https://doi.org/10.71252/2177-34912025720019
revista Ceres
ISSN: 2177-3491

Nutrient Omission in Corn Plant Development Cultivated in Nutrient Solution

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[1] O trabalho foi extraído da coleta de dados de uma disciplina de mestrado como método avaliativo para os discentes, não apresentando fonte financiadora.

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Editors:
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Submitted: August 21st, 2024.
Accepted: April 24th, 2025.

ABSTRACT

Macronutrients are essential for plants, and their deficiency results in decreased productivity, hindering the plant from completing its life cycle. The aim of this study was to evaluate the effect and symptomatology of macronutrient omission in maize (*Zea mays* L.) cultivation. The experiment was conducted in a greenhouse, with the following treatments: T1: no macronutrients; T2: complete except for Nitrogen; T3: complete except for Phosphorus; T4: complete except for Potassium; T5: complete except for Calcium; T6: complete except for Magnesium; T7: complete except for Sulfur; and T8: all nutrients included. Micronutrients were added to the treatments, irrigated with 60% water retention capacity. A Completely Randomized Design was applied, with 5 repetitions per treatment. After 80 days, the analyzed variables were: plant height, number of leaves, stem diameter, fresh mass weight, and dry mass of above-ground and root parts. Analysis of variance was performed, and means were compared using the T-test for multiple comparisons (LSD) at a 5% probability level. Treatments with omission of N, P, and S were the most affected in all evaluated variables. On the other hand, the absence of Ca, K, and Mg nutrients had little impact on plant development.

Keywords: fertilization, plant nutrition, *Zea Mays L.*

INTRODUCTION

Corn *(Zea mays* L.) is one of the most important grain crops in both Brazil and worldwide. It can be grown during the summer, known as the main harvest, or in the winter, referred to as safrinha (in Brazil) or the second harvest. According to data from the National Supply Company[1] for the 2023/24 season, the planted area for this crop in Brazil was 20.86 million hectares, with a yield of approximately 5.553 kg ha^{-1} and a production of 115 million tons. These figures highlight the significance of this crop in the country.

From a nutritional standpoint, ensuring proper nutrition is essential for any crop. To complete their life cycle healthily and achieve the desired yields, plants must be provided with both macro and micronutrients.[2] It's also necessary to estimate the nutrients exported and those that need to be replenished in the soil to prevent system depletion.[3]

The nutritional requirements of corn for macronutrients follow this order: N > K > Ca > Mg > P > S. Each nutrient has its specific role within the plant's metabolism, and a deficiency in any one of them can lead to reduced productivity.[4,5] Therefore, it's crucial to remember Liebig's Law of the Minimum (1840), which states that if even one nutrient is unbalanced or lacking, production will be compromised, even if all other nutrients are sufficient.

Considering this, the nutrient omission method is a quick solution to understand the nutrient requirements and deficiency symptoms of a particular species.[6] This study aimed to analyze the effects and symptoms of macronutrient deficiencies N, P, K, Ca, Mg, and S in corn plants grown in sand-filled pots using Hoagland and Arnon's solutions (1938).

MATERIAL AND METHODS

The experiment was conducted in a greenhouse at the State University of Northern Paraná (UENP/CLM), with sowing taking place on March 28, 2023, using the SHS7930PRO3 hybrid. Four seeds were planted per pot, and later thinned to leave only two plants per pot. The pots had a 4-liter capacity and were filled with 3 kg of sieved construction sand. The treatments are described in Table 1 and were prepared according to the solutions of Hoagland & Arnon.[7]

All treatments included the addition of micronutrients, and watering was done based on the average water loss in the pots, maintaining 60% of the water retention capacity. The nutrient solutions for each treatment were applied twice a week, on Tuesdays and Thursdays, at a rate of 100 ml per pot.

Tabela 1. Description of Treatments

T1: Control	No macronutrients applied
T2: Except N	Complete except Nitrogen
T3: Except P	Complete except Phosphorus
T4: Except K	Complete except Potassium
T5: Except Ca	Complete except Calcium
T6: Except Mg	Complete except Magnesium
T7: Except S	Complete except Sulfur
T8: Complete	Complete with all Nutrients

The experimental design was completely randomized, with 8 treatments and 5 replicates each, totaling 40 pots. Evaluations were carried out 80 days after planting. Plant height was measured from the soil surface to the insertion of the last leaf using a tape measure, and stem diameter was measured with a mechanical caliper. The pots were then dismantled, requiring water to preserve the roots.

