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Use of multi-dimensional scaling for analysis of teak plants (*Tectona grandis*) under omission of macronutrients

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Abstract

The aim of this study was to diagnose the deficiency symptoms and evaluate the production of dry matter, contents and accumulation of macronutrients in teak plants (*Tectona grandis*) grown on substrates with omission of nutrients using the multidimensional scaling analysis. The experimental design was completely randomized blocks with seven treatments with four replications as follows: treatment complete (C), and the individual omissions such as: zero levels of -N (omission of nitrogen), -P (omission of phosphorus), -K (omission of potassium), -Ca (omission of calcium), -Mg (omission of magnesium), -S (omission of sulfur). The statistical analysis model was Multivariate Multidimensional Scaling (MDS) using the statistical Software SPSS 17.0, which summarizes information and points the mechanisms of extreme use fullness. The results showed that omissions of macronutrients cause nutritional deficiency and visual symptoms known to other species as usual. The deficiencies restricted the dry matter production according to the following order: K > N > Mg > Ca > P > S. The leaf content of macronutrients in teak plants subjected to omission of nutrients compared to treatment resulted in complete change in the values as: N = 14.5-20.7 g kg^{-1}, P = 1.0-2.1 g kg^{-1}, K = 3.0-7.1 g kg^{-1}, Ca = 3.9-10.5 g kg^{-1}, Mg = 0.8-4.9 g kg^{-1}, and S = 1.5-2.1 g kg^{-1}. The multi-dimensional scaling analysis demonstrated that calcium, phosphorus and magnesium were limiting factors in the production of dry matter and in macronutrient contents, while nitrogen was accumulated mainly in leaves. Phosphorus and magnesium were accumulated in smaller amounts.

Keywords: mineral nutrition, nutritional deficiency, macronutrient content.
Abbreviations: C_treatment complete; -N_omission of nitrogen; -P_omission of phosphorus; -K_omission of potassium; -Ca_omission of calcium; -Mg_omission of magnesium; -S_omission of sulfur; LDM_leaf dry mass; SDM_stems dry mass; RDM_root dry mass; total TDM_total dry mass.

Introduction

Teak plant (*Tectona grandis*) is a deciduous tree species, belonging to the family Verbenaceae, where is originated from Southeast Asia (Troup, 1921). Due to its high commercial value (Lukmandaru and Takahashi, 2008), it is a good alternative to wood production in the Amazon region, in order to fulfill reforestation which has become a challenge for users of the raw material in timber industry.

This forest species has good indication for reforestation in Brazil, being a promising alternative for investment (Finger et al., 2001). The worldwide production of teak wood is estimated about three million m^3 yr^{-1}, which extremely low production as compared with the current demand of species in the overseas timber market.

Apart from high demand in the domestic and international market, teak plays an important role in the protection and improvement of soils of hilly relief and controlling surface erosion, due the rapid growth and high annual nutrient input on the soils (Barroso et al., 2005). However, fast-growing species exhibit a high rate of ion absorption by plant and a large increase in the rate of absorption, in response to increased external nutrient concentrations, compared to species of slow growth (Aerts and Chapin III, 1980).

Due to the lack of studies on the absorption of nutrients and nutritional requirements of teak plants, we are not able to define the appropriate management of fertilization and nutrient demands of this crop as a widespread cultivation in the Amazonian region. According to Skrebsky et al. (2008), the knowledge of physical and chemical limitations of soil and nutritional and physiological requirements of the species is fundamental to the economic and environmental feasibility including plant in the agricultural production system.

A fast and economical alternative technique to detect the nutritional requirements of a species is utterly missing (Moretti et al., 2011). In the present study, the current technique involves the growth of a plant under field conditions or greenhouse (Marques et al., 2004a), which is tested in a full treatment (with all the necessary nutrients at optimal doses) and a series of treatments, in which the omission of a nutrient is made each time.

According to Laviola and Dias, (2008) and Miranda et al. (2010), the missing element technique is an alternative to provide qualitative information about the nutrients that can limit plant growth. Several studies have been conducted with different species using the missing element technique (Barroso et al., 2005; Skrebsky et al., 2008; Fernandes et al., 2013; Viégas et al., 2008, 2012, 2013).

The aim of this study was to diagnose the deficiency symptoms and evaluate the production of dry matter, contents and accumulation of macronutrients in teak plants (*Tectona grandis*) grown on substrates with omission of nutrients using the multidimensional scaling analysis.

Results and Discussion

Visual symptoms emerged by nitrogen (N) deficiency

The symptoms of nitrogen deficiency in teak plants (*Tectona grandis*) were the second in order of appearance. Symptoms initially started in older leaves, which showed a gradual loss of color, becoming pale green and, in progress, the leaf blades became yellowish (Fig. 1b). With the omission of nitrogen, there was a reduction in plant height, number and size of leaves, compared to full treatment (C). This manifestation of symptoms is due to the role that nitrogen plays in plant as a constituent of chlorophyll molecule and many plant cell components, including proteins, amino acids and nucleic acids. It is one of the most nutrients required by plants. The yellowing of older leaves is characteristic of nitrogen deficiency, which is also observed in the studies by Freitas et al. (2011).

