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Evaluation of the omission of nutrients in the mineral development and composition of young cupuaçuzeiro plants (*Theobroma grandiflorum* (Willd. ex Spreng.) Schum.) progeny 61

Avaliação da omissão de nutrientes no desenvolvimento e composição mineral de plantas jovens de cupuaçuzeiro (*Theobroma grandiflorum* (Willd. ex Spreng.) Schum.) progênie 61

Evaluación de la omisión de nutrientes en el desarrollo y composición mineral de plantas jóvenes de la progenie de cupuaçuzeiro (*Theobroma grandiflorum* (Willd. ex Spreng.) Schum.) 61

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Abstract

Include the abstract in English. (TNR font 10 – simple space) The objectives of the study were to evaluate the fertility of the Yellow Latosol medium texture in plants of cupuassu (*Theobroma grandiflorum*) progeny 61 and to characterize the visual symptoms of macronutrient and micronutrient deficiencies. The plants were grown in nutrient solution containing all macronutrients and micronutrients and in solutions with omission of N, P, K, Ca, Mg, S, B, and Zn, using the missing element technique. The experimental design was completely randomized with eleven treatments and five replications. Growth was evaluated through production and dry matter at 60 days after planting. The progeny showed market potential, as it is more productive than the others, but it presents nutritional requirements similar to those of the cultivars already studied. The nutrient required in greater quantities by the culture was nitrogen, but the omission, but limiting, was that of potassium for biometric variables. The best treatment was complete followed by omission of zinc, but the difference between them was significant. The levels of nutrients in the leaves were similar to those found by other authors in other cultivars. The decreasing order of treatments was C> Zn> T> N> P> Ca> Mg> S> B> K.
Keywords: Theobroma grandiflorum; Fruit growing; Nutritional deficiency.

Resumo

Os objetivos do estudo foram avaliar a fertilidade do Latossolo Amarelo textura média em plantas de cupuaçuzeiro (*Theobroma grandiflorum*) progênie 61 e caracterizar os sintomas visuais de deficiências de macronutrientes e micronutrientes. As plantas foram cultivadas em solução nutritiva contendo todos os macronutrientese micronutrientes e em soluções com omissão de N, P, K, Ca, Mg, S, B, e Zn, utilizando a técnica do elemento faltante. O delineamento experimental foi inteiramente casualizado com onze tratamentos e cinco repetições. Os crescimento foi avaliado através a produção e matéria seca aos 60 dias após o plantio. A progênie mostrou potencial de mercado, pois é mais

produtiva que as demais, porém apresenta exigência nutricional semelhante as das cultivares já estudadas. O nutriente exigido em maiores quantidades pela cultura foi o nitrogênio, porém a omissão, mas limitante foi a do potássio para as variáveis biométricas. O melhor tratamento foi o completo seguido da omissão de zinco, porém a diferença entre ambos foi significativa. Os teores de nutrientes nas folhas foram semelhantes aos encontrados por outros autores em outras cultivares. A ordem decrescente dos tratamentos foi C>Zn>T>N>P>Ca>Mg>S>B>K.
Palavras-chave: Theobroma grandiflorum; Fruticultura; Deficiência nutricional.

Resumen
Los objetivos del estudio fueron evaluar la fertilidad de la textura media de Latosol Amarillo en plantas de cupuaçuzeiro (Theobroma grandiflorum) de la progenie 61 y caracterizar los síntomas visuales de las deficiencias de macronutrientes y micronutrientes. Las plantas se cultivaron en una solución nutritiva que contenía todos los macronutrientes y micronutrientes y en soluciones con omisión de N, P, K, Ca, Mg, S, B y Zn, utilizando la técnica del elemento faltante. El diseño experimental fue completamente al azar con once tratamientos y cinco repeticiones. Se evaluó el crecimiento mediante producción y materia seca a los 60 días después de la siembra. La progenie mostró potencial de mercado, ya que es más productiva que las demás, pero tiene un requerimiento nutricional similar a los cultivares ya estudiados. El nutriente requerido en mayor cantidad por el cultivo fue el nitrógeno, pero la omisión, pero limitante, fue el potasio para las variables biométricas. El mejor tratamiento fue completo seguido de omisión de zinc, pero la diferencia entre ellos fue significativa. Los niveles de nutrientes en las hojas fueron similares a los encontrados por otros autores en otros cultivares. El orden decreciente de tratamientos fue C> Zn> T> N> P> Ca> Mg> S> B> K.
Palabras clave: Theobroma grandiflorum; Cultivo de frutas; Deficiencia nutricional.

1. Introduction

Brazilian agrobusiness has shown strog growth in the last decade, occupying a relevant part of Brazilian GDP. Within the agricultural activity, fruit production was the most prominet sector (Balanço, 2018). Currently Brazil is the third largest fruit producer in the world, behing only China and India, respectively, however, the brazilian insertion in the foreign marketis still inexpressive, mainly in the the case of tropical fruits (CEPEA, 2020; Mota et al., 2020).

The tropical fruticulture is one of the activities with a high national perspective, since Brazil has favorabel ecological conditions in terms of climate, availability of considerabel areas, in addition to high cultural yields, which is superior to other products of brazilian agribusiness, thus showing its market potencial (Gerum et al., 2019).

The cupuaçuzeiro is a tropical fruit native to the Amazon that was initially planted as a backyard crop and over the past few dacades has emerged as one of the best and most promissing in the region (Clement et al., 2010). Its fruit measures 12 to 15 cm in length and 10 to 12 cm in diameter, with na average weight of 1 kg, 30% of pulp and 35 seeds, the hoop can be used to make ice cream, juices, jellies, sweets and yorguts, and seeds, to produce a great quality product, similar to chocolate (Lorenzi et al., 2006).