For the variables of fresh and dry weight of roots and shoots, the weights of these components were recorded for each pot (2 plants). To determine dry mass, the samples were placed in a forced-air oven for 72 hours until all water was removed, and then weighed using an analytical precision scale.

Statistical analysis was performed using RStudio,[8] where the assumptions for analysis of variance (ANOVA) were tested, and the post hoc test was LSD (Least Significant Difference) with a 5% significance level. The number of leaves did not meet the assumptions for ANOVA and was analyzed using non-parametric methods, specifically the Kruskal-Wallis test followed by Dunn's test. Finally, the graphs were generated using the ggplot 2 package in Rstudio.[9]

RESULTS AND DISCUSSION

Table 2 below presents the means for plant height, stem diameter, and number of leaves. All treatments showed significant statistical differences, with the letter A representing the best result, closely matching the complete solution, while the letter E shows results similar to the control for the evaluated parameters.

Nitrogen

When nitrogen (N) was omitted, a severe impact on the vegetative development of the plants was observed. The plants did not reach their expected growth, averaging only 7 leaves and a height of just 28.30 cm, which was significantly lower compared to the complete treatment and closer to the control. Additionally, initial yellowing was observed, followed by the drying and death of older leaves, along with chlorosis in the younger leaves. These symptoms were severe due to the complete omission of this nutrient (Figure 1).

Similar symptoms have been reported by other researchers in experiments involving nitrogen omission in sorghum plants. They visually described it as uniform chlorosis of the vegetative parts, with greater severity in the older leaves. Moreover, nitrogen deficiency also affects grain filling, reducing both the quality and quantity of grains per ear.[10,11]

Gondim,[12] in another study on macronutrient omission, found that nitrogen was the element that most restricted the growth of corn plants, resulting in low stem diameter values and only 3 leaves 30 days after emergence.

Phosphorus

For phosphorus (P), the initial symptoms observed were the characteristic blue-green coloration of the leaves, as documented in the literature.[13] As the deficiency progressed, by the time evaluations were conducted at 80 days, most of the older leaves were completely dried out, and some had died. The plants were unable to develop properly and exhibited abnormalities, such as the appearance of stigmas, though they never produced tassels for pollination to occur (Figure 2). Phosphorus plays a key role in plant growth, and under conditions of deficiency, development is stunted due to phosphorus's primary function in energy transfer and storage.[14]

As shown in Table 1, phosphorus was one of the nutrients that had the most significant impact on the evaluated components compared to the complete treatment. The plants reached an average height of 38.40 cm and had 9 leaves, most of which had compromised photosynthetic activity.

Another characteristic symptom of phosphorus deficiency is thin stems, which was also observed during this experiment. There are also secondary impacts of phosphorus deficiency on the plant. Some studies on sorghum have concluded that phosphorus deficiency significantly reduces the absorption of other nutrients like nitrogen (N) and potassium (K) while increasing the accumulation of boron (B) in both roots and shoots.[10]

Potassium

In the treatment with potassium (K) omission, symptoms took longer to appear and were not severe. The plants managed to grow to an average height of 85.50 cm, which was very close to the complete treatment. Similarly, the number of leaves reached 9, and they remained healthy at the time of evaluation. However, the stem diameter was statistically lower than in the complete treatment, measuring 0.89 cm.

As for the observed deficiency symptoms, the classic symptom of potassium deficiency necrosis along the leaf edges was identified. Literature also confirms that potassium has an antagonistic effect with magnesium (Mg), directly interfering with its absorption.[10,15] Figure 3 below shows a comparison of the treatment with potassium omission. It's important to note that the symptoms might have been milder due to the 80-day evaluation period, as under field conditions, the plants' productive potential would likely be severely compromised.

