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RESEARCH ARTICLE

Symptoms and interrelationships of macro and micronutrients available for soybean

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ABSTRACT

Nutrients have differences in their functions as metabolic and structural constituents in plant organs. The specific identification of the symptoms of excess or deficiency of nutrients is essential for the correct management to be carried out in order to avoid production losses. In this context, this research aimed to evaluate the symptoms of deficiency and excess of nutrients in soybean. The experiment was carried out on a bench, with 3-liter containers, in which uniformly germinated seedlings were selected for implantation. Initially, the seedlings were subjected to a complete nutrient solution to allow for a uniform and unrestricted initial development over a period of one week. Then, the plants were subjected to solutions with twice as much nutrient, absence of nutrients, complete solution and nutrient restriction, individual omissions resulted in morphological changes, which translated into visual symptoms characteristic of the nutritional deficiency of the respective nutrient. The solution with twice the nutrient concentration of the complete solution showed an increase in the absorption of N, Mg, K and Fe, for Cu it was twice the absorption and for Zn five times more. There was a decrease in the absorption of Ca and Mn and, with that, it is concluded that the availability of twice as many nutrients did not result in double their absorption.

Keywords: *Glycine max*, nutrient deficiency, excess nutrients, metabolites, linear relationships, plant nutrients.

INTRODUCTION

After the introduction of soybean in Brazil, it was restricted to Rio Grande do Sul until the 1960s, as it exhibited marginal importance in the context of agribusiness (Dall'agnol, Roessing, Lazzarotto, Hirakuri, & Oliveira, 2007). After studies and advances in the context of genetic improvement and knowledge of the importance of the crop, which today has become the main commodity produced in the world (Ferreira et al., 2020; Frota et al., 2020; Hanyu, Ferreira, Cecon, & Matsuo, 2020). According to Dall'agnol et al. (2007), the crop received this appreciation due to its wide use, in human and animal food and according to Loro et al. (2021), because this culture is a source of proteins and a diversity of macro and micronutrients.

Thus, it triggered an increase in production areas, in which, according to Companhia Nacional de Abastecimento (CONAB) (2020), the world planted area in the 2019/20 season was 122 million hectares and a production of 337 million tons of grain. In Brazil, soybean production in the 2019/20 season was 124 million tons of grain in an area of 36 million hectares, being the world's largest producer of the grain, reaching an mean yield of 3,379 kg ha^{-1} (CONAB, 2020). In the last season (2019/20), the state with the highest production and largest area of soybean cultivation is Mato Grosso, which produced 35 million tons of grain in 10 million hectares. Then, Paraná, which has an area of 5 million sown hectares and a production of 21 million tons of grain. Rio Grande do Sul had a production of 11 million tons of grain in an area of 5 million hectares (CONAB, 2020).

Breeding was substantial for the development of superior genotypes adaptable to specific environments (Carvalho et al., 2016; Szareski et al., 2021). However, for the expression of maximum genetic capacity and thus the phenotypic, an environment that allows the availability of nutrients, moisture, oxygen, permeability, temperature and soil salinity is necessary. One of the main factors that determine the profit of the agricultural enterprise is the adequate nutritional status of the crop (Prado, Franco, & Puga, 2010). Nutrients have differences in their functions as metabolic and structural constituents in plant organs (Vargas et al., 2018). When lacking, symptoms in plants occur as a function of the distribution of nutrients in the plant and the speed of distribution. It is possible to observe different locations of symptoms, which may be in the lower, middle or upper third of the plant, which may favor their identification, relating the affected area in the plant with the mobility of the nutrient. Generally, nutrients with lower mobility show symptoms on younger leaves, and nutrients with medium or high mobility show symptoms on older leaves.

Therefore, the specific identification of the symptoms of excess or deficiency of nutrients is essential for the correct management to be carried out to avoid production losses. Because, metabolic disorders caused by nutrient deficiencies eventually manifest themselves in visible abnormalities (Prado et al., 2010). In this context, this research aimed to evaluate the symptoms of deficiency and excess of nutrients in soybean.

MATERIAL AND METHODS

The experiment was carried out at the Production Physiology Laboratory, at the UNIJUÍ campus, Ijuí-RS. Soybean plants of the cultivar TMG 7062 were used. Physical, chemical and microbiological analyzes of the water were carried out to understand their properties. The experiment was carried out on a bench, with 3-

liter containers, in which seedlings germinated by uniformity were selected for implantation. Initially, the seedlings were submitted to a complete nutrient solution to allow a uniform and unrestricted initial development during a period of one week.

On the following week, the seedlings were transplanted to recipients with excess and deficiency of nutrients. Each container received 3 seedlings, which were fixed on the surface of the containers with Styrofoam, simulating the soil surface. The containers had nutrients suppressed or added every 15 days, along with assessments made through notes. The experiment was terminated after approximately 70 days. Thirty containers were used for the study, so that each container received a solution and 3 fixed seedlings. The solutions used are described in table 1.

Table 1. Solutions used in the containers. Unijuí, Ijuí, Rio Grande do Sul, Brazil.

