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INOCULATION OF TREE SPECIES WITH MYCORRHIZAL FUNGI FERTILIZED WITH ORGANIC FERTILIZER AND STEEL SLAG IN A LEGAL RESERVE AREA

João Lucas Boldt
Universidade Federal do Sul e Sudeste do Pará
jlucasboldt@gmail.com

Eduardo Lucas Terra Peixoto afiliação
Universidade Federal do Sul e Sudeste do Pará
eltpeixoto@unifesspa.br

Gustavo Ferreira de Oliveira
Universidade do Estado de Santa Catarina
gf.oliveira90@hotmail.com

Andréa Hentz de Mello
Universidade Federal do Sul e Sudeste do Pará
andreahentz@unifesspa.edu.br

ABSTRACT: Native species are the most appropriate and effective from the point of view of adaptation compared to exotic species for reforestation in the Amazon. This work aimed to present a forest production model combining the planting of jatobá (*Hymenaea courbaril* L.), sapucaia (*Lecythis pisonis* Camb.) and andiroba (*Carapa guianensis* Aubl) seedlings inoculated with arbuscular mycorrhizal fungi (AMF) and fertilized with vermicompost and steel mill slag in an area of degraded soil. The experiment was implemented in January 2014 in an experimental area at Fazenda Cristalina, São Domingos do Araguaia/PA, in an experimental design consisting of 1 block, containing subdivided plots with 6 treatments, 4 replications and 3 plant species with 16 plants each. portion. The treatments were: 1-control, 2-inoculated with mycorrhizal fungi (IN), 3-vermicompost (V), 4-slag (ESC), 5-inoculated with mycorrhizal fungi+vermicompost (INV) and 6-inoculated with mycorrhizal fungi +slag (INESC). The isolated use of vermicompost, mycorrhizal fungi and steel slag did not promote significant improvements in the development of sapucaia, andiroba and jatobá seedlings. For these species, it is recommended to use the combination of mycorrhizal fungi + slag or mycorrhizal fungi + vermicompost. Species inoculated with AMF plus vermicompost constitute an efficient production technology to compose degraded areas.

KEYWORDS: Biological inputs, Environmental recovery, Sustainability.

INOCULAÇÃO DE ESPÉCIES ARBÓREAS COM FUNGOS MICORRÍZICOS ADUBADAS COM FERTILIZANTE ORGÂNICO E ESCÓRIA DE SIDERURGIA EM ÁREA DE RESERVA LEGAL

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RESUMO: As espécies nativas são as mais apropriadas e eficazes do ponto de vista da adaptação em comparação as exóticas para reflorestamento na Amazônia. Este trabalho teve como objetivo apresentar um modelo de produção florestal combinando o plantio de mudas de jatobá (*Hymenaea courbaril* L.), sapucaia (*Lecythis pisonis* Camb.) e andiroba (*Carapa guianensis* Aubl) inoculadas com fungos micorrízicos arbusculares (FMA) e fertilizadas com vermicomposto e escória de siderurgia em área de solo degradado. O experimento foi implantado em janeiro de 2014 em uma área experimental na Fazenda Cristalina, São Domingos do Araguaia/PA, em delineamento experimental composto por 1 bloco, contendo parcelas subdivididas com 6 tratamentos, 4 repetições e 3 espécies de plantas com 16 plantas em cada parcela. Os tratamentos foram: 1-testemunha, 2-inoculadas com fungos micorrízicos (IN), 3-vermicomposto (V), 4-Escoria (ESC), 5-inoculadas com fungos micorrízicos+vermicomposto (INV) e 6-inoculadas com fungos micorrízicos+escória (INESC). A utilização isolada de vermicomposto, fungos micorrízicos e escória de siderurgia não promoveram melhorias significativas no desenvolvimento de mudas de sapucaia, andiroba e jatobá. Para essas espécies, recomenda-se que utilize a combinação de fungos micorrízicos + escória ou fungos micorrízicos + vermicomposto. As espécies inoculadas com FMA acrescidas de vermicomposto, constituem-se em uma tecnologia de produção eficiente para compor áreas degradadas.

