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Translated from the original in spanish **Original article**

Effect of substrate and arbuscular mycorrhiza on the root system and nutritional status of *Swietenia mahagoni* L. Jacq.

Efecto del sustrato y la micorriza arbuscular en el sistema radical y estado nutricional de *Swietenia mahagoni* L. Jacq.

Efeito do substrato e da micorriza arbuscular no sistema radicular e estado nutricional da Swietenia mahagoni L. Jacq.

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RESUMEN

El estudio se desarrolló con el objetivo de evaluar la influencia de los factores sustratos y cepas de hongos micorrízicos arbusculares (HMA) sobre el sistema radical y estado nutricional de *Swietenia mahagoni* L. Jacq. Los factores probados fueron, factor 1 sustrato: cascarilla de cacao, fibra de coco y aserrín de pino compostado en proporciones 6:2:2 y 2:6:2, y un testigo compuesto por suelo al 100 %; factor dos cepas micorrízicas: *Glomus cubense, Rhizoglomus irregulare* y *Funneliformis mosseae*.

Los nueve tratamientos resultantes del arreglo factorial 3x3, se establecieron bajo un diseño experimental completamente al azar. Fueron medidas las variables relacionadas con el sistema radical (largo de la raíz principal, cantidad de raíces primarias y secundarias, colonización micorrízica) y acumulación de nitrógeno, fósforo y potasio mediante un análisis gráfico de vectores. Los resultados obtenidos demostraron que existió un efecto diferenciado de las micorrizas en el crecimiento de *S. mahagoni*. La inoculación con las cepas micorrízicas mejoró la nutrición de las plantas. El mejor sustrato para el establecimiento de la asociación micorrízica fue el S2 conformado por 20 % de cascarilla de caco + 60 % de fibra de coco + 20 % de aserrín de pino, pero los mejores tratamientos para el crecimiento y nutrición de las plántulas fueron la combinación del sustrato S2 y las cepas *Glomus cubense* y *Rhizophagus irregulare*.

Palabras clave: Análisis de vectores; Colonización micorrízica; Nutrición forestal; Sistema radical.

ABSTRACT

The study was developed with the objective of evaluating the influence of substrate factors and strains of arbuscular mycorrhizal fungi (AMF) on the root system and nutritional status of *Swietenia mahagoni* L. Jacq. The factors tested were: factor 1 substrate: cocoa husk, coconut fiber and composted pine sawdust in proportions 6:2:2 and 2:6:2 and a control composed of 100 % soil; factor 2 mycorrhizal strains: *Glomus cubense, Rhizoglomus irregulare* and *Funneliformis mosseae*. The nine treatments resulting from the 3x3 factorial arrangements were established under a completely randomized experimental design. Variables related to the root system (length of the main root, number of primary and secondary roots, mycorrhizal colonization) and accumulation of nitrogen, phosphorus and potassium were measured by vector graphic analysis. The results obtained showed that there was a differentiated effect of mycorrhizae on the growth of *S. mahagoni*. Inoculation with mycorrhizal strains improved plant nutrition. The best substrate for the establishment of the mycorrhizal association was S2, composed of 20 % coconut husk + 60 % coconut fiber + 20 % pine sawdust, but the best treatments for the growth and nutrition of the seedlings were the combination of substrate S2 and the strains *Glomus cubense* and *Rhizophagus irregulare*.

Keywords: Vector analysis; Mycorrhizal colonization; Forest nutrition; Root system.