Table 2. Means for the components plant height, stem diameter and number of leaves

Treatment	Height (cm)	Diameter (cm)	Number of Leaves
T1: Control	23.20 E	0.2 D	5.9 E
T2: Except N	28.30 D	0.24 CD	7.3 D
T3: Except P	38.40 C	0.31 C	8.8 C
T4: Except K	85.50 B	0.89 B	9.3 AB
T5: Except Ca	85.50 B	0.89 B	9.3 AB
T6: Except Mg	90.20 A	1.09 A	9.8 A
T7: Except S	23.20 E	0.15 D	5.9 E
T8: Complete	87.50 AB	1.18 A	9.7 AB
CV %	4.56	12.24	8.95

Means followed by the same uppercase letters are not significantly different from each other by the T (LSD) test at a 5% probability level for height and diameter. Means followed by the same uppercase letter are not significantly different from each other by the Dunn test at a 5% probability level for the number of leaves. CV % = Coefficient of variation (%).

It's also possible to compare the treatments omitting N, P, and K with the complete treatment, as these three are the macronutrients most required by plants. Figure 4 visually presents this comparison, showing that the complete treatment is noticeably superior to the others mentioned.

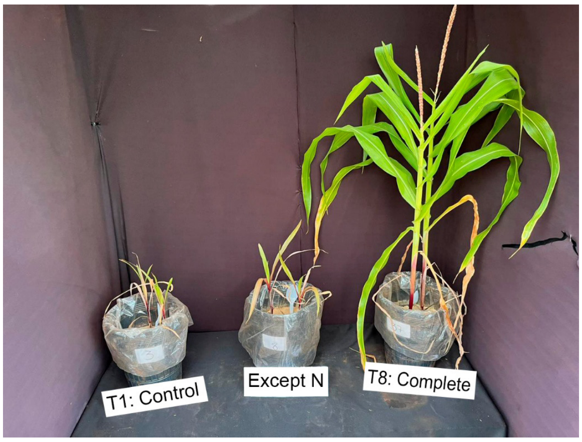
Calcium

Similar to potassium, calcium (Ca) deficiency symptoms appeared later and were mild, with the two treatments showing similar results. The symptoms were limited to chlorosis along the edges of young leaves. The averages were close to those of the complete treatment, and the plants were able to develop sufficiently, even producing tassels.

According to the literature, calcium plays a crucial role in meristematic tissues, and its deficiency can lead to reduced growth in both the shoots and roots. Symptoms typically first appear in young leaves. However, in this study, the severity of calcium deficiency was not as pronounced. Figure 5 shows the comparison of the treatment with calcium omission at 80 days.

Magnesium

The deficiency of magnesium (Mg) observed in this experiment was also mild, primarily manifesting as interveinal chlorosis on the leaves, a well-known characteristic symptom. However, other symptoms commonly noted in the literature, such as significant reduction in the root system and subsequent stunted overall plant growth, were not observed.

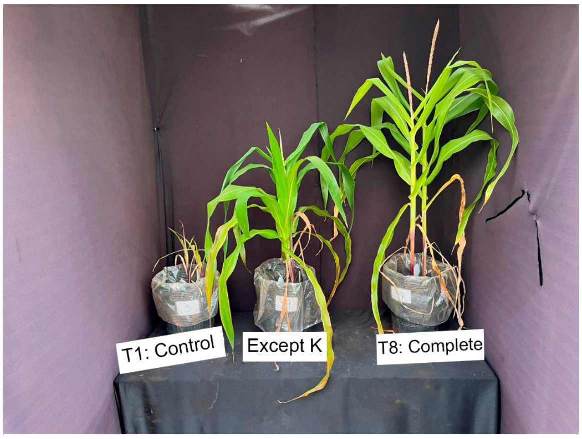


Source: author.

Figure 1. Visual comparison 80 days after plant emergency of the effect of without nitrogen (center) on corn, compared to the control (left) and complete treatment (right).

Source: author.

Figure 2. Visual comparison 80 days after plant emergency of the effect of without phosphorus (center) on corn, compared to the control (left) and complete treatment (right).



Source: author.

Figure 3. Visual comparison 80 days after plant emergency of the effect of without potassium (center) on corn, compared to the control (left) and complete treatment (right).

Source: author.

Figure 4. Effect of without macronutrients on corn growth 80 days after plant emergency. From left to right: except N, except P, except K and complete treatment.