In order to achieve adequate production, attention must be paid to the diferents aspects that make up the production process, among them: an adequate fertilization program, given that the optimization in the use of inputs aiming at the nutricional efficiency ando f great importance in the crop cycle, being essencial for the productivity increase (Roy et al., 2017; Costa, 2020).

Silva et al. (2010) enphasize that the elaboration of fertilization programs must be proceded by the knowledge of the consequences of mineral deficiences on the growth and development of plants, for that, tests are carried out with the technique of the missing element, being possible to determinate the limiting nutrientes for the development os species on any type of soil (Viégas et al., 2005).

Based on this, some researchers seek to remedy the existing gaps in the field of soil fertility in the Amazon region, researching the nutritional needs of the main crops for the region (Lima et al., 2018; Silva et al., 2018; Silva et al., 2020; Mera et al., 2020; Viégas et al., 2020; Tanaka et al., 2020; Silva et al., 2020; Silva et al., 2020; Lima et al., 2020).

Based on the scenario presented, the objetivo of the research was to evaluate the growth and nutricional status of cupuaçu plants (*Theobroma grandiflorum*) progeny 61.

2. Methodology

The experiment was carried out in greenhouse at Embrapa Amazonia Oriental located in the city of Belém in the state of Pará at na altitude of 10 m. the region's climate, according to the Köppen classification, is equatorial Af, with na average annual temperature of 26° C, average annual rainfall of three Thousand millimeters and relative humidity of around 90% (Pereira et al., 2017)

Cupuaçuzeiro seeds from progeny 61, developed by Embrapa Amazônia Oriental, were sown in seedlings that contained black Earth and tanned sawdust as substrate. After they geminate and reach to toothpick point, they were transplanted into polyethylene bags with dimensions of 35 x 18 cm x 0,20 mm pl with a capacity of 5 kg, having as substrate the TADS (thin air-dried soil) of yellow latosol collected at Embrapa Amazônia Oriental headquarters which was sieved in 4mm mesh and sent for analysis, resulting in:

Table 1. Result of soil analysis.

Prof.	**OM**	**P**	**K**	**Na**	**Al**	**Ca**	**Ca+Mg**	**pH**	**Sand Coarse**	**Thin Sand**	**Silt**	**Total Clay**
cm	*g kg^{-1}*	......*mg dm^{-3}*.......			.........*cmol$_C$ dm^{-3}*..........			*H_2O*	....................*g kg^{-1}*.....................			
0-20	13,84	5	10	4	1,5	0,2	0,3	4,3	345	410	126	120

Source: Authors.

The experimental design was completely randomized (DCR), containing tem treatments, wich are: complete (all nutrientes), nitrogen omission (-N), phosphorus omission (-P), potassium omission (-K), magnesim omission (-Mg), calcium omission (- Ca), omission of sulfur (-S), omission of boron (-B), omission of zinc (-Zn) and the control (without nutrient application).

After 45 days of transplatation, mineral fertilizer was applied in the posts according to each treatment and with the technique of the missing elemento, using the following doses and sources:

Table 2. Doses applied in treatments and their respective source.

Nutrient	Dose	Source
N	100 mg kg-¹ of soil	Urea
P	50 mg kg-¹ of soil	Monosodium phosphate
K	90 mg kg-¹ of soil	Potassium chloride
Ca	30 mg kg-1 of soil	Calcium chloride
Mg	30 mg kg-1 of soil	Magnesium chloride
S	7,5 mg kg-¹ of soil	Sodium sulphte
B	1,2 mg kg-¹ of soil	Bporic acid
Cu	1,0 mg kg-¹ of soil	Copper sulfate
Mn	4 mg kg-¹ de soil	Sulfato de manganês
Zn	5 mg kg-¹ of soil	Zilc sulfate

Source: Authors.

The nitrogen and potassium fertilizers were divided into three applications, the first 45 days after transplantation, the second after 90 days and the third after 150 days. For magnesium, two applications were made due to sensitivity of the culture to the deficiency of this nutrient (Cravo & Souza, 1996). The plants were irrigated daily, in order to maintain humidity around 80%.

During the seven months of the experiment, biometric analyzes of plants height, stem diameter, number and dimensions (length and width) of leaves were performed. After the last biometric measurement, the plants were photographed and their parts were broken up, packed in paper bags, identified and and taken to a force circulation oven with na average temperature of 70º C until a contant dry mass is obtained; afterward the parts were ground in a Willey type mil to later determine nutrient detectors.

The biometric analyzes were submitted to Dunett's test with the assistence of Assistat program. The Dickson's quality index was calculated (Dickson et al., 1960), wich is determinated according to the total dry mass (TDM), heigt of the aerial part (HAP), the diameter of colon (DIAM), phitomass of aerial plant (PMAP) wich is given by the sum of dry phitomass of the collection (PMC) and dry leaf phitomass (DLP) and dry root phitomass (DRP), using the formula:

$$IQD = \frac{MST(g)}{\frac{ALT(cm)}{DIAM(mm)} + \frac{MSPA(g)}{MSR(g)}}$$

For the elaboration of graphs, the methodology proposed by (2005). This consists of the standardization of the means found in the Dunett test in function of the different omissions, through the expression:

$$Z_{ij} = (\bar{y}_j - \bar{y}_{.j}) / s_{.j}$$

Where **Zij** is the rate of development of the biometric variable in each treatment; ***y jis*** the mean of the biometric variable **i** in omission **j**; ***yj*** is the mean of variable as a function of all the omissions **j, *sj*** is the stanard deviation of the biometric variables as a function of the omissions. This standardization was performed for each biometric variable using the

Dunett test means using the R language, a Spearman correlation matrix with biometric atributes and a cluster with nutrient contentes using the *python* language were also developed.