RESUMO

O estudo foi desenvolvido com o objetivo de avaliar a influência de fatores de substrato e cepas de fungos micorrízicos arbusculares (FMA) no sistema radicular e estado nutricional da Swietenia mahagoni L. Jacq. Os fatores testados foram: substrato fator 1: casca de cacau, fibra de coco e serrim de pinheiro compostado em proporções 6:2:2 e 2:6:2, e um controle composto de 100% de solo; cepas micorrízicas fator 2: Glomus cubense, Rhizoglomus irregulare e Funneliformis mosseae. Os nove tratamentos resultantes do arranjo fatorial 3x3 foram estabelecidos sob um desenho experimental completamente aleatório. Variáveis relacionadas com o sistema radicular (comprimento da raiz principal, número de raízes primárias e secundárias, colonização micorrízica) e acumulação de azoto, fósforo e potássio foram medidas por análise gráfica vetorial. Os resultados obtidos mostraram que houve um efeito diferenciado de micorrizas sobre o crescimento de S. mahagoni. A inoculação com as estirpes micorrízicas melhorou a nutrição vegetal. O melhor substrato para o estabelecimento da associação micorrizal foi o S2 constituído por 20 % de casca de coco + 60 % de fibra de coco + 20 % de serradura de pinheiro, mas os melhores tratamentos para o crescimento e nutrição das plântulas foram a combinação do substrato S2 e as estirpes Glomus cubense e Rhizophagus irregulare.

Palavras-chave: Análise vectorial; colonização micorrízica; nutrição florestal; sistema radicular.

INTRODUCTION

Swietenia mahagoni L. Jacq. is probably one of the most valuable timber species in the world, the best known and most appreciated for cabinetmaking and all kinds of work requiring high quality wood. It is used for reforestation in various areas of Cuba because it is native, facultative heliophilous, colonizing different successional stages, tolerant to competition, widely distributed in the country, has different growth and development strategies and reproduces easily in nurseries (Ricardo *et al*., 2016).

For nursery production, it is important to choose a substrate with adequate chemical and physical characteristics that provide enough space for roots to grow, since the initial quality and good growth of seedlings depends on it (Arévalo *et al*., 2016). Such characteristics include slightly acid pH, fertility, free of pests and diseases, in addition to presenting minimum values in total porosity of 70 %, aeration porosity of 10 % and water retention porosity of 55 % (Abad *et al*., 2005).

In addition to the appropriate choice of substrate, an alternative to obtain quantity, quality and greater seedling growth is to favor the formation of arbuscular mycorrhizal fungi (AMF), whose inoculation is particularly appropriate in nursery conditions. These allow the plant to expand the exploration of the substrate through the mycelium and transport nutrients to the root, as well as increase the absorption surface of the plant (Oliveira Júnior *et al*., 2019), favoring the absorption of different nutrients including those of low mobility in the soil (Piliarová *et al*., 2019).

However, the beneficial expression of the symbiosis depends on the type of substrate, since its nature and physical and chemical properties affect the establishment and behavior of AMF. Taking into consideration the above, this study aims to evaluate the influence of different substrates and strains of arbuscular mycorrhizal fungi (AMF) on the morphology and nutritional status of *S. mahagoni*.

MATERIALS AND METHODS

Description of the experiment

An experiment was carried out in the nursery of the Center for the Study of Agroforestry Technology (CETAF) belonging to the University of Guantánamo (UG), located at the geographical coordinates 20°12'21'' North latitude and 75°13'37'' West longitude at 87 m above sea level. The climate has a marked dry season from January to March and from November to December; and rainfall from April to June and September to October.

This site has an average annual precipitation and temperature of 1 028 mm and 25.9 °C respectively (INSMET, 2020).

The *Swietenia mahagoni* seeds were obtained from ripe fruits collected from a stand located in the municipality of Jamaica, belonging to the Empresa Agroforestal Guantánamo. The fruits were processed taking into account the aspects established for their processing by Cuban Norm 318/1978. The seeds were used immediately after processing. Prior to sowing, a germination test was carried out with a result of more than 90 % of germinated seeds in all treatments.

Cultivation was done in plastic containers with a capacity of 200 cm^3. After planting and until the first month, irrigation was done manually, twice a day, in the morning and in the afternoon. From the second month only one irrigation was done daily and one month before the end of the crop, the process of hardening of the plants began, consisting of irrigation on alternate days.

Experimental design

The experimental design was completely randomized, with factorial arrangement and five replicates. The factors were: A) AMF strains and B) substrates. Additionally, a control composed of 90% agricultural soil + 10 % cocoa husk (Technical Instructions) was used, for a total of nine treatments (Table 1).