Treatments	Solutions
1	Complete (N, P, K, Ca, Mg, S, B, Cl, Cu, Fe, Mn, Mo and Zn)
2	Absence of all macro and micronutrients, only water
3	Double the nutrients
4	Absence of Nitrogen (-N)
5	Absence of Phosphorus (-P)
6	Absence of Potassium (-K)
7	Absence of Calcium (-Ca)
8	Absence of Magnesium (-Mg)
9	Absence of Sulfur (-S)
10	Absence of Boron (-B)
11	Absence of Manganese (-Mn)
12	Absence of Zinc (-Zn)
13	Absence of Copper (-Cu)
14	Absence of Molybdenum (-Mo)
15	Absence of Iron (-Fe)
16	Excess Nitrogen (+N)
17	Excess Phosphorus (+P)
18	Excess Potassium (+K)
19	Excess Calcium (+Ca)
20	Excess Magnesium (+Mg)
21	Excess Sulfur (+S)
22	Excess Boron (+B)
23	Excess Manganese (+Mn)
24	Excess Zinc (+Zn)
25	Excess Copper (+Cu)
26	Excess Molybdenum (+Mo)
27	Excess Iron (+Fe)
28	Excess Aluminum (+Al)
29	Excess Sodium (+Na)
30	Absence 2

To prepare the solutions deposited in the containers, salts were used which, weighed and dissolved in different concentrations, result in complete soil solutions, with absence or excess of macro and micronutrients. Chemical composition of the nutrient solutions (mL L^{-1}) used to make the solutions were: KH_2PO_4 mol L^{-1}, KNO_3 mol L^{-1}, Ca $(NO_3)^2$ $.4H_2O$ mol L^{-1}, $MgSO_4.7H_2O$ mol L^{-1}, K_2SO_4, 0,50 mol L^{-1}, $CaSO_4$ 0,01 mol L^{-1}, Ca $(H_2PO_4)^2$, 0,05 mol L^{-1}, Mg $(NO_3)^2$. 6 H_2O mol L^{-1}, Micronutrients, Fe –

EDTA. In the laboratory there are incandescent and fluorescent lamps connected to a timer to simulate the hours of light and dark, in order to solve the need for light for photosynthesis in plants, and their photoperiod. The laboratory has an ideal temperature, close to 30 °C, each container has a volume of 3 liters of solution, where aerators are installed in each container to ensure the development of plants in the liquid solution table 2 and table 3.

Table 2. Doses for Nutrient Suppression Effect. Unijuí, Ijuí, Rio Grande do Sul, Brazil.

How much to pipette in the vessels (ml.3L^{-1})	Co	Au	Do	N	P	K	Ca	Mg	S	B	Mn	Zn	Cu	Mo	Fe
KH2PO4 mol L-1	3	0	6	-	-	-	3	3	3	3	3	3	3	3	3
KNO3 mol L-1	15	0	30	-	18	-	15	18	18	15	15	15	15	15	15
Ca (NO3)2 .4H2O mol L-1	15	0	30	-	12	15	-	12	12	15	15	15	15	15	15
MgSO4.7H2O mol L-1	6	0	12	6	6	6	6	-	-	6	6	6	6	6	6
Ca (H2PO4)2, 0,05 mol L-1	30	0	60	-	30	-	-	-	-	30	30	30	30	30	30
Mg (NO3)2. 6 H2O mol L-1	-	0	-	-	-	-	-	-	6	-	-	-	-	-	-
Fe – EDTA	3	0	6	3	3	3	3	3	3	3	3	3	3	3	-
H3 BO3 mol L-1	3	0	6	3	3	3	3	3	3	-	3	3	3	3	3
Mn Cl22, mol L-1	3	0	6	3	3	3	3	3	3	3	-	3	3	3	3
Zn Cl2 mol L-1	3	0	6	3	3	3	3	3	3	3	3	-	3	3	3
Cu Cl2 mol L-1	3	0	6	3	3	3	3	3	3	3	3	3	-	3	3
H2 Mo4.H2O mol L-1	3	0	6	3	3	3	3	3	3	3	3	3	3	-	3
K2SO4 0,50 mol L-1	-	-	-	15	-	-	-	9	-	-	-	-	-	-	-
Ca SO4 0,01 mol L-1	-	-	-	600	-	-	-	-	-	-	-	-	-	-	-
Al Cl3 mol L-1	-	-	-	-	-	-	-	-	-		-	-	-	-	-
Na Cl mol L-1	-	-	-	-	-	-	-	-	-		-	-	-	-	-

The nutrient solutions were completed with a full dose every 15 days and throughout the study period. Symptom evaluations related to the treatments were evaluated every seven days. The plants were kept in the solutions for 70 days of cycle. When the plants were removed, root and shoot were stored separately, in order to weigh each part. Afterwards, the plants were ground whole, root and shoot to then carry out the analysis of nutrient absorption in the plant tissue, through the nitroperchloric digestion method for macro and micronutrient extraction. Then, with the data obtained, it was possible to conclude the effects of imbalance due to the lack or excess of certain nutrients, and what is their relevance in the plant.

The variables analyzed were: 1-normal growth (NG), 2-plant death (PD), 3-chlorotic cotyledon (CC), 4-yellowing cotyledon (YC), 5-cotyledon fall (CF), 6-yellowing trefoil (YT), 7-compromised trefoil expansion (CTE), 8-abnormal stem elongation (ASE), 9-leaf wrinkling (LW), 10-nerve chlorosis (NC), 11-leaf chlorosis (LC), 12-damage on the leaf border (DLB), 13-symptoms on the lower area (SL), 14-symptoms on the apex (SAP), 15-chlorophyll degradation (CD), 27-Shoot Mass (SMASS, g).The analyzed variables for the root, 16-normal root (NR), 17-root growth in length (RGL, cm), 18-short roots (SR, unit), 19-aggressiveness of the root system (ARS), 20-more radicels (MR), 21-less radicels (LR, unit), 22-coarse roots (CR, unit), 23-branched roots (BR, unit), 24-straight roots (STR, unit) and 25-deformed roots (DR, unit), 26-Root Mass (unit). For the assessment of nutrient absorption, there are: 28-Nitrogen (N), 29-Calcium (Ca), 30-Magnesium (Mg), 31-Potassium (K), 32-Phosphorus (P), 33-Copper (Cu), 34-Zinc (Zn), 35-Magnesium (Mn) and 36-Iron (Fe).