Source: author.

Figure 5. Visual comparison 80 days after plant emergency of the effect of without calcium (center) on corn, compared to the control (left) and complete treatment (right).

The averages for this treatment did not differ statistically from the complete treatment for any of the components presented in Table 1. Despite the absence of Mg, the plants developed normally, producing 10 leaves and inflorescences. Figure 6 shows the comparison of the treatment without Mg.

Sulfur

The treatment with sulfur (S) omission was the most adversely affected across all evaluated parameters. The plants exhibited minimal growth, and some even died before the evaluation. For the items presented in Table 1, the results for S were not statistically different from the control. Due to the severe deficiency from the start of the growth cycle, it was not possible to observe specific deficiency symptoms.

Sulfur is directly involved in protein metabolism and grain filling, and it is one of the most critical nutrients required by corn. These factors likely explain the severity of the symptoms observed in this study.[16]

Generally, sulfur deficiency symptoms include reduced plant size, shortened internodes, generalized chlorosis, and wrinkled appearance of tissues.[13] Figure 6 shows the comparison of the treatment with sulfur omission.

These treatments served as reference points for comparing the analyzed variables and assessing the symptoms observed in the other treatments. Figures 8 and 9 illustrate the general aspects of each treatment and the symptoms recorded in each pot throughout the experiment.

Control and Complete Treatments

In addition to the components presented in Table 1, fresh and dry masses of roots and shoots were also evaluated, resulting in the graphs shown in Figures 10 and 11.

For root parameters, it was observed that treatments with omitted Ca and Mg had higher fresh and dry mass values. As previously described, these treatments showed mild and late deficiency effects. In contrast, treatments with omissions of S, P, and N had low fresh and dry mass values. This reflects the severity of the deficiencies, resulting in very little biomass, which directly impacts production, especially in field conditions.

Regarding the fresh and dry mass of shoots, similar trends were observed. Treatments with omitted K, Ca, and Mg were closest to the complete treatment, with Mg not differing statistically. Treatments with omissions of N, P,

Source: author.

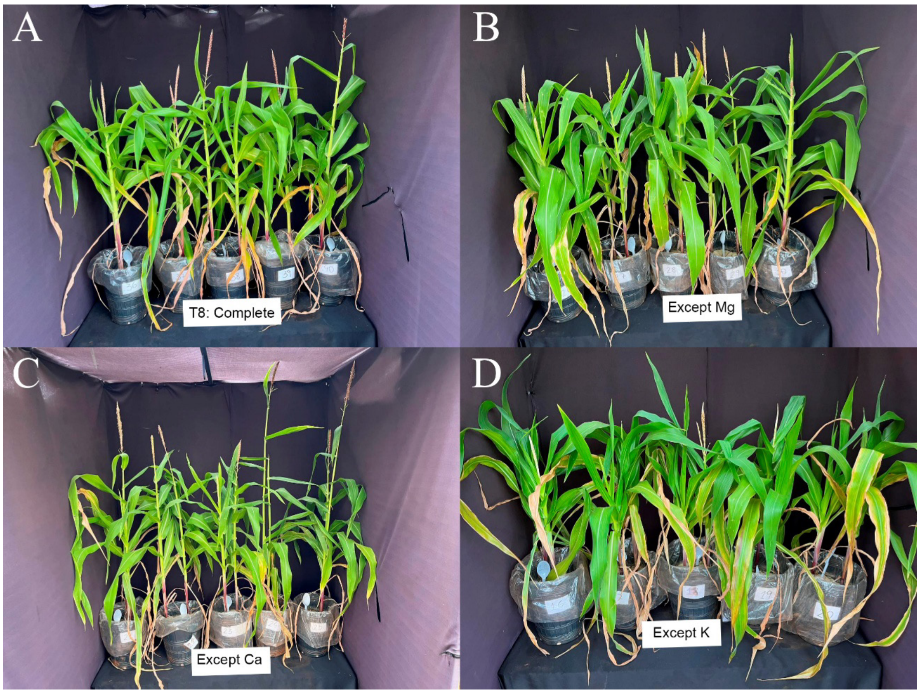
Figure 6. Visual comparison 80 days after plant emergency of without magnesium (center) on corn, compared to the control (left) and complete treatment (right).