Table 1. - Description of the treatments applied in the experiment

Treatment	HMA strains	Substrate composition (%)
T1	-	60Cc + 20Fc + 20Asp
T2	-	20Cc + 60Fc + 20Asp
T3	*Glomus cubense*	60Cc + 20Fc + 20Asp
T4	*Glomus cubense*	20Cc + 60Fc + 20Asp
T5	*Rhizoglomus irregulare*	60Cc + 20Fc + 20Asp
T6	*Rhizoglomus irregulare*	20Cc + 60Fc + 20Asp
T7	*Funneliformis mosseae*	60Cc + 20Fc + 20Asp
T8	*Funneliformis mosseae*	20Cc + 60Fc + 20Asp
T9 (Witness)	-	90Sa +10Cc

Sa: agricultural soil; Cc: cocoa husk; Fc: coconut fiber; Asp: pine sawdust.

The HMA strains used were: *Funneliformis mosseae*, *Glomus cubense* and *Rhizoglomus irregulare*, with 30, 33 and 36 spores g^{-1} of inoculant, respectively, from the National Institute of Agricultural Sciences (INCA). Inoculation was carried out by the seed coating method (Fernandez *et al*., 2001).

The substrates were sterilized at 120°C for 15 minutes in autoclave for three times, and these were: S1) cocoa husk 60 % + coconut fiber 20 % + pine sawdust 20 % (6:2:2) and S2) 20 % cocoa husk + 60 % coconut fiber + 20 % pine sawdust (6:2:2:2). Table 2 presents the chemical and physical characteristics of the substrates and their optimum intervals suggested by Abad *et al*. (2005) and Arévalo *et al*. (2016), which are between the optimum values, but not for substrate S2 in which phosphorus is below the optimum interval.

Table 2. - Chemical and physical characteristics of the substrates

Substrate	Chemical properties					
	pH	MO (%)	N (%)	P (%)	K^+ (%)	CE ($dS.m^{-1}$)
S1	6,20	77,20	1,86	1,43	1,79	3,13
S2	7,70	66,66	1,40	0,10	1,19	2,27
Optimum interval	**5,3-6,5**	**>50**	**>1,3**	**>0,7**	**>0,2**	**<3,5**
Substrate	**Physical properties**					
	DA ($g\ mL^{-1}$)	DR ($g\ mL^{-1}$)	PT (%)	DMP (mm)	RH (%)	
S1	0,38	1,67	82,02	0,45	65,49	
S2	0,31	1,68	76,16	0,35	70,76	
Optimum interval	**0,2-0,4**	**1,45-2,64**	**75-85**	-	**>50**	

Variables evaluated

The variables evaluated at the end of the experiment (120 days) included: length of the main root (cm), measured from the neck to the apex, using a graduated ruler; the number of fine and thick roots (No.) were determined by visual count. Root AMF colonization was obtained from root staining according to the methodology described by Yon *et al*., (2015) and subsequently the percentage of mycorrhizal colonization was determined using the method described by McGonigle *et al*., (1990). Leaf samples were taken to determine: nitrogen concentrations (%) by the Kjeldahl method, phosphorus (%) by colorimetric method and potassium (%) by flamometry with a flame photometer.

Statistical analysis

The data obtained for the variables evaluated were subjected to analysis of variance and comparison of means using Tukey's test (ɑ=0.05 %). The degree of association between the variables was evaluated by means of a correlation analysis using Pearson's coefficient. A principal component analysis was also performed for all the indicators evaluated. All this was done using the SPSS ver. 23 statistical program for Windows.

Seedling nutritional status was diagnosed by the vector graph method proposed by Park *et al*., (2015), which jointly analyzes the relative changes of the variables plant component mass, concentration and nutrient content. The vectors were plotted with a macro-based program programmed in Excel (http://bit.ly/2Eok8GF). The main effects were determined according to the graphical interpretation, as suggested by López and Alvarado (2010) and Xiao *et al*., (2019).