Table 3. Doses for the Effect of Excess Nutrients. Unijuí, Ijuí, Rio Grande do Sul, Brazil.

How much to pipette in the vessels (ml.3L-1)	N	P	K	S	Mg	Ca	B	Mn	Zn	Cu	Mo	Fe	Al	Na
KH2PO4 mol L-1	3	6	6	3	3	3	3	3	3	3	3	3	3	3
KNO3 mol L-1	30	15	30	15	15	15	15	15	15	15	15	15	15	15
Ca (NO3)2 .4H2O mol L-1	30	15	15	15	15	30	15	15	15	15	15	15	15	15
MgSO4.7H2O mol L-1	6	6	6	12	12	6	6	6	6	6	6	6	6	6
Ca (H2PO4)2, 0,05 mol L-1	30	60	30	30	30	60	30	30	30	30	30	30	30	30
Mg (NO3)2. 6 H2O mol L-1	-	-	-	-	6	-	-	-	-	-	-	-	-	-
, Fe – EDTA	3	3	3	3	3	3	3	3	3	3	3	6	3	3
H3 BO3 mol L-1	3	3	3	3	3	3	6	3	3	3	3	3	3	3
Mn Cl22, mol L-1	3	3	3	3	3	3	3	6	3	3	3	3	3	3
Zn Cl2 mol L-1	3	3	3	3	3	3	3	3	6	3	3	3	3	3
Cu Cl2 mol L-1	3	3	3	3	3	3	3	3	3	6	3	3	3	3
H2 Mo4.H2O mol L-1	3	3	3	3	3	3	3	3	3	3	6	3	3	3
K2SO4 0,50 mol L-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca SO4 0,01 mol L-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Al Cl3 mol L-1	-	-	-	-	-	-		-	-	-	-	-	6	-
Na Cl mol L-1	-	-	-	-	-	-		-	-	-	-	-	-	6

RESULTS AND DISCUSSION

Through tissue analysis, it was possible to obtain information regarding the characteristics and absorption of macro and micronutrients by plants submitted to the different solutions (Table 4) and to analyze the symptoms of plant deficiencies and suppression (Figures 1 and 2). In the complete solution with all nutrients, there are no symptoms and cotyledon senescence occurred at stage V4, with a well-developed and branched root. Its fabric composition was composed of 23.95% N, 16.41% Ca, 22.17% Mg, 47.64% K, 60.58% P, 14.39% Cu, 6.53% and Zn, 72.66% Mn and 73.41% of Fe. In the solution with twice the nutrients, the plants presented leaves of reduced size, dark green, and without symptoms, reaching stage v4. Its roots showed little development and reduced size. Also, there is a small increase in the absorption of N, Mg, K and Fe, for Cu there was twice as much absorption and for Zn five times more. There was a decrease in Ca and Mn contents.

For the solution in the absence of nutrients, it is observed in the younger leaves aspects of chlorosis followed by necrosis with dark green nerves. The plants survived until the V3 stage, their roots showed little development and premature cotyledon senescence. As for absorption, there was a great reduction in the percentages, in which the plants stopped absorbing in the nitrogen-restricted solution, -34.43% of N, in the calcium-restricted solution, -40.97% of Ca, in the solution with restriction of magnesium, -19.42% of Mg, in the solution with copper restriction, -1.80% of Cu and in the solution with magnesium restriction, -17.87% of Mn, whereas the other nutrients only decreased their absorption compared to the complete solution, while for the solution with potassium restriction there was an absorption of 17.36%, for the solution with phosphorus restriction there was an absorption of only 1.35%, for the solution with zinc restriction there was double of absorption when compared with the complete solution, reaching 12.54% of Zn and for the absence of iron there was an absorption similar to the complete solution, reaching 64.24% of Fe.

Table 4. Relationship of nutrient accumulation as a function of Nutrient Absence. Unijuí, Ijuí, Rio Grande do Sul, Brazil.

%	N[1]	Ca	Mg	K	P	Cu	Zn	Mn	Fe
Complete	23.95	16.41	22.17	47.64	60.58	14.39	6.53	72.66	73.41
Double	30.02	6.65	37.86	53.00	45.63	33.53	30.43	57.97	81.58
Absence	-34.43	-40.97	-19.42	17.36	1.35	-1.80	12.54	-17.87	64.24
Excess	31.35	15.32	36.59	57.61	50.27	31.10	20.00	78.48	76.66
Absence K	.	16.84	35.88	.	.	.	.	.	.
Excess K	.	3.12	46.50	.	.	.	.	.	.
Absence Mg	.	-11.30	1.30	55.27	.	.	.	.	.
Excess Mg	.	4.90	44.08	22.18	.	.	.	.	.
Absence Ca	.	.	.	62.33	.	.	.	.	.
Excess Ca	.	.	.	41.26	.	.	.	.	.
Absence Mn	.	.	.	.	.	22.60	16.69	.	.
Excess Mn	.	.	.	.	.	23.65	9.48	.	.
Absence Zn	.	.	.	.	.	14.39	.	68.30	.
Excess Zn	.	.	.	.	.	20.98	.	76.47	.
Absence Cu	.	.	.	.	.	.	3.37	67.62	.
Excess Cu	.	.	.	.	.	.	34.62	69.10	.

[1]Nitrogen (N), Calcium (Ca), Magnesium (Mg), Potassium (K), Phosphorus (P), Copper (Cu), Zinc (Zn), Manganese (Mn), Iron (Fe).