Consequences of phosphorus (P) deficiency in the plant

Symptoms of phosphorus deficiency appeared before sulfur and after the other macronutrients shortages. Older leaves exhibited dark green color and drastic reduction in plant height, compared to full treatment (Fig. 1c). There reduced growth under P deficiency is commonly known to many species, which is explained by the reduction of cell divisions (Chiera et al., 2002). The more intense green color of the leaves emerges due to the decrease in protein synthesis, when the phosphorus is deficient, resulting in an increased amount of sugars in the vegetative organs of the plant; thus, favoring the synthesis of anthocyanin in leaves (Mengel and Kirkby, 2001). The dark green colour of plants was also observed in clones of *Eucalyptus grandis* and *E. Urophylla* as a result of the omission of phosphorus (Silveira et al., 2002).

Visual symptoms promoted by potassium (K) deficiency

Potassium deficiency was the first to appear, indicating that teak plants are sensitive to this macronutrient deficiency. It was characterized by marginal chlorosis from the apex of older leaves, progressing toward the central part of leaf. With the progress, the chlorosis spread to entire surface of the leaf, followed by severe necrosis (Fig. 1d). Potassium deficiency also caused reductions in plant height and number of leaves, as well as fall of basal leaves. The effect of potassium, limiting plant growth, is due to the role it plays in protein synthesis and translocation of sugars, membrane permeability, and activities of various enzymes involved in respiration and photosynthesis processes required for the opening and closing of stomata. Chlorosis at the apex and margins of older leaves was also described by Rocha Filho et al. (1978) as symptoms of potassium deficiency in plants of *E. Urophylla.*

Consequences of calcium (Ca) deficiency in teak plant

Symptoms of calcium deficiency were manifested before phosphorus and sulfur and after potassium, nitrogen and magnesium. The omission of calcium (-Ca) resulted in abnormalities visible on younger leaves, characterized by very low and uneven growth, leaf distortion and curving of ventral surface in a "shell" shape (Fig. 1e). The lack of calcium causes a reduction in the growth meristematic tissue, observed initially in terminal buds and in young leaves (Mengel and Kirkby, 2001). Sarcinelli et al. (2004) studying *Acacia holicericeae* and Viégas et al. (2012) studying mahogany plants (*Swietenia macrophylla*) described visual symptoms of calcium deficiency similar to those noticed in this study.

Symptoms of magnesium (Mg) deficiency

Symptoms of magnesium deficiency were the third in order of appearance, after nitrogen. In older leaves, chlorosis interveinal in secondary ribs was observed, while remaining was green. As the process progressed the necrosis was occurred (Fig. 1f). This pattern of chlorosis occurs because the chlorophyll in vascular bundles remains unchanged for longer than chlorophyll in the cells between the bundles (Taiz and Zeiger, 2009). Magnesium is very mobile in phloem and; thus, redistributes easily in leaves and older tissues to the parts with higher demand such as meristems and reserve organs (Epstein and Bloom, 2005). This explains why the occurrence of symptoms in teak plants initially appears in older leaves. Camargos et al. (2002) observed the magnesium deficiency and interveinal chlorosis in older leaves followed by necrosis in Brazil nut tree (*Bertholletia excelsa*), similar to those observed in this study.

Visual symptoms promoted by sulfur (S) deficiency

Symptoms of sulfur deficiency were the last to come forward. Young leaves showed lighter green color as compared to leaves of the complete treatment (Fig. 1g). This also has been observed in mahogany plants (Viégas et al., 2012). The importance of sulfur for crops is being emphasized due to promote increases in production. Sulfur plays an important role in the formation of methionine (21% S) and cysteine (27% S), chlorophyll and protein synthesis, seed oil content and nutritional value of forage (Jamal et al., 2009).

Multivariate analysis of dry mass production

Fig. 2 shows the bivariate and detection of three dimensions. It demonstrates the dispersion of three variables relation such as leaf dry mass (LDM), stems dry mass (SDM) and root dry mass (RDM) in teak plants (*T. grandis*), segregated by a quantitative variable (g kg^{-1} of dry mass). This quantitative variable (g kg^{-1} of dry mass) indicates major production in teak plants. It is observed that the dry mass under the complete treatment (C) was higher than omission treatments such as -N, -P, -K, -Ca, -Mg, and -S, because it encompasses all nutrients, in amounts appropriate for plant growth.

The omission of calcium caused lower dry matter production ($p \leq 0.05$) for leaf dry mass > root dry mass > stems dry mass, which accounts for LDM (10.09 g $plant^{-1}$), RDM (6.64 g $plant^{-1}$), SDM (5.22 g $plant^{-1}$) compared to

Table 1. Macronutrient content (g kg^{-1}) in leaves of teak plant (*Tectona grandis*) according to complete treatment and the omission of individual nutrients.

Treatments	N	P	K	Ca	Mg	S
	------------------------	------------------------	------------------------ g kg^{-1}	------------------------	------------------------	------------------------
Complete (C)	20.7	2.10	7.10	10.5	4.90	2.10
Omission of N	14.5*	2.40	12.0*	8.70	3.50*	1.40*
Omission of P	21.6	1.00*	1.11*	12.1	4.20*	1.40*
Omission of K	24.3	5.00*	3.00*	17.3*	8.70*	2.10
Omission of Ca	26.7*	4.60*	13.8*	3.90*	8.00*	2.60*
Omission of Mg	26.0*	4.60*	13.6*	16.6*	0.80*	2.40
Omission of S	22.8	2.70	11.8*	16.1*	5.80*	1.50*
D.M.S. (5%)	05.3	0.03	0.23	0.37	0.07	0.04
C.V. (%)	12.05	6.20	9.75	15.41	7.00	10.36

*Means followed by asterisks in the same column differ significantly from complete at 5% probability by Dunnett's test.