RESULTS AND DISCUSSION

Although a significant response was observed in all the variables evaluated in *S. mahagoni* at the end of cultivation with the joint application of substrate and mycorrhiza, it was the mycorrhizal factor that generated the greatest variation in these parameters, surpassing the levels of variability generated by the substrate factor and the interaction between the two (Table 3). This suggests that regardless of substrate

concentrations, mycorrhizal fungi are capable of facilitating plant growth. The results are in agreement with studies conducted on other species, where mycorrhizal treatments were highlighted
(Aguirre-Medina *et al*., 2019; Oliveira Júnior *et al*., 2019; Quiñones-Aguilar *et al*., 2020).

Table 3. - Mean squares and significance level of root system and nutritional parameters of *S. mahagoni* at the end of cultivation

Source of variation	LRP (cm)	CRP	CRS	Cabbage (%)	N (%)	P (%)	K (%)
Treatment	13,42***	276,96***	1068,86**	872,53**	31,67***	25,37***	20,07***
Witness *vs.* Rest	0,85*	10,04*	720,04***	573,54***	1,65*	2,15*	2,05*
Substrate (S)	1,57*	171,11***	838,51***	143,99***	10,35**	17,10**	15,43**
Strains (HMA)	27,05***	525,03***	2190,4***	1129,92***	58,21**	72,12**	41,29**
S X HMA	3,73*	64,21***	24,45***	27,32***	8,53**	9,70**	7,55**

*= *P*< 0.05; **= *P*< 0.01; ***= *P*< 0.001; LRP= length of main root; CRP and CRS= number of primary and secondary roots; Col= percentage of mycorrhizal colonization; N= nitrogen; P= phosphorus; P= potassium; AMF= arbuscular mycorrhizal fungi.

Root system morphology and mycorrhizal colonization

In relation to the analysis of the attributes related to the root system (Table 4), it was observed that the seedlings benefited with the combination of the S2 substrate made up of 20 % cocoa husk + 60 % coconut fiber + 20 % pine sawdust in interaction with the mycorrhizal strains *G. cubense* and *R. irregulare* (T4 and T6), with an increase with respect to the control of 15 and 10 % for LRP, 25 and 20 % for CRP, 30 and 25 % for CRS. The lowest values corresponded to the non-mycorrhizal treatments, which corroborates that mycorrhiza benefits root emission (Aguirre-Medina *et al*., 2019), in correspondence with high values of porosity and good aeration, which favors root growth and, therefore, the development of the aerial part of the plant.

In this sense, some authors have pointed out that mycorrhizae are beneficial fungi, which can increase root development up to 200 % in a group of plants, being an important component of the soil microflora, noting that they can increase nutrient absorption by roots between seven and 250 times depending on the crop (Alvero *et al*., 2011).

Table 4. - Effect of organic substrates and arbuscular mycorrhiza on the root system of *S. mahagoni* at the end of cultivation

Treatments	Length of main root (cm)	Number of roots		Mycorrhizal colonization (%)
		Primary	Secondary	
T1	17,62[c]	24,20[c]	70,00[c]	-
T2	16,11[c]	23,10[c]	73,40[c]	-
T3	19,29[b]	30,80[b]	89,90[b]	48,25[bc]
T4	19,38[a]	38,10[a]	97,20[a]	52,45[a]
T5	18,97[b]	32,50[b]	87,90[b]	46,31[c]
T6	19,46[a]	36,50[a]	96,50[a]	51,35[ab]
T7	19,07[b]	29,20[b]	88,70[b]	40,75[d]
T8	18,87[b]	30,70[b]	95,30[b]	42,25[d]
T9 (Witness)	14,55[d]	20,90[c]	71,80[c]	-
ES*	**0,207***	**0,648***	**1,174***	**0,026***

Different letters in the same column differ for P < *0.05*.ES- Standard error.

The greater number of secondary roots obtained in treatments T4 and T6 could be due to the physical characteristics of the substrate (Table 2), in which a greater number of secondary roots were generated, capable of colonizing the root ball faster. In this regard, Álvaro *et al*., (2014) cited by López *et al*., (2020) state that the abundant emission of secondary roots demonstrates high quality and guarantees rapid plant growth after planting; they also refer that the number of first-order secondary roots has shown correlation to improve plant performance in the field.