3. Results and Discussion

3.1 Biometric Analyzes

Figure 1 shows the values of Spearman's correlation coefficients for the biometric variables analyzed during the experimente. It is inferred that, in general, there are positive correlations between most componentes; however, although positive, they are low, showing and interdependence between them.

Figure 1. Spearman's correlation coefficient for cupuaçuseiro biometric variables.

Source: Authors.

According to Vieira (2010) positive values in one Spearman's correlation indicate that high points of one variable correspond to high points of another coma to which it correlates, so that the association between these is considered weak when it obtains values equal to or less than 0.30, moderate when between 0.30 and 0.70, and strong when greater than 0.70.

From the Spearman coefficient, it can be inferred that the stem diameter attribute of plants influences the weight of total dry matter more than their height. The weight of the sample root is inversely correlated with the width of the leaf, that is, in this case, larger leaves imply less weight of dry root mass.

Observing the answer obtained by the Dickson Quality Index (IQD), it is possible to infer that, among all the biometric variables analyzed, the dry mass of the roots and the total dry mass present the highest values, showing the strong correlation between these variables not only on IQD, but also on height, diameter and number of leaves, the latter being a moderate correlation; on the other hand, the leaf width attribute has an inverse correlation with the 1QD. Binotto (2007) and Evaristo etal. (2020) in experiments with forest species, described observations similar to those obtained in the present study.

Regarding the influence of diet treatments on the growth of plant response, after applying the Dunett test, it was inferred that, with the exception of denitrogen omission in the plant height, the other omissions limited the development of the progeny61 when compared to the complete treatment (Table 3).

The nutrients that were more limiting in the height of the plants were Mg, Ca and P.Gomes (2002) and Silva et al. (2011) emphasize that, among the many biometric variables, plant height is a very relevant characteristic c to estimate the quality standard of nurseries, besides being easy to measure, therefore, it has always been used efficiently.

Table 3. Biometric data of cupuaçuzeiro progeny 61, depending on the treatments.

Treatments	Hight (cm)	Diameter (cm)	Núm. of Leaves	Size of Leaves
Complet	46,37	9,84	26,00	200,25
Witness	42,25 -	9,43 ns	11,00 -	112,50 -
Omission of N	50,75 +	9,69 ns	10,75 -	160,62 -
Omission of P	35,25 -	8,05 -	9,00 -	138,75 -
Omission of K	38,50 -	6,85 -	10,50 -	154,00 -
Omission of Ca	33,00 -	9,62 ns	8,75 -	130,50 -
Omission of Mg	32,00 -	7,22 -	11,25 -	197,75 ns
Omission of S	44,75 ns	8,02 -	9,75 -	206,62 ns
Omission of B	36,25 -	7,57 -	14,00 -	176,50 ns
Omission of Zn	44,75 ns	9,74 ns	17,50 -	180,00 ns
DMS	3,91	1,66	4,16	38,13
CV%	4, 79	9,55	16,01	11,38

"+" Significant and superior to the complete treatment; "-" Significant and inferior to the complete treatment; "Ns" Not significant, by Dunnett's test, at a 5% probability level.
Source: Authors.

The absence of the magnesium nutrient resulted in a 31% reduction in plant height.

This nutrient plays an important role in the activity of many enzymes, especially those that act in the photosynthesis and respiration of plants (Marschner, 2012). Therefore, the reduction of magnesium, consequently, leads to losses in photosynthesis, an important physiological process by which plants synthesize organic compounds (Mareco et al., 2015), which, finally, negatively affects the growth of plants.

The second nutrient that most affected plant height was calcium, causing a reduction of 28% and the third was phosphorus, with a reduction of 24%. Both calcium and phosphorus are nutrients highly required by plants (Li et al., 2013;

Evaristo et al., 2020), Natale et al. (2005) and Maia et al. (2015) describe that its absence limits growth and promotes physiological changes and disorders in plants, as they are part of important metabolic and structural processes.