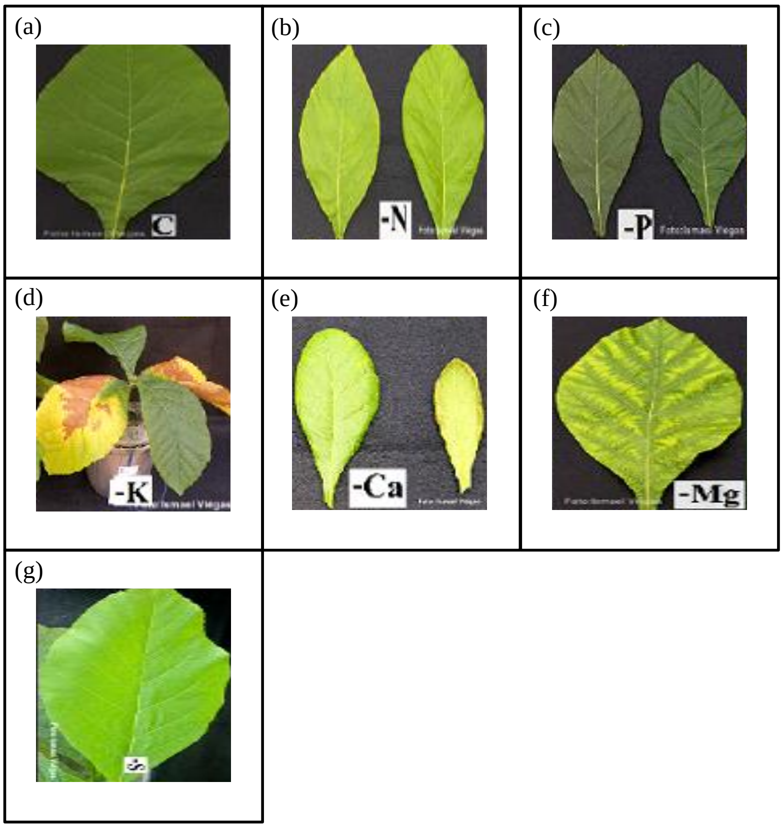

Fig 1. Young leaf of teak plant (*Tectona grandis*) in complete treatment (a) and deficiency symptoms individual omission of nitrogen (b), phosphorus (c), potassium (d), calcium (e), magnesium (f), and sulfur (g) cultivated in nutrient solution lacking nutrients.

treatment (C), wherein the dry matter production was LDM (33.41 g plant^{-1}), RDM (30.23 g plant^{-1}), and SDM (21.60 g plant^{-1}). Moreover, it appears that the omission of sulfur (-S) showed leaf dry mass of 30.79 g plant^{-1}, root dry mass of 25.42 g plant^{-1} and stem dry mass of 10.49 g plant^{-1}.

The sum of leaf and stem dry mass was 15.31g plant^{-1}, representing the shoot dry mass of the treatment (-Ca), whose value was higher than that obtained by Souza et al. (2006) with 9.26 g plant^{-1} in ipê-roxo (*Tabebuia impetignosa*). On the other hand, the root dry mass of purple-ipe was over teak. However, root dry mass of ipê-roxo in complete and with omission of sulfur (-S) was lower than teak plants.

In Fig.3, the interaction of dry mass of leaves, stems, roots, (g kg^{-1} of plant), is represented by a boxplot, in which the best interaction occurred in the first quadrant (Quadrant I), indicating that all of dots under boxes are directly due to influence of macronutrient omissions, but may be analyzed singly. In this sense, it appears that the lower part of the circle of macronutrients expresses major nutrient limitation, characterizing plant requirements in terms of calcium, phosphorus, and magnesium.

Multivariate analysis of macronutrient content

The Complete treatment (C), which depicts the macronutrient contents in teak plants, explained 42.66% of the total variance of the data that encompassed the following variables: X1-Variable Complete (C); X2-Variable (-N); X3-Variable (-P); X4-Variable (-K); X5-Variable (-Ca); X6-Variable (-Mg); X7-Variable (-S) (Table 2). All those variables are related to the production of leaf dry mass (LDM), stem (SDM), and roots (RDM), which have a positive relation with that component. The variables are sources of understanding in the explanations of the symptoms related to low production of stem dry mass. In this component

Table 2. Principal components in levels of macronutrients (g kg^{-1}) and their corresponding scores (loadings) in teak plant (*Tectona grandis*) according to complete treatment and individual nutrient omission.