In the case of inoculated substrates, the difference is marked in favor of substrate S2, benefits that may be related to the low phosphorus content (Table 2). In this case, the fungal activity associated with the plant generates a system of mutual benefit, since AMF modify the morphology of the rootlets, giving the plant a better capacity to reach water and dissolve nutrients, which can solve the problem of imminent depletion of the phosphate stock and other elements such as nitrogen, zinc, copper, iron, potassium, calcium and magnesium. It can also cause a change in nutrient uptake and at the same time allow the induction of host defenses (Uc-Ku *et al*., 2019; Piliarová *et al*., 2019).

For their part, Brito *et al*., (2017) indicate that the activity and benefit of the symbiosis are more visible when these are found in phosphorus-deficient soils. In this condition, plants of *Schizolobium parahyba var. amazonicum* (Huber ex Ducke) Barneby inoculated with the fungus *Rhizophagus clarus* presented higher growth rates in relation to the control. This situation could explain the behavior of the strains studied in this experiment, since the S1 substrate was characterized by higher values of available phosphorus.

In general, the substrates evaluated (S1 and S2) were superior to the production control where soil is used in greater proportion, which resulted in the lowest response among the substrates evaluated for this stage or phase of crop development, so it would be advisable to use it only in the case of not having other complementary materials, also taking into account what is stated in the literature, not to use soil in containers with small volumes because phytosanitary problems and poor root development can occur (Valenzuela, 2019).

The increased root growth of mahogany plants obtained on organic substrates inoculated with different AMF species and combinations has been previously reported (Gómez *et al*., 2018; Rajan *et al*., 2020; Falcón *et al*., 2020). These authors express that the effectiveness in growth is possibly due to a synergistic influence when combining AMF and organic substrates. On the other hand, the variability in the growth of mahogany plants associated with mycorrhizal fungi may be due to several factors such as the species of mycorrhizal fungus, the species of mahogany, the functional complementarity or synergism of the mycorrhizal fungi, and the response of each host (high or low dependence on mycorrhizal fungi) (Abd El-Kader *et al*., 2016).

Root mycorrhizal colonization showed significant statistical differences (Tukey $p \leq 0.05$) due to the effect of AMF treatments (Table 4). The highest mycorrhization percentages were obtained in substrate S2 inoculated with *G. cubense* and *R. irregulare* (T4 and T6) with values of 52.45 and 51.55 %, respectively, without statistical differences with respect to substrate S1 inoculated with the same strains (T3 and T5). These mycorrhization values were significantly higher than those achieved with *F. mosseae* in both substrates (40.75 and 42.25 %). In all inoculated substrates, mycorrhization percentages between 40.75 and 52.45 % were present. This allows affirming that there is a certain degree of dependence between the plant and the AMF, an element of great importance due to the fact that, in the mycorrhizal symbiosis, the fungus allows the increase in the acquisition of nutrients, mainly those of low mobility in the soil, such as phosphorus, at the same time that the plant provides carbon compounds for the growth of the fungus (Mei *et al*., 2019). These results show the infective specificity that AMF establish in plants, depending on the characteristics of each substrate (Feijen *et al*., 2018).

Similar results were described by Aguirre-Medina *et al.,* (2019), who inoculated AMF on *Tabebuia donnell-smithii* Rose, finding high levels of mycorrhization. In other studies it has been observed that West Indian mahogany plants are colonized by *Glomus hoi like* (Oconor *et al*., 2011), which is comparable to the results found in the present work, both with strain *G. cubense* and *R. irregulare*, since both colonized the roots of West Indian mahogany, with strain *G. cubense* standing out.

Table 5 shows the results of the correlation analysis, in which it can be seen that the percentage of mycorrhizal colonization presented a positive and significant correlation with all the chemical characteristics of the soil evaluated, except with the organic matter content and mean particle diameter. The length of the main root and the number of primary and secondary roots showed positive and significant correlations with total porosity.

This result may indicate that the colonization rate was closely related to some properties of the substrate. In this regard, it has been reported that in the presence of high nutrient availability, plant response to mycorrhizal inoculation is limited, although this response will depend on several factors, including pH, which can affect nutrient uptake (mainly P) by the plant (Martín-Alonso *et al*., 2017).