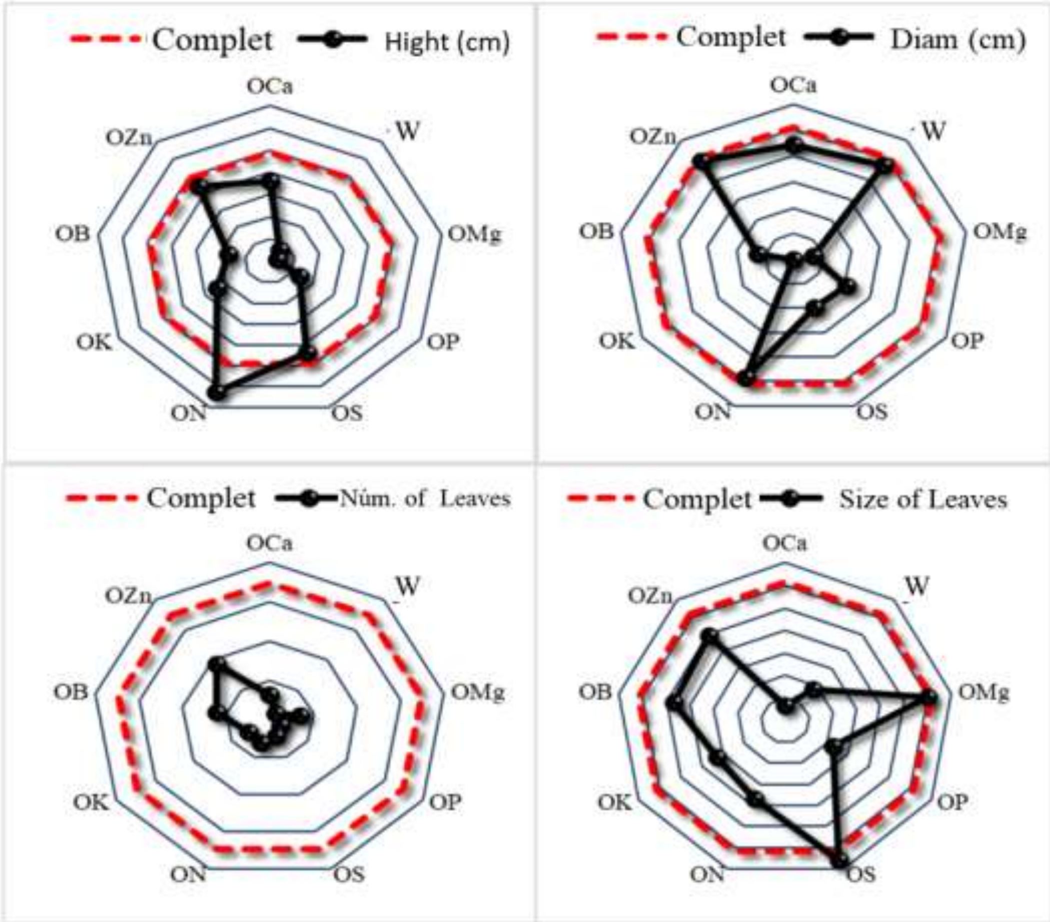
Regarding the stem diameter, the treatments that most impaired the development of the plants were the omissions of K, Mg and B. The omission of potassium generated a reduction of 30% because this nutrient is required in large quantities by the plants (Niu et al., 2013). Such an effect was expected, given that this nutrient is of paramount importance for maintaining electro neutrality, acting free in plant tissue, or linked to compounds produced in photosynthesis (Marschner, 2012)

The omission of the magnesium nutrient also significantly affected the stem diameter of the progeny, with a reduction of 27%; sequentially, the micronutrient boron appears with a 23% reduction in diameter. Silva et al. (2017) describe magnesium as a central component of the chlorophyll molecule and of extreme importance in processes involving plant energy metabolism; on the other hand, boron is related to the structure of the cell membrane and the metabolism of polysaccharides and nucleic acids (Marschner, 2012).

The other two variables evaluated were the number and size of leaves whose most limiting nutrients were calcium and phosphorus, with a reduction of 44% and 33%, respectively, Rodrigues et al (1993) characterized the symptoms of calcium deficiency as, among others, deformation and reduction in the number and size of leaves and chlorosis. Results similar to those obtained with this experiment were exposed by Barreto et al. (2017) and Coelho et al. (2020).

To demonstrate the development of each variable, the polar graph was applied, which presents the biometric data inherent to the variable in each omission compared to the reference value (complete treatment) (Nunes et al., 2005). In Figure 2 it is possible to infer a wilted ball behavior, that is, the treatment rates were lower than the reference value (complete treatment) showing that, for these variables, the total application of nutrients was more efficient than the other treatments.

Figure 2. Graphical representation of the biometric variables Height (Alt), Stem diameter (Diam), Number (Number of leaves) and Leaf size.



Source: Authors.

In Figure 2, it is possible to observe that, of all biometric variables, the number of leaves was the one that most distanced from the reference value, and it can be concluded that this biometric aspect was the one that suffered most severely the consequences resulting from the omissions of nutrients.

Biometric variables, such as: dry phytomass of the root system and dry phytomass of the aerial part, are the most used in determining the quality standard of seedlings (Binotto, 2007), therefore, in Table 4 it is possible to observe that the complete application of nutrients significantly increased the dry matter production of all parts of the plant, causing a significant gain in the weight of the dry leaves.

Table 4. Leaf dry mass (LDM), stem dry mass (SDM), root dry mass (RDM), total dry mass (TDM) and Dickson index (DI) in cupuassu plants progeny 61, depending on the treatments.

Treatments	LDM (g)	SDM (g)	RDM (g)	TDM (g)	DI
Complet	15,65	14,66	13,57	43,89	6,31
Witness	7,39 -	9,30-	9,28 -	25,98 -	4,13 -
Omission of N	6,27 -	10,08-	8,45 -	24,81 -	4,94 -
Omission of P	5,76 -	11,10-	9,80 -	22,68 -	3,70 -
Omission of K	6,18 -	7,39-	5,41 -	18,99 -	4,00 -
Omission of Ca	5,91 -	6,19-	10,43 -	22,54 -	2,34 -
Omission of Mg	8,20 -	4,90-	8,81 -	21,92 -	3,47 -
Omission of S	6,88 -	7,88-	5,13 -	19,90 -	2,31 -
Omission of B	7,44 -	5,42-	6,75 -	19,63 -	2,92 -
Omission of Zn	12,01 -	12,95-	9,30 -	34,27 -	4,63 -
DMS	1,72	2.04	2,36	3,71	1,07
VC%	10,95	11.25	13,45	7,21	13,65

"+" Significant and superior to the complete treatment; "-" Significant and inferior to the complete treatment; "Ns" Not significant, by Dunnett's test, at a 5% probability level.
Source: Authors.