Component	Initial Eigenvalues			Sums of Squared Loadings		
	Total	Variance	Cumulative	Total	Variance	Cumulative
	%					
Complete (C)	2.560	42.669	42.669	2.560	42.669	42.669
Omission of N	1.507	25.121	67.790	1.507	25.121	67.790
Omission of P	1.196	19.934	87.724	1.196	19.934	87.724
Omission of K	0.447	7.455	95.180			
Omission of Ca	0.254	4.232	99.412			
Omission of Mg	0.035	0.588	100.000			

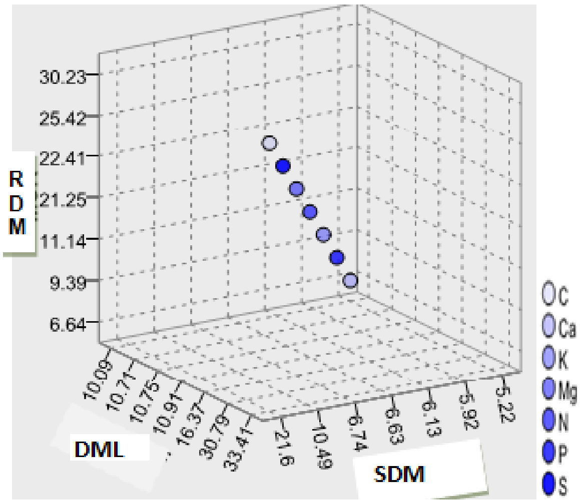

Fig 2. LDM: Leaf dry mass, SDM: stems dry mass, RDM: root dry mass (g plant^{-1}) in teak plant (*Tectona grandis*) grown in nutrient solution.

Table 3. Principal components in accumulation of macronutrients (g kg^{-1}) and their corresponding scores (loadings) in teak plant (*Tectona grandis*) according with complete treatment and individual nutrient omission.

Component	Initial Eigenvalues			Sums of Squared Loadings		
	Total	Variance	Cumulative	Total	Variance	Cumulative
	%					
Complete (C)	4.774	79.562	79.562	4.774	79.562	79.562
Omission of N	0.511	8.512	88.074			
Omission of P	0.365	6.086	94.161			
Omission of K	0.233	3.890	98.051			
Omission of Ca	0.102	1.699	99.750			
Omission of Mg	0.015	0.250	100.000			

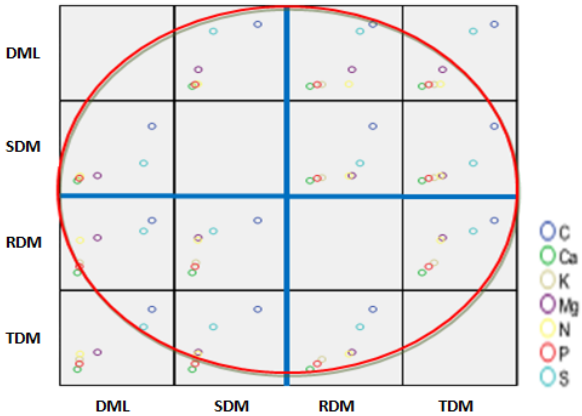

Fig 3. Boxplot between of LDM: leaf dry mass, SDM: stems dry mass, RDM: root dry mass, and the total TDM: total dry mass expressed as g plant^{-1} in teak plants (*Tectona grandis*) cultivated in nutrient solution lacking nutrients.

the variables are in three dimensions of multivariate multidimensional scaling (MDS), at a system level of cultivation under controlled greenhouse conditions.

The variable X2 (-N) explains 25.12% of the total variance, proving to be a limiting nutrient in plant development, but not as limiting as phosphorus, calcium and magnesium. They exhibit low level of explanation less than 25%, featuring this postulate, in this type of multivariate analysis.

The variable X3 (-P) had the highest factor loading and explained 19.43% of the total variance, proving to be an important nutrient in plant development, with the degree of nutrient limitation, precisely because of its low level of explanation for the multivariate analysis, below 25% of the variance. This fact may probably be attributed to the functions that phosphorus performs in the plant, acting as an integral component of important cell compounds such assugar-phosphate, intermediates of respiration and photosynthesis, besides being a component of nucleotides used in the energetic metabolism, as ATP, DNA, and RNA (Taiz and Zeiger, 2009).

Ribeiro et al. (2006) studied the influence of fertilization in teak seedlings and found that phosphorus is important for the growth of the species. This fact was also observed by Marques et al. (2004a, b), Neves et al. (2004), Maffeis et al. (2000), Souza et al. (2006, 2010), Gonçalves et al. (2008), and Sarcinelli et al. (2004) on nutritional deficiency studies of various forestry plants such as paricá, andiroba, ipê-roxo, eucalyptus, mahogany, angico-vermelho and acácia. The researchers noted that phosphorus is important in growth, leaf production and root elongation and its limitation leads to lower production.

The variable X5 (-Ca) presents low factor loading. Besides, it does not have any participation in explaining the percentage of variance due to its value well below 25% of the variance. However, the omission of calcium affects the content of this element in teak plant, being in the conduct amplitude of multidimensional scaling model and in the micro level of competitiveness with the other treatments (C; -N; -P; -K; -Ca; -Mg; and -S). The Ca omission becomes critical in relation to nutritional requirement, especially more limiting for teak plants, compared to phosphorus. In low concentrations of Ca, this plant presents symptoms of nutritional deficiencies more severe than the omission of phosphorus, since its limitation causes reduction in plant growth and leaf distortion, among other disorders.

The concentration of calcium in plant was lower in the treatments with omission of calcium (-Ca), magnesium (-Mg), and sulfur (-S) which can probably be attributed to the lower performance of low calcium absorption arising from competitiveness by absorption sites with magnesium.