PALAVRAS-CHAVE: Insumos biológicos, Recuperação ambiental, Sustentabilidade.

INOCULACIÓN DE ESPECIES ARBÓREAS CON HONGOS MICORRÍZICOS FERTILIZADOS CON FERTILIZANTE ORGÁNICO Y ESCORIA DE ACERO EN UN ÁREA DE RESERVA LEGAL

RESUMEN: Las especies nativas son las más apropiadas y efectivas desde el punto de vista de la adaptación en comparación con las especies exóticas para la reforestación en la Amazonía. Este trabajo tuvo como objetivo presentar un modelo de producción forestal combinando la siembra de plántulas de jatobá (*Hymenaea courbaril* L.), sapucaia (*Lecythis pisonis* Camb.) y andiroba (*Carapa guianensis* Aubl) con hongos micorrízicos arbusculares (HMA) y fertilizadas con vermicompost y escoria de acería en una zona de suelo degradado. El experimento se implementó en enero de 2014 en un área experimental en Fazenda Cristalina, São Domingos do Araguaia / PA, en un diseño experimental que consta de 1 bloque, que contiene parcelas subdivididas con 6 tratamientos, 4 repeticiones y 3 especies de plantas con 16 plantas cada una. . Los tratamientos fueron: 1-control, 2-inoculado con hongos micorrízicos (IN), 3-vermicompost (V), 4-escoria (ESC), 5-inoculado con hongos micorrízicos + vermicompost (INV) y 6-inoculado con hongos micorrízicos + escoria (INESC). El uso

aislado de vermicompost, hongos micorrízicos y escoria de acero no promovió mejoras significativas en el desarrollo de plántulas de sapucaia, andiroba y jatobá. Para estas especies, se recomienda utilizar la combinación de hongos micorrízicos + escoria u hongos micorrízicos + vermicompost. Las especies inoculadas con HMA más vermicompost constituyen una tecnología de producción eficiente para componer áreas degradadas.

PALABRAS CLAVES: Insumos biológicos, Recuperación ambiental, Sostenibilidad.

INTRODUCTION

The Amazon is considered one of the biggest biomes in biodiversity in the planet, in flora and fauna, being currently recognized as the last agriculture frontier from Brazil, in which, from the end of XX century, this region has been target of intensive exploratory activities of the most diverse natural resources (VELHO, 1981).

The logging in the Amazon Forest has been focus of world concern and, in some cases, has taken species of great economic values for the list of extinction risk. However, the logging in the region performs relevant role for the productive activities that create job and income, mainly in Pará state (HENTZ et al., 2011).

This way, this region needs the research to attend the increasing demand of more sustainable forest products, such the practice of reforestations with native species and the agroforestry systems (SAFs), which are the most indicated to achieve the aim of produce sustainably in the region (HOMMA et al., 1998).

Thus, the area of legal reserve represents important role for the biome sustainability, because it is necessary for the sustainable use of the natural resources, conservation and rehabilitation of the ecological processes (Novo Código Florestal, 2012). Therefore, the necessity of study native species as alternative to recompose areas of the Amazon biome is of Paramount importance, due to market conditions and specially the offer of low impact extractivism (HENTZ et., 2011).

In the Amazon the use of biological incomes for the production of tropical native species is one technology tuned with the ecologically correct and environmentally acceptable speech, the incomes as arbuscular mycorrhizal fungi (AMF), help the plants in their development, mainly in degraded areas with soils extremally poor as the Amazonians, being able to contribute to the survival in these areas (MOREIRA; SIQUEIRA, 2006; HENTZ et al., 2011).

Besides the AMF, the fertilizing with organic compounds can also contribute to the perennialization of forest species, such the vermicompost and the soil correction as steel slag. The vermicompost is produced with worm help and presents as product an elevated compound with elevated nutritional value, containing phosphor (P), calcium (Ca) and potassium (K) that can be used in the composition of substrates for the production of forest plant seedlings (STEFFEN et al., 2011).