The most limiting omissions were similar to the results obtained on the size and quantity of leaves, thus showing that the production of the leaf area of the progeny 61 is extremely limited in the absence of nutrients P <Ca <K. A similar report was described by Silva et al. (2005) in umbuzeiro (Spondias tuberosa). According to Pedreira and Mello (2001), about 90% of the dry weight of plants consists of compounds from the biological fixation of atmospheric CO_2 and transformation into carbohydrates to be used in the synthesis of tissues, as an energy source and translocated to the different parts of the plant. In conditions of low levels of P, a reduction in the photosynthetic rate occurs (Sempiterno et al., 2020).

The dry mass variable of the stem was most affected by the omission of nutrients Mg <B <Ca. Magnesium is essential for the normal development of plants and its deficiency limits plant growth, so it is not unexpected that its deficiency causes a reduction in the growth of the aerial part, stem and root (Cakmak, 2013).

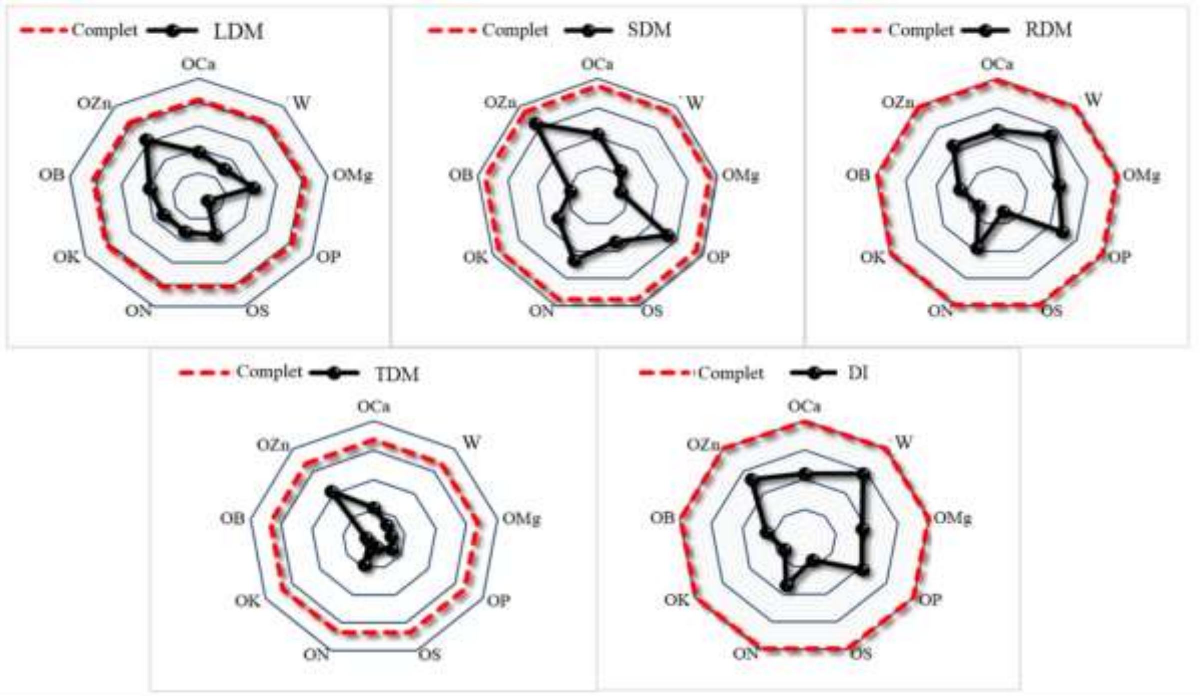
The dry mass of the roots was reduced in all treatments, except the complete one, the most severe limitations were with S <K <B in relation to the complete one. Sulfur participates in the structure of essential amino acids and its deficiency interrupts the synthesis of proteins and sugars. There is also an accumulation of organic N- and N-NO_3, resulting in plants of smaller size and number of leaves (Maia et al., 2015).

The total dry mass, which is the sum of all dry parts of the plant, revealed that the most harmful omissions were K <B <S, when compared to the complete treatment. Through Dickson's quality index, the seedlings that obtained the highest

indexes, as expected, were submitted to complete treatment, all omissions reduced the seedling quality in the following increasing order S <Ca <B <Mg <P <K <T <Zn <N <C.

In Figure 3, it is possible to infer that the variables had a lower performance when nutrients were omitted. It is also noted that the weight of the dried leaves was the most affected by the omissions, presenting the most distant rates of the complete treatment. This aspect can be justified by the previous results where the omissions limited the production of leaves that ended up impacting the weight.

Figure 3. Graphical representation of the variables dry mass of the leaf, stem, root, total and Dickson index in cupuaçuzeiro progeny 61 depending on the treatments.



Source: Authors.

3.2 Symptoms Of Deficiencies.

3.2.1 Nitrogen

In Figure 4, it can be seen that the omission of the nutrient nitrogen caused chlorosis followed by necrosis at the edges of the older leaves, also the omission of nitrogen reduced the plant height and root growth when compared to the complete treatment. This symptom is due to the insufficiency of this element in the plant moving from the older leaves and organs to the younger ones, consequently the old leaves start to show a light color (Malavolta et al., 2006; Santos et al., 2019).

3.2.2 Phosphorus

The cupuaçu leaves subjected to induced phosphorus deficiency (Figure 4) showed a dark green color, reduced plant height and less root development. According to Taiz and Zeiger (2013), just as it can occur in N deficiency, some species under P deficiency can produce excess anthocyanins, giving the leaves a slightly purple or dark green color. This is because the deficiency of P causes the inhibition of carbohydrate synthesis, thus increasing the levels of sugars, causing it to stimulate the synthesis of anthocyanin (Marschner, 2012).