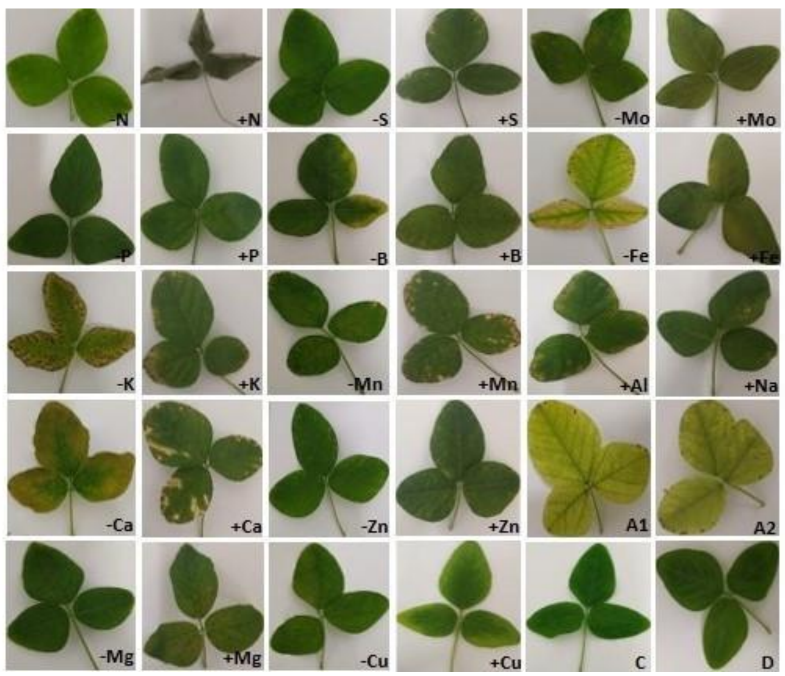
In the absence of N, the plants showed visual symptoms of chlorosis throughout the plant, yellowing on the edge of the trefoils, light green leaves, absence of cotyledons, and developed up to the V5 stage. Report that in N deficiency there is a total chlorosis of the older leaves, followed by necrosis. As well as Prado et al. (2010), report reduced development, fewer leaves, shorter height, smaller stem diameter and less dry matter. The lower development of plants is explained by the functions of this nutrient in plant metabolism as a constituent of all amino acids, proteins and nucleotides. However, a large root growth was observed, reaching almost one meter in length. Absorption in solution without N is much lower than solutions with excess N, twice all nutrients and complete solution. The excess of nitrogen (N) presented the seedling senescence, with the presence of the cotyledons, where it reached the V3 stage. Poorly developed roots. As for nutrient absorption, there was a solution with an excess just for nitrogen, there was a result very close to the solution with twice the nutrients and a greater absorption compared to complete, reaching 7% more.

Plants with absence of phosphorus (P) presented well-marked nerves in their trefoils, cotyledon senescence, reaching stage V5. Its roots have developed well, but with reduced root size. Sfredo and Borkert (2004), report that plants express reduced growth, low pod insertion and older leaves with a bluish-green coloration.

As well as Rosolem and Tavares (2006), describe that the deficiency occurred initially in the older leaves, which turned yellow, retaining some green veins. The solution with no P showed much lower absorption results when compared to the complete solutions, a solution with twice the nutrients, and the solution with excess P. When the solution with only excess of phosphorus (P) was used, the plants showed areas of chlorosis on the leaf, with spots of necrosis on the edge, absence of cotyledons. Well-formed roots, with short radicels. For the absorption of the solution with excess of P, there was a 10% reduction in absorption when compared to the complete solution, and a 5% increase in absorption when compared to twice that of all solutions.

The solution without potassium showed trifoliates with reduced size, green in the center and chlorosis at the edges, followed by necrosis. Sfredo and Borkert (2004), describe that the symptoms are characterized by interneval chlorosis, followed by necrosis on the edges and apex of old leaves, due to the formation of putrescine. Prado et al. (2010), also describe that a deficiency of these nutrients results in chlorosis in the margins of older leaves, followed by leaf tissue necrosis.

Figure 1. Symptoms observed in plant trefoils. Unijuí, Ijuí, Rio Grande do Sul, Brazil.



Nitrogen Restriction (-N), Excess Nitrogen (+N), Sulfur Restriction (-S), Excess Sulfur (+S), Molybdenum Restriction (-Mo), Molybdenum Excess (+Mo), Phosphorus Restriction (-P) , Excess Phosphorus (+P), Boron Restriction (-B), Excess Boron (+B), Iron Restriction (-Fe), Excess Iron (+Fe), Potassium Restriction (-K), Excess Potassium (+K), Manganese Restriction (-Mn), Excess Manganese (+Mn), Excess Aluminum (+Al), Excess Sodium (+Na), Calcium Restriction (-Ca), Excess Calcium (+Ca), Zinc Restriction (-Zn), Excess Zinc (+Zn), Absence 1 (A1), Absence 2 (A2), Magnesium Restriction (-Mg), Excess Magnesium (+Mg), Copper Restriction (-Cu), Excess Copper (+Cu) , Full (C) and Double (D).

Figure 2. Symptoms observed in plant roots. Unijuí, Ijuí, Rio Grande do Sul, Brazil.

Nitrogen Restriction (-N), Excess Nitrogen (+N), Sulfur Restriction (-S), Excess Sulfur (+S), Molybdenum Restriction (-Mo), Molybdenum Excess (+Mo), Phosphorus Restriction (-P) , Excess Phosphorus (+P), Boron Restriction (-B), Excess Boron (+B), Iron Restriction (-Fe), Excess Iron (+Fe), Potassium Restriction (-K), Excess Potassium (+K), Manganese Restriction (-Mn), Excess Manganese (+Mn), Excess Aluminum (+Al), Excess Sodium (+Na), Calcium Restriction (-Ca), Excess Calcium (+Ca), Zinc Restriction (-Zn), Excess Zinc (+Zn), Absence 1 (A1), Absence 2 (A2), Magnesium Restriction (-Mg), Excess Magnesium (+Mg), Copper Restriction (-Cu), Excess Copper (+Cu) , Full (C) and Double (D).