Source: author.

Figure 7. Visual comparison 80 days after plant emergency of without sulfur (center) on corn, compared to the control (left) and complete treatment (right).

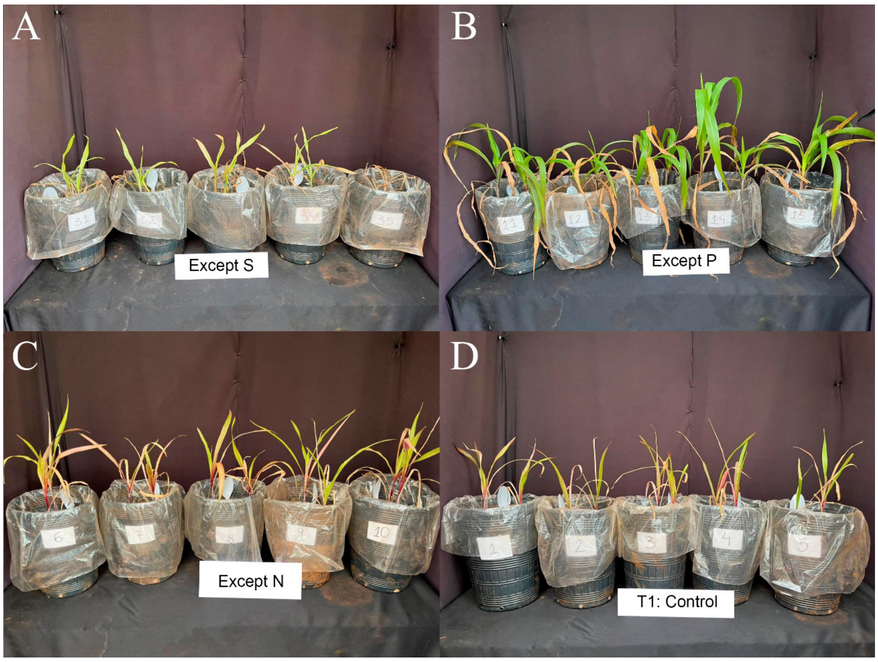
and S produced the least mass and did not differ from the control. Even the most notable treatments had relatively low biomass production.

Similar studies, such as those by Gondim,[12] report significant reductions in both shoot and root mass for all macronutrients, highlighting differences in effects between root and shoot biomass.



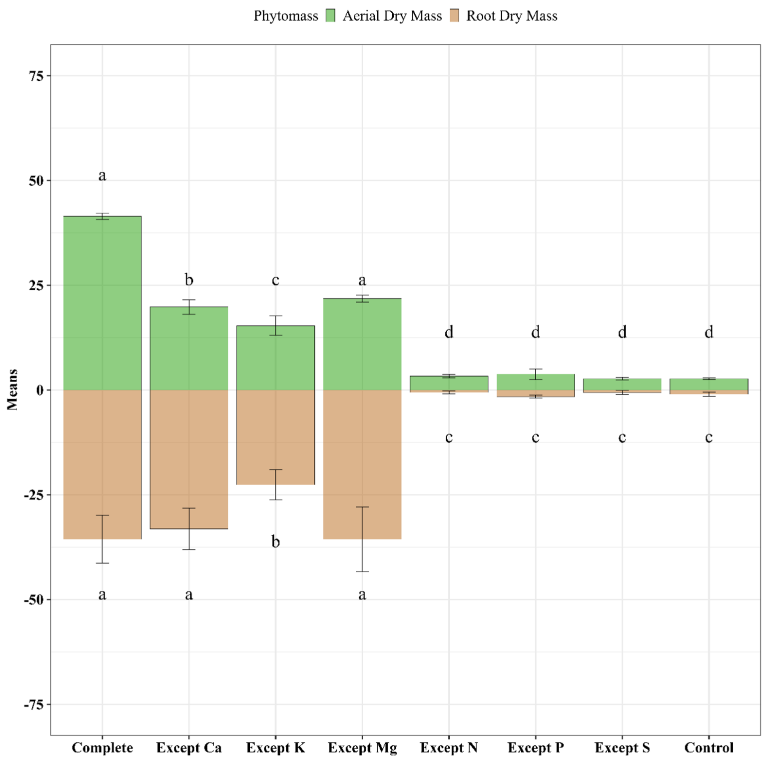
Source: author.