3.2.3 Potassium

Plants that received nutrient solution with potassium omission (Figure 4) showed yellowing followed by necrosis at the edges of the leaves and also reduced growth, as well as their roots. Chepote et al. (2013) and Santos et al. (2019) described similar symptoms, where the leaves initially had chlorosis and necrotic spots of the older leaves, whose progression occurs from the edges towards the center, together with this reduction of the emission of new roots. According to Calmak (2005), potassium is the most abundant cation in plant tissue, having several physiological functions, among them: cell elongation, stomatal resistance and influence on photosynthetic rate.

3.2.4 Calcium

The omission of calcium (Figure 4) caused deformation in the leaves, less height and reduced development of the roots. The Ca's functions are related to the coordination capacity, promoting stability and reversible intermolecular bonds, predominantly in the plasma membrane and in the cell wall (Marschner, 2012).

3.2.5 Magnesium

Interneval chlorosis was identified in the leaves of plants where Mg was omitted (Figure 4), in addition to leaf chlorosis, plants subjected to magnesium omission showed reduced growth when compared to complete treatment and low root development. Similar nutritional disorders have been described by Almeida et al. (2011) and Santos et al. (2019).

3.2.6 Sulfur

Plants subjected to sulfur omission (Figure 4) did not present well-defined symptoms of visual impairment, only a slight loss of green color. In the roots the volume was reduced with the omission of sulfur. The symptoms of sulfur deficiency are similar to that of nitrogen, however, as the S is not very mobile in the phloem, the symptoms appear in the youngest leaves, without such a symptom picture similar to that described by Morocco et al. (2010).

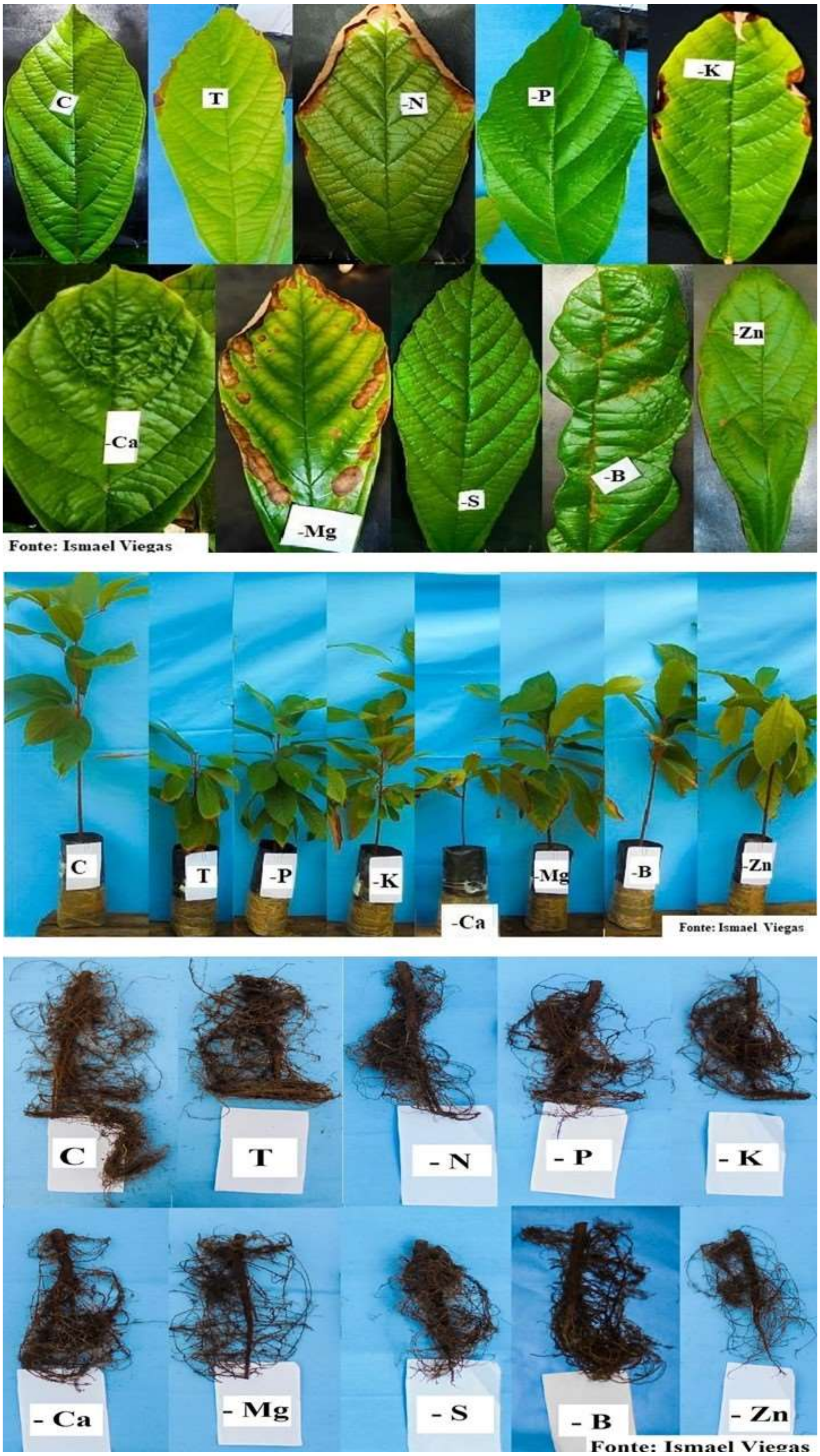
3.2.7 Boron

In Figure 4, it can be seen that the main symptom of boron deficiency was deformation. Ramos et al. (2009) and Chepote et al. (2013), observed similar symptoms in other cultures. This effect on the morphology of the fruit is due to the action of B in the structuring of the cell wall and in the functionality of the plasma membrane (Del; Huang, 1997).