In this work, the availability of nutrients in the substrate did not limit the colonization rate; on the contrary, it influenced the degree of root colonization. However, Ji and Bever (2016) report that plants growing in low phosphorus conditions, such as those developed in the S2 substrate, increase amino acid exudation, reducing sugars and carboxylic acids, which favors mycorrhization. In addition to the above, total porosity; water retention capacity and aeration capacity were optimal in both substrates, which favored colonization.

Table 5. - Pearson's correlation coefficient between the chemical-physical characteristics of the substrate and the variables of the root system evaluated in *S. mahagoni*

	pH	MO	N	P	K	CE	PT	DMP
Col	0,859*	0,598	0,885*	0,887*	0,754*	0,834*	0,884*	0,692
LRP	0,008	0,412	-0,538	-0,126	-0,183	-0,611	0,804*	-0,628
CRP	-0,626	0,646	0,108	-0,381	-0,551	0,150	0,852*	0,191
CRS	0,699	0,392	0,676	0,708	0,741	0,696	0,822*	0,542

*Correlations significantly different from zero, with a confidence level of 95.0 %; LRP: length of the main root; CRP and CRS: number of primary and secondary roots; Col: percentage of mycorrhizal colonization; PT: total porosity; DMP: mean particle diameter; MO: organic matter.

In the case of the length of the main root, quantity of primary and secondary roots, it is possible that the positive correlation with total porosity is due to the percentage of porosity, which is above 75 % in both substrates, a characteristic that facilitates infiltration, effective root depth and air circulation, stimulating the uniform and abundant development of the root system, which favors plant growth and development (Abad *et al*., 2005).

In the principal component analysis for the chemical-physical characteristics of the substrates with the variables evaluated (Figure 1), the formation of two components was observed, which explained 86.35 % of the total variability, 61.18 % of the variance being explained by principal component 1 (horizontal axis).

The variables that contributed most to the formation of the first component were the percentage of mycorrhizal colonization, number of secondary roots, total porosity, electrical conductivity, substrate pH and N, P, K and DMP contents. For the second component, the variables with the greatest contribution were the length of the main root, the number of primary roots and the percentage of organic matter in the substrate.

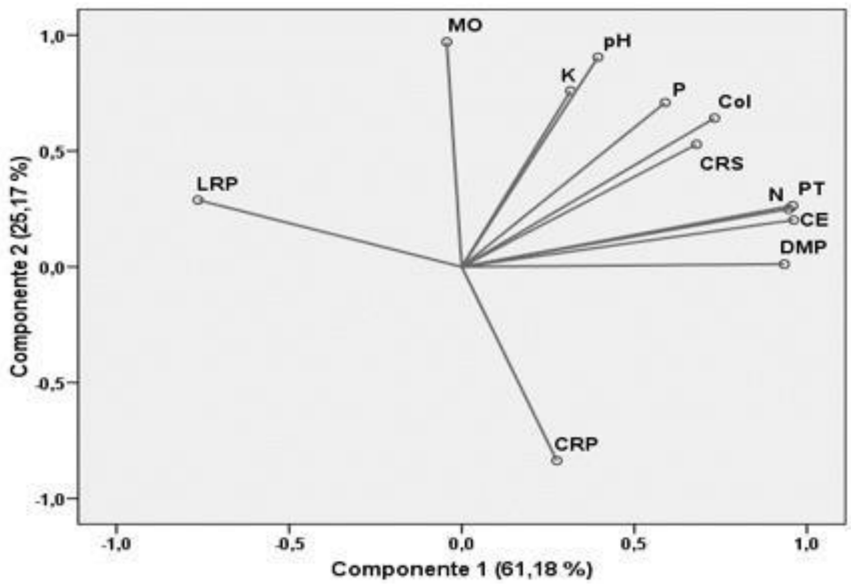

Figure 1. - Results of the Principal Component Analysis

LRP: length of main root; CRP and CRS: number of primary and secondary roots; Col: percentage of mycorrhizal colonization; PT: total porosity; DMP: mean particle diameter; MO: organic matter.