Figure 8. Overview of treatments 80 days after plant emergency: Complete (A), Except Magnesium (B), Except Calcium (C), and Except Potassium (D).



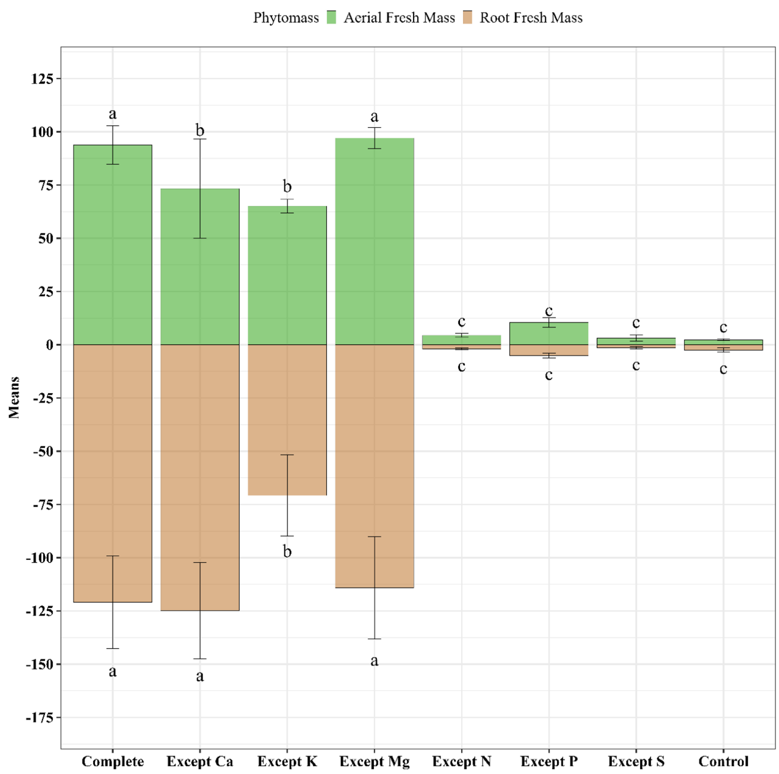
Source: author.

Figure 9. Overview of treatments80 days after plant emergency: Except Sulfur (A), Except Phosphorus (B), Except Nitrogen (C), and Control with Total Omission (D).



** Columns followed by the same uppercase letter do not differ statistically from each other by the T (LSD) test at a 5% probability level. C.V.% Dry Mass Aerial Part = 11.08; **C.V.% Dry Mass Root = 24.11.

Figure 10. Graph of dry mass for the aerial part and dry mass for the root.



** Means followed by the same uppercase letter vertically do not differ statistically from each other by the T (LSD) test at a 5% probability level. C.V.% Fresh Mass Aerial Part = 20.88; **C.V.% Fresh Mass Root = 28.93.

Figure 11. Graph of fresh mass for the aerial and fresh mass for the root of corn under macronutrient omission effects.

CONCLUSIONS

N, P, and S are crucial for corn growth. The omission of these nutrients had a significant impact, resulting in the lowest values for all evaluated variables, particularly biomass accumulation and plant height. In contrast, the omission of Ca, K, and Mg had a moderate effect, with results statistically similar to the complete treatment (T8).

The study highlights that each nutrient plays a distinct role and impacts the crop cycle differently. Even nutrients with moderate effects resulted in observable differences compared to well-nourished plants, underscoring the importance of maintaining the correct balance of nutrients N, P, K, Ca, Mg, and S.

Finally, the experiment proved highly valuable in demonstrating nutritional deficiency symptoms to students in the Fertility and Fertilization course. Besides observing the characteristic visual symptoms, they also witnessed the impact on the corn crop cycle.

ACKNOWLEDGEMENTS, FINANCIAL SUPPORT AND FULL DISCLOSURE

We would like to thank the Postgraduate Program in Agronomy (PPAGRO/UENP) for the support and structure provided for this study.

AUTHOR CONTRIBUTIONS

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