3.2.8 Zinc

In Figure 4 the plants with zinc deficiency showed elongation, deformation and chlorotic and necrotic spots on the leaves. Among the characteristics commonly reported in the literature, there is a reduction in the growth of internodes and elongated leaves. This occurs because this nutrient participates in functions essential to metabolism and hormonal functions responsible for plant growth (Toledo, 2017).

Figure 4. Symptoms of nutrient deficiencies (-N, -P, -K, -Ca, -Mg, -S, -B and -Zn) in Cupuassu leaves, plants and roots, progeny 61, compared to treatment complete (C) and control (T).



Source: Authors.

3.3 Nutrient content and interaction

For the visual representation of nutrient contents and their relationship with treatments, dendrogram representation was used, a graphic model where each branch represents an element, while the root represents the grouping of all elements, so that, the more distant, the lower the degree of similarity between groups (Yokomizo et al., 2020).

Analyzing the treatments in Figure 5, it is possible to notice that there is the formation of a chain, a situation where there is an initial group of one or more elements that starts to form, at each iteration, a new group of only one element, becoming it is difficult to define a cut-off level to classify the elements in groups (Doni, 2004).

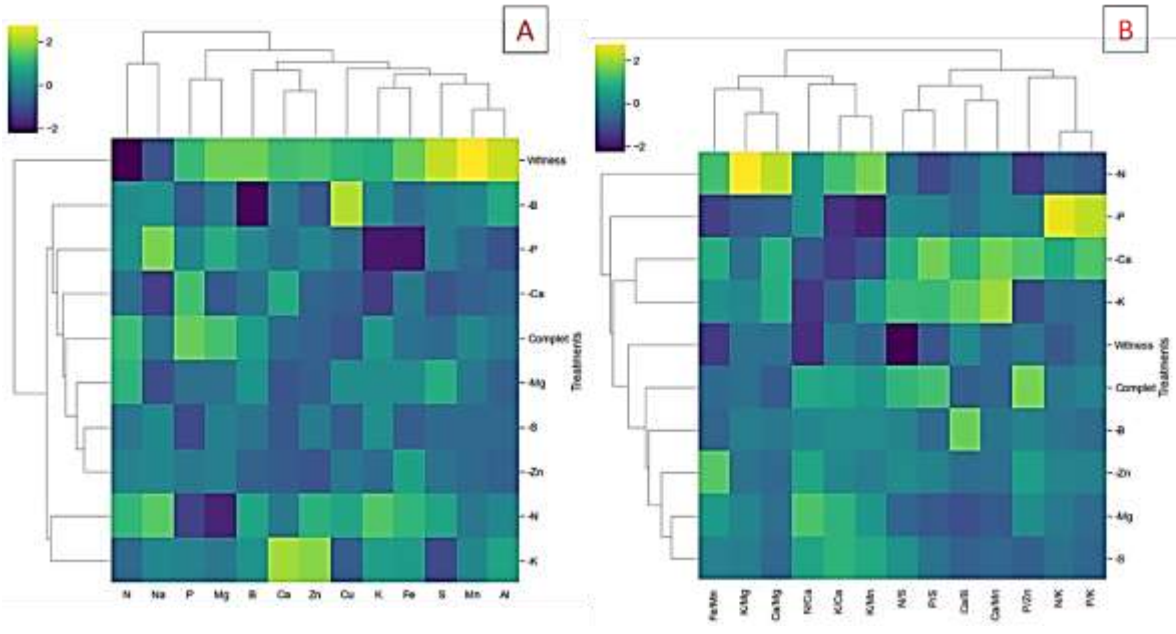
Thus, 5 different groups can be distinguished (Figure 5a): the nutrients N and Na were the ones that were most distant from the others, after this we have the second cluster that is composed of P and Mg, the third formed by B, Ca and Zn, the latter two having the lowest Euclidean distance within this group. The fourth cluster was composed of K and Fe and the fifth and last cluster is formed by S, Mn and Al, the latter two being of shorter Euclidean distance.

Within the cluster (Figure 5a) it can be seen that the control treatment showed the highest levels and the nutrients that stood out the most were Mn, S, Al, Mg and B. In addition, the elements Mn and Al were the ones that presented shorter Euclidean distance, indicating greater proximity between both. While the nutrient nitrogen was the most affected by the omission of nutrients, among all this treatment was the most unbalanced.

On the other hand, with respect to interactions between nutrients (Figure 5b), two distinct groups were formed: those mostly formed by interactions with Ca, Mg or Mn and those mostly formed by other interactions. Regarding the treatments, there was also the division into two large clusters where one is composed of the omissions of N, P, Ca and K, this group being the most influential in the contents of the omissions, causing greater imbalance, since the other cluster is composed by the treatments T, Complete, Omission of B, Zn, Mg and S, this grouping is what causes smaller unbalances in the relationships.

Regarding the first cluster (interactions with Ca, Mg and Mn), Andrade (2019) in an experiment with orange trees, discusses the interactions between these three nutrients, so that the greater presence of one leads to less absorption of the other (Ca / Mg and Ca / Mn) being described as competitive inhibition, or in cases where the deficiency of one nutrient can lead others to deficiency (Mg / Mn).