The implementation of substrates from mineral origin appears as an option for planting the forest species. The steel slag contains several nutrients for plants and They can also be used in the agriculture as soil corrective and also as a fertilizing able to supply some nutrients for the plants, specially the Silicon (Si).

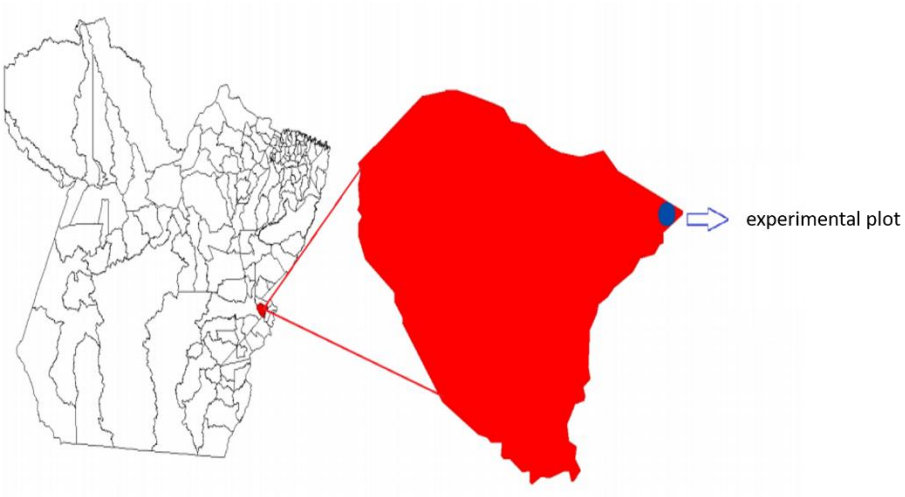
This work aimed to show a model of forest production that combined the seedling planting of *jatobá* (*Hymenaea courbaril* L.), *sapucaia* (*Lecythis pisonis* Camb.) and *andiroba (Carapa guianensis* Aubl) inoculated with arbuscular mycorrhizal fungi (AMF) and fertilizing with vermicompost and steel slag in area of degraded soil in the Cristalina farm in São Domingos do Araguaia – PA.

MATERIAL AND METHODS

The present study was implemented in January 2014 in the area of legal reserve from the Cristalina farm in São Domingos do Araguaia-PA (Figure 1), (48º29'055'' S 05º36'135" W), with the species *andiroba (Carapa guianensis* Aubl.), *jatobá* (*Hymenaea courbaril* L.) and *sapucaia* (*Lecythis pisonis* Camb.)

inoculated with AMF and fertilizing with vermicompost and steel slag.

Figure 1. Location of São Domingos city, Pará (at left) and Cristalina farm (at right).



Source: GAMA, (2015).

The climatic classification of the city according to Köppen is Afi with annual average temperature of 27.4 ºC, with average of the maximums of 32.2 ºC and minimums of 22.6 ºC. The annual average of total precipitation in the studied period was 1.487 mm (GAMA; HENTZ, 2017).

The soil from the experimental area was classified as Petric Plinthosol, characterized by their low potential of use (EMBRAPA 2013). The relief was characterized as slightly smooth and of small thickness with the presence of mother rock near the surface. Soil samples were collected in the experimental area and sent to the laboratory of soil fertility analysis from the Embrapa Amazônia Oriental (Table 1).

Table 1. Soil chemical characteristics in the layer (0-40 cm) of the experimental area in Cristalina farm in São Domingos do Araguaia - PA.

Characteristics	Value	Interpretation[6/]	Interpretation[7/]
	---------- Legal reserve area ----------		
pH in water (1:2.5)	5.3	Medium	-
P (mg/dm^3)[1/]	2.0	Medium	Low
K (mg/dm^3)[1/]	23	Low	Low
Na^+ (mg/dm^3)[1/]	14	-	-
Al^{3+} ($cmol_c/dm^3$)[2/]	1.3	High	High
Ca^{2+} ($cmol_c/dm^3$)[2/]	1.0	Low	Low
Mg^{2+} ($cmol_c/dm^3$)[2/]	0.3	Low	Low
SB ($cmol_c/dm^3$)[3/]	1.4	Low	Low
t ($cmol_c/dm^3$)[4/]	1.7	Low	-
m (%)[5/]	29.2	Low	-