Figure 1 shows how substrate pH has a close relationship with the variables related to nutrient availability, which are grouped in the upper right quadrant, this result may indicate that pH is the main factor that will determine the degree of nutrient availability, coinciding with Martín-Alonso *et al*., (2017), who point out that nutrient availability has a high relationship with pH which determined the response of *Canavalia ensiformis* to mycorrhizal inoculation.

In this regard, Kawahara *et al*., (2016) propose that the relationship established between substrate pH ranges and the effect of mycorrhizal colonization is truly complex, depending not only on the fungal species, but also on the type of soil, the form in which the nutrients are found (fundamentally P and N and other elements such as Cu, Zn, Mo, B, etc.) and to a lesser extent on the plant species on which it develops.

Nutritional analysis

Regardless of the corresponding effect among the factors evaluated, the plants with the greatest amount of nutritional reserves were those produced in the inoculated treatments. Figure 2 shows the vector trend for relative aerial biomass (change in aerial biomass with respect to the control) of this study. According to the vector nomograms and taking as a reference point the nutritional status of the plants of the control treatment (T9), in nitrogen the plants of the non-mycorrhizal treatments (T1 and T2) had a dilution effect and those of the mycorrhizal treatments (T3, T5, T7 and T8) had a dilution effect, (T3, T5, T7 and T8) and (T4 and T6), showed sufficiency and luxury consumption, respectively (Figure 2A), which indicates an increase in the absorption of this element through the symbiotic formation of root organs (Feijen *et al.,* 2018), thus

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allowing plants to be more resistant to different adverse changes that may exist in an ecosystem.

Alvarado-Hernández and Raigosa (2012) emphasize that nitrogen is a constituent of proteins, chlorophyll, nucleic acids and other plant substances. An adequate supply of nitrogen promotes plant growth, increases the biomass/root ratio, and is essential for the formation of stems, branches and leaves.

On the other hand, AMF have been shown to actively participate in the transfer of N from the soil to the host plant (Bücking and Kafle, 2015). From these premises, a positive effect of inoculation with *R. irregulare* on N uptake, on the increase in N concentrations in aerial biomass, as observed in Figure 2A and, consequently, an improvement of nitrogen nutrition of the species, could be expected.

Phosphorus supply (Figure 2B) was luxurious in the mycorrhizal treatments (T3, T4, T5, T6, T7 and T8), but not in the non-mycorrhizal treatments (T1 and T2), which showed a dilution in the leaf tissue and therefore did not provide sufficient quantities. López and Alvarado (2010) suggest that under these conditions the element under study can limit growth. The consumption of luxury in mycorrhizal plants is denoted by the greater displacement of each vector towards the upper right corner of Figure 2B. In this context, the results obtained on phosphorus uptake in this study show that AMF played a very important role in the translocation of this nutrient to the forest species evaluated, since the fungal hyphae act as an extension of the plant root, allowing the absorbent length of the root to grow and consequently soil exploration to increase as well. The roots can reach where the phosphorus is located and thus facilitate phosphorus uptake (Mei *et al*., 2019). In addition, mycorrhizal association has been observed to increase phosphorus content in *Swietenia mahagoni* leaves (Falcón *et al*., 2020).

