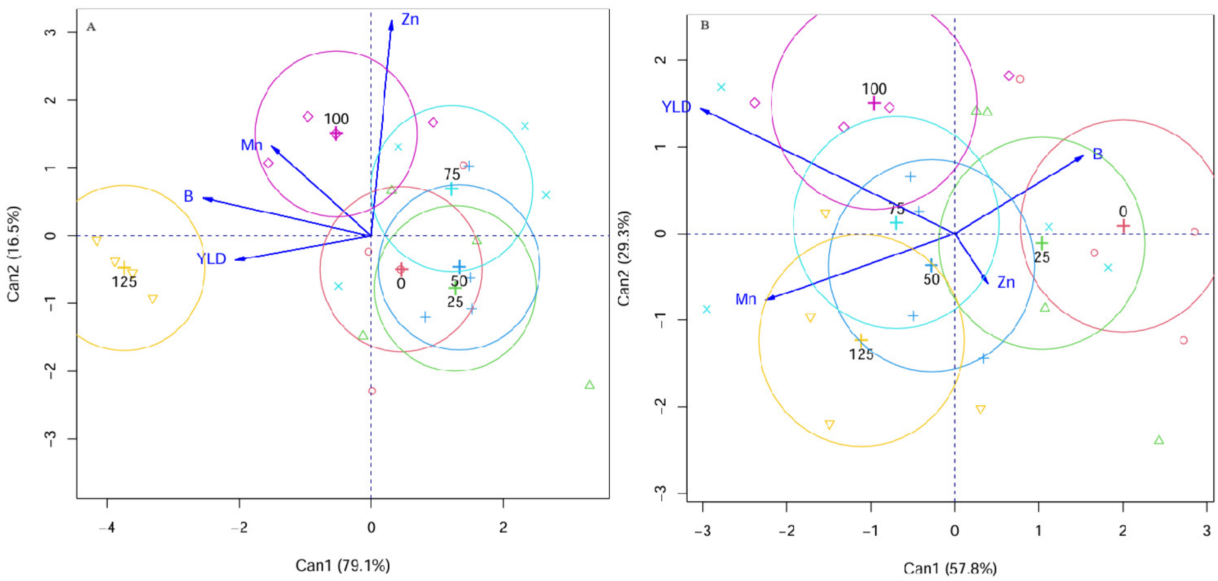

Figure 5. Analysis of canonical variables between yield, boron (B), manganese (Mn) and zinc (Zn), in soybean (A) and corn (B) crops, cultivated in Neossolo Quartzarênico (Quartzipsamment) in the 2022-2023 crop year

CONCLUSIONS

- Leaf contents of B in soybean and Mn in corn responded linearly to the increase in the doses of the fertilizer studied, which contains multiple micronutrients.
- Leaf Zn content in soybean obtained the maximum increase with the estimated dose of 77.0 kg ha^{-1} of the fertilizer studied, leading to the maximum leaf accumulation of 38.7 mg kg^{-1} of Zn.
- Soybean responded linearly to the increase in the dose of fertilizer containing multiple micronutrients, reaching a grain yield of 5,535.9 kg ha^{-1} with a dose of 125.0 kg ha^{-1}.
- For the corn crop, the maximum estimated dose of fertilizer containing multiple micronutrients was 115.8 kg ha^{-1}, which led to grain yield of 12,454.5 kg ha^{-1}. Corn grain yield showed a high correlation with Mn contents.
- In sandy soil, soybean and corn crops responded to the application of fertilizer containing multiple micronutrients.

AUTHORSHIP CONTRIBUTION STATEMENT

ALVES JÚNIOR, W. P.: Conceptualization, Data curation, Methodology, Supervision, Writing – review & editing; **RIBEIRO, D. O.:** Data curation, Project administration, Writing – review & editing; **SILVA, A. J.:** Formal Analysis, Methodology, Software, Supervision, Writing – review & editing; **SCHENKEL, J. A. C.:** Funding acquisition, Methodology, Writing – review & editing; **PEREIRA, R. M.:** Formal Analysis, Funding acquisition, Writing – review & editing; **OLIVEIRA, J. T.:** Data curation, Project administration, Supervision, Visualization, Writing – review & editing.

DECLARATION OF INTEREST

The authors declare that they have no financial or personal interests that could influence the work reported in this article.

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