The omission of calcium is associated with low concentrations of sulfur (S) and Mg, causing nutritional disorders. Sulfur is constituent of various vitamins and co-enzymes essential to cell metabolism. Magnesium (Mg) plays a key role in the activation of enzymes involved in respiration, photosynthesis and the synthesis of DNA and RNA, and is part of the chlorophyll molecule (Taiz and Zeiger, 2009). Such processes can be activated without much precision, because calcium is not available to the plant at levels that would be needed in the regulation of these cellular processes, associated with nutrients such as sulfur and magnesium. Hence, calcium deficiency reduces metabolism and the activation of enzymes within the cell. This reduction of calcium and magnesium content may be due to the effect of inhibition during the absorption process by interaction with other ions (Paiva et al., 2002).

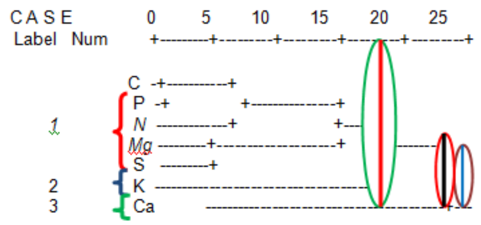

Fig 4. Dendrogram of scaling distance of macronutrient content in teak plants (*Tectona grandis*) grown in a greenhouse, Belém city, State of Pará, Brazil.

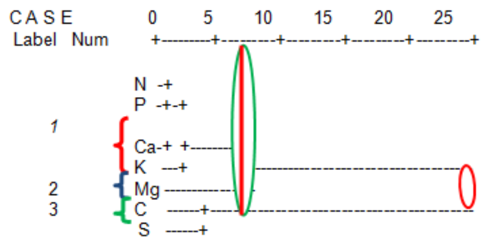

Fig 5. Dendrogram of scaling distance of macronutrient contents in teak plants (*Tectona grandis*) grown in a greenhouse, Belém city, State of Pará, Brazil.

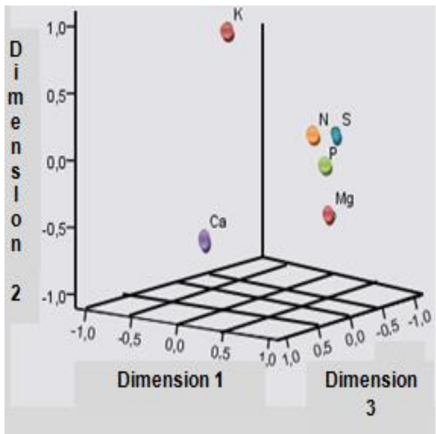

Fig 6. Dispersion of nutrient contents in teak plant (*Tectonia grandis*) based on treatments omitted, the scheduling system. The axes represent the three-dimensional multidimensional.

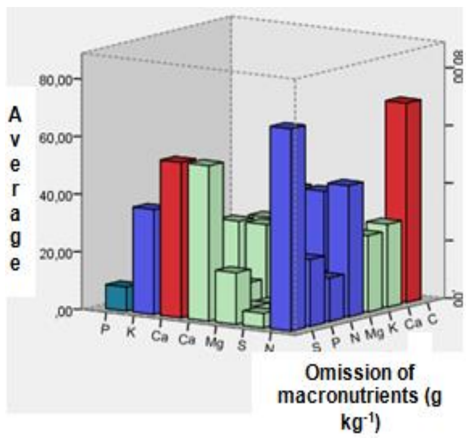

Fig 7. Means of the contents of macronutrients in teak plant (*Tectonia grandis*) by method Kurtosi.

Multivariate analysis of accumulation of macronutrients

In Table 3, we can see that the factor analysis grouped only one factor. The first factor, Complete treatment (C), groups all indicators such as variables: X1 - Variable Complete (C); X2 - Variable (-N); X3 - Variable (-P); X4 - Variable (-K); X5 - Variable (-Ca); X6 - Variable (-Mg); X7 - Variable (-S), explaining 79.56% of the total variance for macronutrients accumulated in teak plants (*Tectona grandis*). This meaning that 79.56% of complete treatment is what most accumulates nutrient in teak plant, by having levels considered suitable for the plant, while the other treatments such as omissions of –N, -P, -K, -Ca, -Mg, and -S show little accumulation, promoting different degrees of interference in teak tree, subject to omission of each one.

When the teak tree subjected to nitrogen and potassium omissions, we noticed higher values of accumulation in treatments with omission of nitrogen rather than potassium omission (Table 3). This fact was reported by Souza et al. (2010) and Santos (2006) that attributed it to the phenomenon of competition that occurs between nitrogen and potassium.

The dendrogram, a tree-shaped graph that represents the clustering process, reinforces this belief, where one can see that the cluster 3 had its interaction with distance rescheduled to eighteen (18), while cluster 1 and 2 had a distance around twenty-five (25) by a parallel line to the horizontal axis. In this study, it was adopted the Euclidean distance of eighteen (18) for content and 8.5 for the accumulation of nutrients in teak plants with the purpose of analysis approach of such data (Fig. 4 and 5).

In Fig. 4, the dashed line parallel to horizontal axis intersects three branches connecting by analyzing three different groups of content of omitted macronutrient: Group 1 (omissions of P, N, Mg, and S), Group 2 (omission of K); Group 3 (omission of Ca) and a branch to accumulate nutrients omitted, such as: Group 1 (omissions of P, Ca, K, and Mg), Group 2 (complete treatment) (Fig. 5).