[1/]Extractor of Mehlich -1 (Vettori, 1969); [2/]Extractor KCl 1 mol/L (Vettori, 1969); [3/]Sum of bases (SB) = Ca^{2+} + Mg^{2+} + K^++ Na^+.; [4/]CTC effective (t) = SB + Al^{3+}; [5/]Aluminum saturation (m) = 100 Al^{3+}/t.; [6/]Commission of soil fertility from Minas Gerais state (1989).; [7/]Recommendations of fertilization and liming for the Para state (2010).

The experimental design was composed of one block containing subdivided installments with six treatments four repetitions and three plant species (6 x 4 x 3 = 72 installments) with 16 plants in each installment. The block was divided in six rows with 12 installments. The treatments were 1- testimony, 2- inoculated with mycorrhizal fungi (IN), 3- Vermicompost (V), 4- Slag (SLA), 5- Inoculated with mycorrhizal fungi + vermicompost (INV) and 6- Inoculated with mycorrhizal fungi + slag (INESL).

The space between lines was 2.5 m x 2.5 m and 2.0 m x 2.0 m between seedlings, considering a firebreak of 5 m, totalizing a total area of 6401,8 m^2, corresponding to 0.64 ha. The total number of planting seedlings were 1152, 384 of each specie. The pit openings were performed with the help of motorized auger. The pits for planting had 25 cm of diameter and 30 cm of depth.

The hydrogel was used in all treatments, being added after the pit openings aiming to keep soil humidity for more time. Immediately after the application the seedlings were planted in the pits.

The initial evaluations for this work occurred in April/2014, the performed evaluations followed until the 365 days after the field planting, the seedlings of the evaluated forest species were acquired in the commercial nursery of Parauapebas-PA city after a period of six months of development. The AMF were originated from the Inoculum bank of the Faculty of Agricultural Science of Marabá (FCAM), being composed of 1 g of inoculum, containing a mix of the species *Glomus clarum* and *Glomus etunicatum*.

The AMF were inoculated in the moment of seedlings planting in the pits. The used steel slag was originated from donation of one steel company located in Marabá-PA city, being placed 100 g of its product in each pit. The vermicompost is originated from the Project "Introduction of the agroforest extension from Agronomy course through the creation of worms *Eisenia foetida* for the vermicompost production", produced in the earthworm of the Unity II from the Federal University from the South and Southeast of Para (UNIFESSPA).

Measurements were performed each 30 days and followed the pattern of temporal analysis during a period of 365 days measuring the plants silviculture characteristics (number of leaves, size and neck diameter). The average of the achieved results in silviculture measurements were processed through the software Sisvar (FURTADO, 2000) and following were evaluated about their normality and variance and the results were presented in figures and parameters with significative differences were highlighted with asterisks (*).

RESULTS AND DISCUSSION

The seedlings survival rates, independently of the treatments at the 365 days in the field, was considered satisfactory, from the 384 seedlings of