Figure 5. Hierarchical distribution(cluster) of leaf nutrient contents (a) and their interactions (b) in the different treatments.



Source: Authors.

Considering the leaf contents alone, the treatment with the highest N content was the complete one with 25.78 g / kg, on the other hand, the control and the treatment with N omission, which proved to be the most unbalanced in the relationships, presenting high contents in the K / Mg and Ca / Mg ratios and very low levels in the P / Zn and P / S ratios, showed a reduction of 17% with the N content of 21.45 g / kg and of 36% with the content of 16.47 g / kg, respectively. These results differ from Alfaia and Ayres (2004) and Schroth et al. (2001) whose observed levels vary between 15.7 and 18.5 g / kg. However, this difference can be explained by the presence of natural nitrogen in the soil of the present test, so that, when there was an increase in more nitrogen, the levels of the other treatments increased.

The complete treatment was the one that showed to be more balanced, without presenting extreme values for the relationships, such treatment increased the P / Zn and P / S ratio more and affected the Ca / Mg ratio more, the omission of B improved the B / ratio Ca, the omission of Zn improved the content of the Fe / Mn ratio, the omission of Mg increased the content of N / Ca and the omission of S increased the ratio of K / Ca, the latter omissions did not reduce the contents of the other relations.

In the relation between nitrogen / potassium, the treatment that favored most was the omission of potassium (10.09 g / kg) and the treatment that most reduced the content of the relationship was the omission of nitrogen with a content of 1.75 g / kg; nitrogen metabolism in plants requires adequate amounts of potassium in the cytoplasm (Xu et al., 2003), being important for the production of amino acids and crop productivity, with potassium involved in nitrogen metabolism stages in plants (Marschner, 2012).

The highest levels of phosphorus were obtained in the complete treatment 1.02 g / kg and the lowest were in the omission of magnesium with a 41% reduction with a content of 0.60 g / kg and calcium, with a 39% reduction and content 0.62 g / kg. Values similar to these were found by Costa (2006) also in cupuaçuzeiro plants. In the phosphorus / potassium ratio, the best value was obtained in the K omission (0.34 g / kg content) and the lowest in the Mg omission (0.06 g / kg), equally, in the phosphorus / zinc ratio, whose the best value was obtained in the complete treatment (12.14 g / kg) and the lowest, in the omission of Mg (5.11 g / kg), it is inferred the important participation of this third element in the interactions with phosphorus.

According to Ova et al. (2015), the interaction of phosphorus with zinc can affect the absorption, translocation and concentration of these nutrients in plant tissues, causing inadequate relationships between them; Andrade (2019) states that the lack of Mg can accentuate the deficiencies of Zn and Mn, and confer greater absorption of K, given that they compete for the same loader site.

The potassium contents were benefited by the omission of Mg presenting 10.63 g / kg, while the treatments with the lowest contents of this nutrient were the omission of K with a reduction of 72% in relation to the complete and 2.32 g / kg of content and the control with 3.73 g / kg and 55% reduction; Alfaia and Ayres (2004) found similar values in seedless cupuaçuzeiro leaves.

The omission of sulfur provided the highest foliar calcium contents, 4.93 g / kg, while the omission of calcium resulted in a content of 2.15 g / kg with a 15% reduction. The magnesium contents showed great variation between treatments, so that in the nitrogen omission there was the highest leaf content of Mg with 3.04 g / kg, while the magnesium omissions and the control presented the lowest values, 0.59 g / kg and 1.24 g / kg, respectively.

In the calcium / boron ratio, the omission of boron was the one that most increased the leaf content; the calcium / manganese ratio was benefited by the omission of sulfur, the treatments that most reduced the content of the ratio were the complete treatment, the omission of phosphorus and potassium. These relationships need great attention, as there is competition for the absorption sites, therefore, the proper relationship between them is essential to make the absorption of these elements maximum, since excess Ca can also reduce the absorption of K and Mg (Malavolta, 2006; Marschener, 2012).

The nitrogen omission caused the sulfur content to rise to 3.24 g / kg, showing an interrelation between both, whereas the treatment with sulfur omission conferred a content of 1.42 g / kg. One of the best definitions of the relationships between the elements of mineral nutrition in plants, especially with regard to nitrogen / sulfur, is cited by Malavolta (2006), with the definition that nutrients are related in an interactive way called synergy, where the presence one provides an increase in the absorption of another.

Similar to what happened with sulfur, the treatment that most contributed to the increase in the leaf boron content was the omission of N, resulting in 0.051 g / kg of content, whereas in the omission of boron, 0.023 g / kg of content was obtained. . The sulfur omission was the one that most elevated the leaf zinc content in the leaves, which was 0.136 g / kg, whereas the treatments that most reduced this content were the zinc omission, with 0.079 g / kg content, corresponding to 42% of reduction in relation to the complete treatment, and the omission of boron, with 0.081 g / kg of Zn leaf content.

The control treatment in general showed low levels in all relationships, especially in the N / S where the lowest content of the entire matrix occurred.

4. Conclusion

The progeny showed market potential, as it is more productive than the others, but it presents nutritional requirements similar to those of the cultivars already studied.

The nutrient required in greater quantities by the culture was nitrogen, but the omission, but limiting, was that of potassium for biometric variables.

The best treatment was complete followed by omission of zinc, but the difference between them was significant.

The levels of nutrients in the leaves were similar to those obtained by other authors in other cultivars.

The decreasing order of treatments was C> Zn> T> N> P> Ca> Mg> S> B> K.

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