According to the results analyzed in Fig.4, it is observed that the omission of calcium (-Ca) showed a major limitation for teak plants with content of 0.39 g kg^{-1} in leaf of plants. This result was lower than that found by Sarcinelli et al. (2004) in *Acacia holosericea*, with 6.5 g kg^{-1} of plant.

Regarding the accumulation of nutrients in teak leaves (Fig. 5), it is observed that the plant has obtained a value of accumulation in the treatments under the omission of potassium of 3.23 g kg^{-1}. This value was lower than that determined by Fiore et al. (2010) in jatobá plants, whose potassium content was 51.39 g kg^{-1} of plant.

The omissions of macronutrients in teak plants (*T. grandis*) were coded in relation to the missing element and designed in the three-dimensional plane based on nutritional dissimilarity coefficients (Fig. 6). It is observed that most of the omitted nutrients in some treatment was distributed between accesses reference of treatments (behavioral treatments in the three-dimensional plane), which element is below the level considered appropriate for plant growth. However, the projection of these nutrients in three-dimensional plane also evidenced that while the selections occupy four out of 16 quadrants formed by the dimensions 1 and 2, the accesses reference occupy only one quadrant. The nutrients that have higher nutrient limitation occupied only a marginal quadrant, wherein plant development shortly occurred, such as: reducing height, number of leaves and fall of basal leaves.

When confronting this nutrient in relation to the other, it is clear that the scale of deficiency for the other nutrients appear to be distant. Therefore, it presents possibilities for significant explanations to the degree of nutritional requirement of this plant. This happens due to the fact that a small concentration of calcium in plants has low translocation. It is known that this element plays an important role in the regulation of many cellular processes such as control of transcription and cell survival until release of chemical signals, which causes manifestation of nutrient deficiency symptoms (Taiz and Zeiger, 2009).

According to Ribeiro et al. (2006), calcium is limiting to teak plant growth. Moreover, the author adds that nitrogen causes an increase in plant growth when in presence of phosphorus. I was not observed in this study, following an order of nutrient limitation of Ca, P, Mg, and K.

Fig. 7 shows the average macronutrient contents in teak plants (*T. grandis*), where highest averages were recorded in omissions of nitrogen with 15.05 g kg^{-1} of plant. On the other hand, it is observed that under omission of nitrogen, the accumulation was greater than 15.05 g kg^{-1}, where if the omission of phosphorus is related, this value is 1.07 g kg^{-1} of plant, and so, for the other treatments, such as with the omission of potassium (3.23 g kg^{-1} of plant), omission of calcium (3.94 g kg^{-1} of plant), omission of magnesium (1.31 g kg^{-1} of plant) and omission of sulfur (4.93 g kg^{-1} of plant).

In this regard, nitrogen was the nutrient that highly accumulated on teak leaves, while phosphorus and magnesium were the least accumulated. This occurred, probably due to the fact that the lowest magnesium accumulation is due to increases in calcium accumulation in teak leaves suggesting that their mobility in the plant was influenced by calcium. This effect was contrary to those observed by Sarcinelli et al. (2004) in *Acacia holosericea* seedlings.

Materials and Methods

Location of the experiment

The experiment was conducted in a greenhouse at Embrapa, Eastern Amazon, in Belém city, State of Pará, located in the geographic coordinates 1° 28’ 0’’ S e 48° 27’ 0’’ W, with air temperatures ranging from 24°C to 30°C for 200 days. According to Köppen, the climate of Belém can be classified as the type Afi, tropical rainy climate with small annual thermal amplitude and average monthly rainfall exceeding 60 mm.

Plant material and seedlings selection

The teak seeds from a commercial plantation in the Dom Elizeu city, State of Pará, were sown in seed bed having substrate of mixture of sawdust and sand in 3:1 ratio. The seedlings with an average height of 10 cm were selected and any remained residue were removed from their roots and transplanted to plastic pots containing 5 kg of silica (type zero coarse), one plant each.

Plant acclimatization and implementation of the experiment

Plants were acclimatized in the Waard (1969) nutrient solution diluted to 1:10 concentration (1 liter solution to 10 liters distilled water), for a period of 30 days. Subsequently, plants were supplied with full strength solution undiluted solution (complete) and with omissions of macronutrients according to each treatment. The pots were irrigated by percolation, drained daily in the afternoon and irrigated in the morning, getting nine hours irrigated and 15 hours drained by exchanging the solution at 15 day-intervals and maintained at pH 5.5 ± 0.5.

Experimental design

The experimental design was a completely randomized with five replications including seven treatments, as specified: complete (C) (macronutrients + micronutrients) as described by Viégas et al. (2013), and the individual omissions, zero levels of nitrogen (-N); phosphorus (-P); potassium (-K); calcium (-Ca); magnesium (-Mg) and sulfur (-S). The nutrient solutions were supplied by percolation in pots, and drained daily in the afternoon and irrigated in the morning, getting 9 hours irrigated and 15 hours drained (Viégas et al., 2014).

Collection of vegetal material

When all deficiency symptoms of macronutrients were well established pictures were taken. Samples of leaves, stems and roots were collected and dried in an oven with forced air circulation at 70°C until constant weight. The dry matter corresponding to each part of plants per pot per treatment was weighed (g $plant^{-1}$) and triturated in mill type Willey to determine the analysis of vegetal tissues (Cruz et al., 2011).