Well-developed roots with very short radicels. For absorption in the absence of K, 30% lower levels were obtained when compared to the complete solution, and 36% less when compared to the solution with twice all nutrients. In addition, potassium in the absence of magnesium had an 8% increase in absorption when compared to the complete solution, 2% more compared to the solution with twice as many solutions, 38% more when compared to the absence and 2% less when compared to the solution with only the excess of K. Also, the potassium in the solution without Ca had an absorption 45% higher than the solution with the absence and when compared to the solution without Mg we had an absorption similar to the absorption observed in the absence of K.

For the excess of potassium, plants with the tip of the leaves with the presence of necrosis, stained, with absence of cotyledons, reached stage V5. Roots with short and poorly developed radicels. The solution with only excess K had a 10% increase in absorption when compared to the solution with all nutrients, 4% more compared to the solution with twice all solutions and 40% more when compared to the absence of all nutrients. Furthermore, when there was an excess of Mg, an absorption of 35% less K was obtained when compared to the excess of potassium alone. And when analyzed with excess calcium there was a 16% reduction in absorption. In plants with absence of calcium (Ca) there was the yellowing of the trefoils, in the direction of the edges to the center of the leaves, the younger ones presented wrinkling, and the plant had presence of cotyledons until V4, in addition its roots had reduced growth. Similar symptoms were found by (Sfredo & Borkert, 2004), the symptoms occur at the growth points, both in the root and in the shoot, the symptoms appear in the younger parts of the plant, atrophying the root system, killing the apical bud. Sfredo and Borkert (2004), state that the symptoms occurred in young leaves, presenting internerval chlorosis, with deformation in the limb, followed by plant lodging.

The solution without Ca showed a great reduction in the absorption of the nutrient, and the same happens when compared to the solutions with excess of Ca, the solution with twice the nutrients and the complete solution. When the solution with the absence of calcium was together with the solution without K, calcium absorption had a great increase, while when it was together with the solution with Mg, there was a reduction in absorption again. The excess of calcium (Ca) showed plants with chlorosis from the edge to the center of the leaves, with necrotic zones, in addition to the absence of cotyledons, and development up to the V4 stage. Its roots had a lesser development, getting shorter, and also with shorter radicels. Calcium absorption, when the solution was found in excess, resembled the complete solution, but when the solution had doubled the nutrients, showed a large reduction in its absorption, being only half of what was found in the solution with excess of Ca. Furthermore, in the solution without Ca, it was found that the plant stopped absorbing more than 50% of Ca. And when the solution with excess of Ca is together with the solutions with excess of K and of Mg, there is a large reduction in the accumulation of Ca.

The absence of magnesium (Mg) showed only symptoms of chlorosis in the leaves and well-developed roots. According Sfredo and Borkert (2004), the oldest leaves show internerval chlorosis (light yellow) and pale green veins. Absorption where the solution was lacking in Mg was found to be deficient, whereas in solutions with excess Mn and double all the nutrients there was a great increase in absorption where the two are similar, in the complete solution there was also an increase in absorption, smaller than in the other solutions compared, but much greater than the absence. When together with the solution with the absence of K, the solution with absence showed a great increase in absorption, whereas when together with the solution without Mg its increase in absorption was not so great.

Excess magnesium (Mg) caused the appearance of leaves with chlorosis from the base to the tips, followed by lesions, which at the leaf tip progressed to necrosis, with cotyledons falling, and plant development to stage V4, with well-developed roots. Prado et al. (2010), report internerval chlorosis of older leaves. State that the deficiency of this nutrient initially causes a pale green color on the edges, later passing to a marginal chlorosis in the older leaves. The solution with an excess of Mg presented absorption similar to that it had in the solution with twice as many nutrients, whereas in the complete solution there was a reduction in absorption, and when compared with the absence, there was a great increase. Furthermore, an increase in absorption was also observed when the solution with excess of Mg was found together with the solutions with excess of K and Mg.

Plants in the solution with no sulfur (S) demonstrated stunting at the base of younger leaves, absence of cotyledons, and well-developed roots. On the other hand, plants in the solution with excess sulfur (S) showed necrosis at the edge of the leaves, absence of cotyledons, development up to the V4 stage, with well-developed roots. The scarcity of sulfur results in general chlorosis of the leaves, including the veins, which change from pale green to yellow. Plants lacking boron (B) showed stunted younger leaves, with chlorosis and yellowish edges, presence of cotyledons, and development up to the V4 stage. Roots showed thickening and lower root development. The excess of boron (B) showed plants with chlorosis throughout the leaf followed by necrosis in the leaf tips, absence of cotyledons and plant development up to the V4 stage. Its roots were thin, but well developed. Described that in the absence of boron, the leaflets of young leaves are deformed, wrinkled, often thicker and dark blue-green in color. Mascarenhas, Miranda, Bataglia, Pereira and Tanaka (1988), in studies showed malformation of leaflets, reduced growth providing the development of lateral buds, which resulted in overbudding. As for boron toxicity, according to Sfredo and Borkert (2004), it is characterized by brown spots on the edges of the leaves, evolving to necrosis on the margins and interverval punctuations with wrinkling of the leaves.