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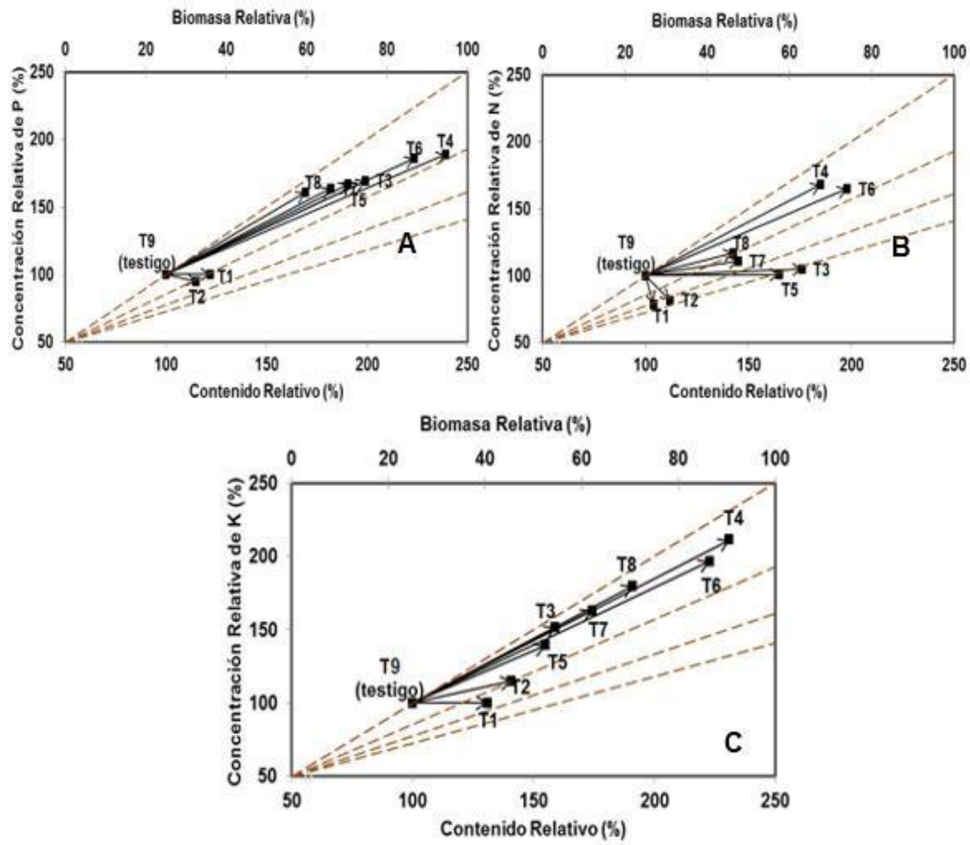

Figure 2. - Vector nomogram of the nutritional status of nitrogen (N), phosphorus (P) and potassium (K) of *S. mahagoni* seedlings at the end of the crop

With respect to potassium, the plants of the mycorrhizal treatments (T3, T4, T5, T6, T7 and T8) had in common luxury consumption effects; however, this response was more representative in treatments T4 and T6. In seedlings of treatments T1 and T2, a sufficiency effect was recorded, so this element does not limit the increase in dry weight (Figure 2C). According to Alvarado-Hernández and Raigosa (2012), potassium, after nitrogen is the essential element required in greater quantities by the plant. The same authors argue that most plant species have a preference for the absorption of this nutrient, since it plays a role as a transporter of other elements, in addition to being essential for osmoregulation and stomatal control.

It is interesting to note that the addition of different AMF has been effective in improving the nutritional status of aboveground biomass and growth of *S. mahagoni*, despite the phosphorus concentrations in the substrates, as some studies report that the effect of mycorrhizal inoculation can be inhibited in the presence of high phosphorus contents (Ji and Bever, 2016). However, others have found that plants inoculated with efficient AMF strains can achieve effective mycorrhizal performance, even in substrates with high phosphorus concentrations, provided that other nutrients limit their growth and development (Mei *et al*., 2016).

Similar results were found by Gómez *et al*., (2018), when investigating the variation of nutritional efficiency and growth of four forest species (*Pachira quinata (Jac.) W.S. Alverson, Gmelina arborea Roxb, Eucalyptus sp. and Acacia mangium Willd.)*, by infection with four AMF inocula, where the efficiency of macro- and micronutrient uptake was higher in inoculated plants than in non-inoculated plants, especially in soils with low available phosphorus.

The results obtained at the end of the nursery culture showed that the best substrate for the establishment of the mycorrhizal association was S2 (20 % coconut husk + 60 % coconut fiber + 20% pine sawdust), but the best treatment for plant root growth was with this substrate and with the strains *Glomus cubense* and *Rhizophagus irregulare*.

Inoculation with the mycorrhizal strains improved the nutritional status of the plants. These results can support decision making in reforestation activities related to S. mahagoni species and its cultivation in nurseries with container technology.

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