Determination of macronutrient content

The plant tissue analyzes were conducted at the Laboratory of Soil and Plant Tissue of Embrapa Eastern Amazon, in which the determinations of foliar levels of macronutrients (nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur) were performed according to the methodology of Malavolta et al. (1997) and Embrapa (1997). From the nutrient content in the leaves (g kg^{-1}) and the dry matter of plant tissue, it was possible to calculate the accumulation of macronutrients (g kg^{-1}) (Laviola and Dias, 2008).

Experimental design and Statistical analyzes

The experimental design was completely randomized design with 7 treatments and four replications. In total, 28 plots, each plot consisted of a pot containing a plant was analyzed.
The experimental data were analyzed by ANOVA using F-test and the means compared by Dunnett's test, at 5% probability, and by Multivariate and Multidimensional Scaling analyzes (MDS) by using the statistical software SPSS 17.0 (Corrar et al., 2009).

Conclusions

The omission of macronutrients in the nutrient solution induces the occurrence of deficiency symptoms in teak plants, easily characterized by reductions in foliar content of those nutrients. They occur in the following order: K > N > Mg > Ca > P > S. The method of Multivariate Multidimensional Scaling analyzes (MDS) has been an important statistical tool in the study of nutritional deficiency in teak plants (*Tectona grandis*). Calcium, phosphorus and magnesium are limitingfactors in the production of dry matter in Tectona grandis. Foliar content of calcium, phosphorus, magnesium and potassium are the most limiting factors for teak plants (*Tectona grandis*) growth. Nitrogen was more accumulated in leaves, while phosphorus and magnesium were accumulated in small amounts.

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References

Aerts R, Chapin III FS (1980) The mineral nutrition of wild plants revisited: A re-evaluation of processes and patterns. Adv Ecol Res. 30: 1-67.

Barroso DG, Figueiredo FAMMA, Pereira RC, Mendonça AVR, Silva LC (2005) Macronutrient deficiency diagnosis in teak seedlings. Rev Árv. 29: 671-679.

Camargos SL, Muraoka T, Fernandes SAP, Salvador JO (2002) Nutritional diagnoses in young *Bertholletia excelsa* plants. Rev Agric Trop. 6: 81-96.

Chiera P, Thomas J, Rufty T (2002) Leaf initiation and development in soybean under phosphorus stress. J Exp Bot. 53: 473-481.

Corrar LJ, Paul E, Dias Filho JM (2009) Multivariate analysis for management courses, accounting sciences and economics. FIPECAFI - Research Institute of Accounting, Actuarial and Financial Research. Ed. Atlas, 1th Edition. 541p.

Cruz FJR, Lobato AKS, Costa RCL, Lopes MJS, Neves HKB, Oliveira Neto CF, Silva MHL, Santos Filho BG, Lima Junior JA, Okumura RS (2011) Aluminum negative impact on nitrate reductase activity, nitrogen compounds and morphological parameters in sorghum plants. Aust J Crop Sci. 5: 641-645.

Embrapa (1997) Manual methods of analysis of soils. 2th Edition. Rio de Janeiro: Embrapa. 212p.

Epstein E, Bloom AJ (2005) Mineral nutrition of plants: principles and perspectives. 2th Edition. Sinauer Associates, Sunderland. 400p.

Fernandes AR, Matos GSB, Carvalho JG (2013) Nutritional deficiencies of macronutrients and sodium in peach palm seedlings. Rev Bras Frutic. 35: 1178-1189.

Finger Z, Finger FA, Drescher R (2001) Teca (*Tectona grandis* L. F.): Plant this idea. In: Brazilian Symposium Graduate in Forestry, 1, Santa Maria - RS. Proceedings. Santa Maria: UFSM. CD-Rom.

Fiore RA, Gardini EMM, Gardini AMM, Santana BID, Neves DR, Santos JB (2010) Nutrient accumulation in seedlings of *Hymenaea* L. on weed interference. In: XXVII Brazilian Congress of Weed Science - Convention Center, Ribeirão Preto, Brazil. Proceedings. Ribeirão Preto: UNESP.

Freitas MSM, Monnerat PH, Carvalho AJC, Vasconcellos MAS 2011 Deficiency symptoms of macronutrientes and boron in sweet passion fruit plant. Rev Bras Frutic. 33(4):1329-1341.

Gonçalves EO, Paiva HN, Neves JCL, Gomes JM (2008) Growth of angico vermelho (*Anadenanthera macrocarpa* (Benth.) Brenan) seedlings under different macronutrient doses. Rev Árv. 32: 1029-1040.

Jamal A, Ko K, Kim HS, Choo YK, Joung H, Ko K (2009) Role of genetic factors and environmental conditions in recombinant protein production for molecular farming. Biotech Adv. 27: 914-923.

Laviola BG, Dias LAS (2008) Nutrient concentration in *Jatropha curcas* L. leaves and fruits and estimated extraction at harvest. R Bras Ci Solo. 32: 1969-1975.

Lukmandaru G, Takahashi K (2008) Variation in the natural termite resistance of teak (*Tectona grandis* Linn. fil.) wood as a function of tree age. Ann For Sci. 65: 708-715.

Maffeis AR, Silveira RLVA, Brito JO (2000) Macronutrients and boron deficiencies reflexes on plant growth, production and essential oil in *Eucalyptus citriodora*. Sci Forest. 57: 87-98.