The absence of manganese (Mn) showed chlorosis stains on the leaves followed by necrosis in the center, edges and nerves, there was the absence of cotyledons, and the plant developed up to the V4 stage. Roots showed less development. Symptom similar to that reported by Sfredo and Borket (2004), in which there is chlorosis in greenish-yellow tones of younger leaves and according to, it is possible to verify brown necrotic areas that develop on the leaves as the deficiency becomes more severe. It was observed that in the solution without Mn the plant stopped absorbing 18% of Mn and when compared to the complete solution, a solution with twice the nutrients and a solution with excess of Mn had an even greater decrease in absorption. When the Mn-absent solution was combined with the Zn and Cu-absent solutions, a large increase in Mn absorption was noted.

Excess manganese (Mn) caused chlorosis, necrosis spots that went from the edges to the center of the leaves, absence of cotyledons and development up to the V4 stage. Its roots were well developed. The excess of this nutrient causes toxicity that can be seen in young leaves with wrinkling of the leaflets and necrotic spots on the leaf (Sfredo & Borkert, 2004). The solution with the excess of Mn, when compared to the complete solution and the solution with twice the nutrients, had a 6% and 17% decrease in Mn absorption, respectively. When analyzing the solution with an excess of Mn and the solution without Mn, there is a great decrease in its absorption. When the solution without Mn was together with the solutions without Mn and without Cu, there was a decrease in absorption of approximately 10%.

For plants with no zinc (Zn), they presented chlorotic zones in the younger leaves and onset of necrosis. Its roots were long and well developed. Its absorption, when comparing the absence of Zn with the complete solution, practically doubled the absorption of Zn. And when comparing the solution with the absence of Zn and the solution with excess of Zn, there was a decrease of 8% in absorption, and when analyzing with the solution that has twice all nutrients, there was a reduction of 18% in Zn absorption. When the solution without Zn was together with the solution without Mn, there was an increase in the absorption of Zn. In the solution with the absence of Cu, however, there was a reduction in the absorption of Zn.

For the excess of zinc (Zn) in the plants, there were chlorosis spots followed by necrosis, the absence of cotyledons, and its development until the V5 stage. Sfredo and Borkert (2004), report small, chlorotic and lanceolate leaves, and the younger leaves have golden-yellow interverval chlorosis and the veins a dark green color. The roots were well developed, but with shorter roots. As for its absorption, it was found that when comparing the solution with excess Zn and the complete solution, there was an increase in the absorption content of practically 3 times more. When analyzing the excess Zn solution with the solution with twice the nutrients, there was a decrease in absorption, and when compared to the solution without Zn, there was an increase in absorption in the solution with excess Zn. Furthermore, it can be observed that when the excess Zn solution was together with the excess Mn, there was a reduction in the absorption of Zn. And when the solution with excess of Zn was together with the solution with excess of Cu, there was a great increase in the absorption of Zn.

The absence of copper (Cu) caused chlorosis in practically all the leaves, with well-marked veins, and the absence of cotyledons, with the plant developing up to the V4 stage. The youngest leaves take on a grayish-green or bluish-green color, generally causing necrosis at the tips of the leaflets of the new leaves (Sfredo & Borkert, 2004). Its roots were well developed, but with some thickening at the top. For the absorption of nutrients when compared to the absence of Cu with the complete solution, it was found that the plant failed to absorb about 16% of Cu. And when compared to the solution with excess Cu and twice all nutrients, it was found that the plants stopped absorbing at least 33% of Cu. Also, when there was a solution with the absence of Cu and the solutions without manganese and zinc, the plants absorbed about 22% of Cu.

Plants with excess copper (Cu) had lighter leaf edges, with light green color and darker green in the center, their veins were lighter, older leaves with chlorosis and onset of necrosis. Its roots have developed well. As for nutrient absorption, when comparing the solution with the excess of Cu and the solution with twice as many nutrients, there was a similarity in the percentage of absorption. When comparing the solution with the excess of Cu with the complete solution, it can be seen that the excess allowed twice as much absorption. And when comparing the excess of Cu with the absence, it was found that the plant stopped absorbing the nutrient. Furthermore, when the excess of iron was verified together with the excess of manganese and zinc, it was noted that the iron absorption decreased by about 10%.

In the solution without molybdenum (Mo), the plants showed reduced leaf growth, with the presence of chlorosis, the trefoil with parts of brown and the beginning of necrosis in the leaf tips. Sfredo and Oliveira (2010) observed that in molybdenum deficiency the plants became yellowish and young leaves twisted, with necrotic spots on the leaflet margins. When there was an excess of molybdenum (Mo), it was possible to observe the darkening of the center of the leaves, spots of necrosis towards the center towards the edges, and that the plant developed until the V5 stage. Its roots have developed well.

For the solution without iron (Fe) there were symptoms of yellowing leaves with onset of necrosis, well-outlined dark green veins, had cotyledon senescence, and showed a lower development reaching V3 stage. Poorly developed roots. Describe that in the initial stage of the development of symptoms, the areas between the veins of the soybean leaves start to present a yellowish color. Its absorption, when purchased with the complete solution, a solution with twice the nutrients and a solution with excess iron, was lower, but it still absorbed a large percentage of the nutrient, reaching approximately 65% of Fe. The solution with excess iron (Fe) shows darkened leaves with spots of chlorosis, appearance of necrosis on the edges, absence of cotyledons, and the plant has reached stage V5. Its roots were short, but with a well-developed structure. Regarding its absorption, when there was only excess Fe, it was noted that the plant showed greater absorption when compared to the complete solution, and showed the same tendency when comparing it to the solution with the absence of all nutrients. However, when compared to the solution that contained twice as many nutrients, it showed a decrease in absorption, and it can be concluded that the absorption of Fe is dependent on the presence of other nutrients.