Malavolta E, Vitti GC, Oliveira SA (1997) Evaluation of the nutritional state of plants: principles and applications. Piracicaba: Potafos. 319p.

Marques TCLLSM, Carvalho JG, Lacerda MPC, Mota PEF (2004a) Nutrient requeriment of *Schizolobium amazonicum*, Herb. (Paricá) seedlings. Rev Cerne. 10: 167-183.

Marques TCLLSM, Carvalho JG, Lacerda MPC, Mota PEF (2004b) Initial growthing of Paricá (*Schizolobium amazonicum*) under nutrient omission and sodium in nutritive solution. Rev Cerne. 10: 184-195.

Mengel K, Kirkby EA (2001) Principles of plant nutrition. 4th Edition. Bern: International Potash Institute. 849p.

Miranda RS, Sudério FB, Sousa AF, Gomes Filho E (2010) Nutritional deficiency in cowpea seedlings due to omission of macro and micronutrients. Rev Ciênc Agron. 41: 326-333.

Moretti BS, Furtini Neto AE, Pinto SIC, Furtini IV, Magalhães CAS (2011) Growth and mineral nutrition in seedlings of Australian cedar (*Toona ciliata*) subjected to nutrient deprivation. Cerne. 17: 453-463.

Neves OSC, Benedito DS, Machado RV, Carvalho JG (2004) Growth, dry matter yield and N, P, K, Ca, Mg and S accumulation in andiroba seedling shoots (*Carapa guianensis* Aubl.) cultivated in lowland soil, in function of phosphorus doses. Rev Árv. 28: 343-349.

Paiva HN, Carvalho JG, Siqueira JO (2002) Nutrient content in cedro (*Cedrela fissilis Vell.*) seedlings submitted to increasing levels of nickel in nutrient solution. Rev Árv. 26: 279-284.

Ribeiro FA, Macedo RLG, Venturim N, Morais VM, Gomes JE, Yoshitami Junior M (2006) Effect of crop fertilization on the establishment of seedlings *Tectonia grandis* L.F. (teak). Rev Ci Eletr Eng Florest. 7: 1-13.

Rocha Filho JV, Haag HP, Oliveira GD (1978) Deficiency of macronutrients, boron and iron in *Eucalyptus urophylla*. Anais ESALQ. 35: 9-34.

Santos, R.A.C. 2006. Effects of increasing doses of nitrogen, phosphorus and potassium in seedlings of mahogany (*Switenia macrophylla*) and stick (*Ochroma pyramidale*) and selection of extractors of phosphorus and potassium. Master dissertation, Faculdade de Ciências Agrárias, Universidade Federal do Amazonas. Manaus, Amazonas, 63p.

Sarcinelli TS, Ribeiro Júnior ES, Dias LE, Lynch LS (2004) Symptoms of nutritional deficiency in seedlings of *Acacia holosericea* submitted to absence of macronutrients. Rev Árv. 25: 173-181.

Silveira RLVA, Moreira A, Takashi EN, Sgarbi F, Branco EF (2002) Deficiency symptoms of macronutrients and of boron in hybrids clones of *Eucalyptus grandis* with *Eucalyptus urophylla*. Rev Cerne. 8: 107-116.

Skrebsky EC, Nicoloso FT, Rauber JMR, Castro GY, Jucoski GO, Santos DR (2008) Characterization of the nutritional demands of young plants of *Pfaffia glomerata* in a Paleudalf soil by means of the missing nutrient technique. Ci Rural. 38: 989-996.

Souza CAS, Tucci CAF, Silva JF, Ribeiro WO (2010) Nutritional requirements and growth of mahogany (*Swietenia macrophylla* King.) plants. Acta Amaz. 40: 515-522.

Souza PA, Venturin N, Macedo RLG (2006) Mineral fertilization of ipê-roxo (Tabebuia impetiginosa). Ci Florest. 16: 261-270.

Taiz L, Zeiger E (2009) Plant Physiology. 4th Edition. Porto Alegre: Artmed. 848p.

Troup RS (1921) The silviculture of Indian trees. Volumes I and II. Oxford: Clarendon Press. 471p.

Viégas IJM, Galvão JR, Silva Júnior ML, Melo NC, Oliveira MS (2014) Growth, mineral composition and symptoms of visual impairment in nutrition ipeca. Rev Caatinga. 27: 141-147.

Viégas IJM, Sousa GO, Silva AF, Carvalho JG, Lima MM (2013) Mineral composition and visual symptoms of nutrients deficiencies in long pepper plants (*Piper hispidinervum* C. DC.). Acta Amaz. 43: 43-50.

Viégas IJM, Lobato AKS, Rodrigues MFS, Cunha RLM, Frazão DAC, Oliveira Neto CF, Conceição HEO, Guedes EMS, Alves GAR, Silva SP (2012) Visual symptoms and growth parameters linked to deficiency of macronutrients in young *Swietenia macrophylla* plants. J Food Agric Environ. 10: 937-940.

Viégas IJM, Gonçalves AAS, Frazão DAC, Conceição HEO (2008) Effects of the omissions of macronutrients and boron in the symptomatology, growth and production of dry mass in açaí palm. Rev Ciênc Agrár. 50: 129-141.

Waard PWF (1969) Foliar diagnosis, nutrition and yield stability of Black pepper (*Piper nigrum*, L.) in Sarawak. Amsterdam, Royal Tropical Institute. 149p. (Communication, 58).