The excess of aluminum (Al) caused the yellowing of leaf edges, followed by necrosis, where the plant developed until the V4 stage with cotyledon senescence. Well-developed roots, with very short roots. Plants exhibit reduced size, developmental disorders, smaller leaves with dark green color, yellowing and necrosis at the tips of the leaflets. The excess of sodium (Na) in the plants showed up as hydrochloric spots, followed by necrosis at the ends of the leaves, absence of cotyledons reaching stage V4. Its roots had a good development, but with very short roots.

Correlation studies allow identifying and quantifying morphological associations (Carvalho et al., 2015). Thus, it is clear that normal roots have a significant and positive relationship with branched roots, however, due to the greater presence of normal roots, a reduction in root and short roots (SR) is observed. Root growth in length shows a significant negative correlation with deformed roots, thick roots, fewer radicels and short roots, that is, due to the increase in root length, there is a tendency to reduce these listed variables, however it showed a positive correlation with straight roots due to straight roots showing greater lengths. On the other hand, short roots are positively correlated with deformed roots, as deformed roots have their development compromised. This can be proven by the result of a negative correlation between short roots and aggressiveness of the root system, showing that short roots exhibit less development capacity.

Roots with greater presence of radicelles show a positive correlation with branched roots, thus, it is clear that the ramifications are determinant for the presence of the roots, in addition, a negative correlation is perceived between roots with more roots and roots with less radicel. It is observed that the correlation between branched roots and straight roots is negative, this is due to the fact that branched roots present lateral development and straight roots develop vertically.

It is observed that normal growing seedlings show a negative correlation in relation to chlorophyll degradation, shallow leaf symptoms, leaf chlorosis, wrinkling of the leaves, and compromised expansion of the trefoils and yellowing of the trefoil. In the analysis of hydrochloric cotyledon, it is observed that there is a significant positive correlation with symptoms in the lower part, cotyledon fall and yellowing, that is, the presence of hydrochloric cotyledons shows a tendency to damage the plant. In the analysis of the yellowing of the cotyledon, a positive correlation with the fall of cotyledons is observed, as the yellowing of this organ is associated with senescence and its fall.

The yellowing of the trefoil is positively correlated with symptoms at the top and bottom of the plant, damage to the leaf border and leaf chlorosis. The compromised expansion of the trefoils is positively correlated with the wrinkling of the leaves, that is, when the wrinkling of the trefoils occurs, it presents difficulty in expansion. Leaf wrinkling exhibits a positive correlation with symptoms at the apex, as wrinkling occurs in developing leaves. Likewise, leaf border damage showed positive correlations with symptoms in the lower part, as well as they were positively correlated with chlorophyll degradation.

It is observed that for the significant correlations, all are characterized as positive. The nutrient-free solution is found to be significantly and positively correlated with all symptoms of nutrient restriction, except sulfur, magnesium, copper and twice as many nutrients. Furthermore, the complete solution exhibited positive correlation with copper, magnesium, phosphorus and nitrogen restriction, which means that plant symptoms were similar either in complete solution or restriction of the nutrients described. In the solution with twice as many nutrients, it was observed that there was a significant positive correlation only with magnesium restriction.

The solution without nitrogen exhibited a positive correlation with the symptoms observed also in the restrictions of phosphorus, magnesium, zinc, copper, molybdenum and iron. In P restriction, there is a positive correlation with symptoms of solutions with magnesium, manganese, copper and molybdenum restriction. Likewise, for potassium restriction there is a significant correlation with symptoms of calcium, boron, manganese, zinc, molybdenum and iron restriction solutions. In the solution with calcium restriction, symptoms correlated in solutions without boron, manganese, zinc and iron were obtained. The magnesium-restricted solution showed similar symptoms with sulfur, copper and molybdenum-restricted solutions. Boron restriction symptoms were shown to be correlated with iron, molybdenum and zinc restriction symptoms. Manganese restriction showed a strong correlation with symptoms presented in zinc, copper, molybdenum and iron restrictions. When there was zinc restriction, symptoms that resembled the symptoms of copper, molybdenum, and iron restriction were presented. In the absence of copper, symptoms were correlated with symptoms presented in molybdenum and iron.

When analyzing the linear correlation between the solutions in excess of nutrients evaluated in the experiment, it is observed that for the significant correlations all are characterized as positive. It is noticed that the solution without nutrients expressed a significant positive correlation with all solutions due to the symptoms in the plants, except in the solutions with excess of molybdenum, nitrogen, twice as many nutrients and complete solution. The complete solution showed a significant correlation with excess molybdenum, zinc, manganese, boron and calcium. In addition, the solution with twice the nutrients showed correlation with excess molybdenum, zinc and nitrogen, as well as excess nitrogen showed symptoms correlated with excess molybdenum, copper, boron and potassium.

Symptoms of excess phosphorus correlate with symptoms of excess sodium, aluminum, copper, manganese, boron, sulfur, magnesium, calcium, and potassium. Likewise, calcium exhibits correlation with the same variables as phosphorus. However, excess magnesium exhibits symptoms that correlate with symptoms of excess sodium, aluminum, iron, copper, manganese, boron, and sulfur. Similarly, excess sulfur exhibits symptoms in leaves similar to sodium, aluminum, iron, copper, zinc, and manganese, and boron exhibits symptoms that corroborate sodium, aluminum, molybdenum, copper, zinc, and manganese. Similarly, excess manganese is positively correlated with symptoms of sodium, iron, molybdenum, copper, and zinc. Symptoms of excess zinc in soybean leaves were positively correlated with excess sodium and molybdenum. Excess copper corroborates its symptoms in leaves with excess aluminum, iron and molybdenum, likewise excess iron showed a positive correlation with symptoms of excess sodium and aluminum, as well as excess aluminum showed correlated symptoms with excess sodium.

CONCLUSIONS

Thus, individual omissions resulted in morphological changes, which were translated into visual symptoms characteristic of the nutritional deficiency of the respective nutrient. The absorption dynamics was observed, in which it was concluded that some nutrients are exclusively dependent on others, and if there is no equilibrium dynamics, absorption will be compromised and, consequently, the productive potential as well.

The solution with twice the nutrient concentration of the complete solution showed an increase in the absorption of N, Mg, K and Fe, for Cu there was twice as much absorption and for Zn five times more. There was a decrease in the absorption of Ca and Mn. And with this it is concluded that the availability of twice as many nutrients, did not result in double their absorption.

REFERENCES

Carvalho, I. R., Nardino, M., Demari, G. H., Bahry, C. A., Szareski, V. J., Pelissari, G., Ferrari, M., Pelegrin, A. J., Oliveira, A. C., Maia, L. C., & Souza, V. Q. (2016). Bi-segmented regression, factor analysis and AMMI applied to the analysis of adaptability and stability of soybean. *Australian Journal of Crop Science*, 10(10), 1410-1416. https://doi: 10.21475/ajcs.2016.10.10.pne63

Carvalho, I. R., Souza, V. Q., Nardino, M, Follmann, D. N., Schmidt, D., & Baretta, D. (2015). Correlações canônicas entre caracteres morfológicos e componentes de produção em trigo de duplo propósito. *Pesquisa Agropecuária Brasileira*, 50, (8), 690-697. https://doi.org/10.1590/S0100-204X2015000800007

CONAB – Companhia Nacional de Abastecimento. Séries históricas. (2020). Brasilia, DF: CONAB. https://www.conab.gov.br/info-agro/safras/serie-historica-das-safras?start=30

Dall'agnol, A., Roessing, A. C., Lazzarotto, J. J., Hirakuri, M. H., & Oliveira, A. B. (2007). *O complexo agroindustrial da soja brasileira*. Londrina, PR: Embrapa Soja. Circular Técnica, 42.

Ferreira, L. L., Ricardo Viana de Carvalho, P., Fernandes, M. de S., Silva, J. G., Ricardo Carvalho, I., & Lautenchleger, F. (2020). Neural network and canonical interrelationships for the physiological aspects of soybean seedlings: effects of seed treatment. *Agronomy Science and Biotechnology*, 6, 1–11. https://doi.org/10.33158/asb.r116.v6.2020

Frota, R. T., Carvalho, I., Demari, G. H., Loro, M. V., Hutra, D. J., Lautenchleger, Francine, … Aumonde, T. Z. (2020). Molybdenum and potassium in the foliar fertilization and seed quality in the soybean. *Agronomy Science and Biotechnology*, 6, 1–9. https://doi.org/10.33158/asb.r117.v6.2020

Hanyu, J., Costa, S., Cecon, P., & Matsuo, É. (2020). Genetic parameters estimate and characters analysis in phenotypic phase of soybean during two evaluation periods. *Agronomy Science and Biotechnology*, 6, 1–12. https://doi.org/10.33158/asb.r104.v6.2020

Loro, M. V., Carvalho, I. R., Silva, J. A. G., Moura, N. B., Hutra, D. J., & Lautenchleger, F. (2021). Artificial intelligence and multiple models applied to phytosanitary and nutritional aspects that interfer in the physiological potential of soybean seeds. *Brazilian Journal of Agriculture - Revista de Agricultura*, *96*(1), 324–338. https://doi.org/10.37856/bja.v96i1.4258

Mascarenhas, H. A. A., Miranda, M. A. C. D., Bataglia, O. C., Pereira, J. C. V. N. A., & Tanaka R. T. (1988). Deficiência de boro em soja. *Bragantia*, 47(2), 325-331.

Prado, R. M., Franco, C. F., & Puga, A. P. (2010). Deficiências de macronutrientes em plantas de soja cv. BRSMG 68 (Vencedora) cultivada em solução nutritiva. *Comunicata Scientiae, 1* (2), 114-119. http://hdl.handle.net/11449/71983

Rosolem, C. A., & Tavares, C. A. (2006). Sintomas de deficiencia tardia de fosforo em soja. *Revista Brasileira de Ciencia Do Solo*, 30(2), 385–389. https://doi.org/10.1590/S0100-06832006000200018

Sfredo, G. J., & Borkert, C. M. (2004). *Deficiências e toxicidades de nutrientes em plantas de soja.* Londrina, PR: Embrapa Soja. Circular Técnica, 231.

Sfredo, G. J., & Oliveira, M. C. N. (2010). *Soja: Molibdênio e Cobalto*. Londrina, PR: Embrapa Soja. Circular Técnica, 322.

Szareski, V. J., Carvalho, I. R., Kehl, K., Levien, A. M., Rosa, T. C., & Souza, V. Q. (2021). Adaptability and stability with multivariate definition of macroenvironments for wheat yield in Rio Grande do Sul. *Pesquisa Agropecuária Brasileira*, 56. e02468. https://doi.org/10.1590/s1678-3921.pab2021.v56.02468

Vargas, R. L., Schuch, L. O., Barros, W. S., Rigo, G. A., Szareski, V. J., Carvalho, I. R., Pimentel, J. R., Troyjack, C, Jaques, L. B. A., Souza, V. Q., Rosa, T. C., Aumonde, T. C., & Pedó, T. (2018). Variabilidade de macronutrientes e micronutrientes em sementes de soja. *Journal of Agricultural Science* 10(4), 209-222. doi:10.5539/jas.v10n4p209