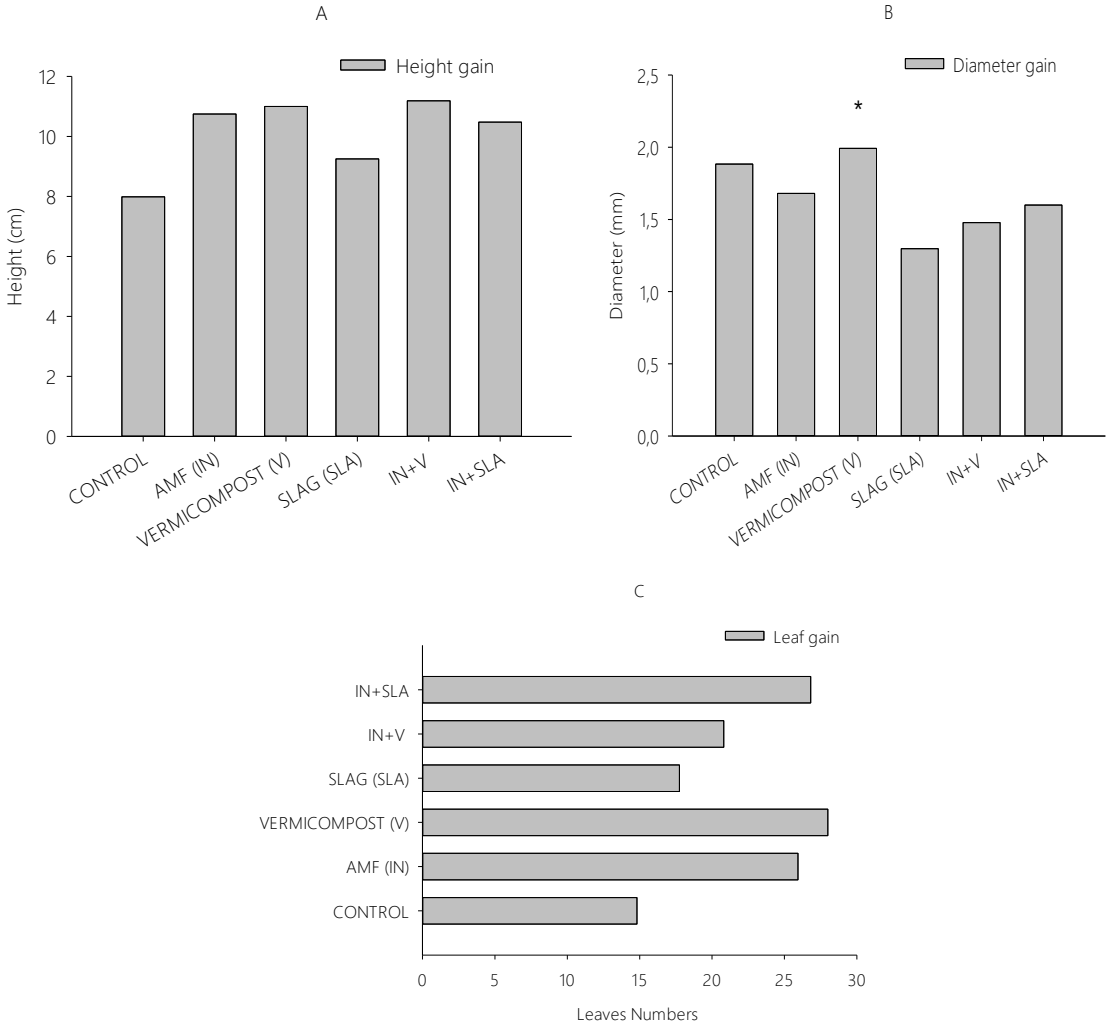
each specie, only 21 *jatobá*, 15 *sapucaia* and 18 *andiroba* seedlings dyed, representing a percentage of 94.54%, 96.1% and 95.32%, respectively.

Few studies with similar objective of this work were performed for the southeast region of Para, hampering the comparison of the data found in this research, however, in studies performed in Maraba by Hentz et al. (2017a) and Hentz et al. (2017b), evaluating the native forest species survival, the authors found survival rate in the field around of 80%, when inoculated with mycorrhizal fungi.

Franco et al. (2017) verified a survival rate of 77.5% ninety (90) days after planting the forest essences and native fructiferous from Maraba region, Para southeast. Even in different conditions of soil and weather from the ´present study, the results of this work corroborate that of the cited authors, showing the importance and efficiency of the mycorrhizal association with native species.

Sapucaia presented significative result for the diameter variable, in which the treatment with vermicompost provided best response for the evaluated parameter at 365 days in the field (Figure 2).

Figure 2. Growth parameters of the *sapucaia* seedlings evaluated in the different treatments at 365 days in the field.



AMF = Arbuscular mycorrhizal fungi, A=Height, B= Diameter, C= Leaves Numbers (*) refer to the treatments that presented significant statistical diferrence according to Ferreira (2000).
Source: Elaborated by the author.

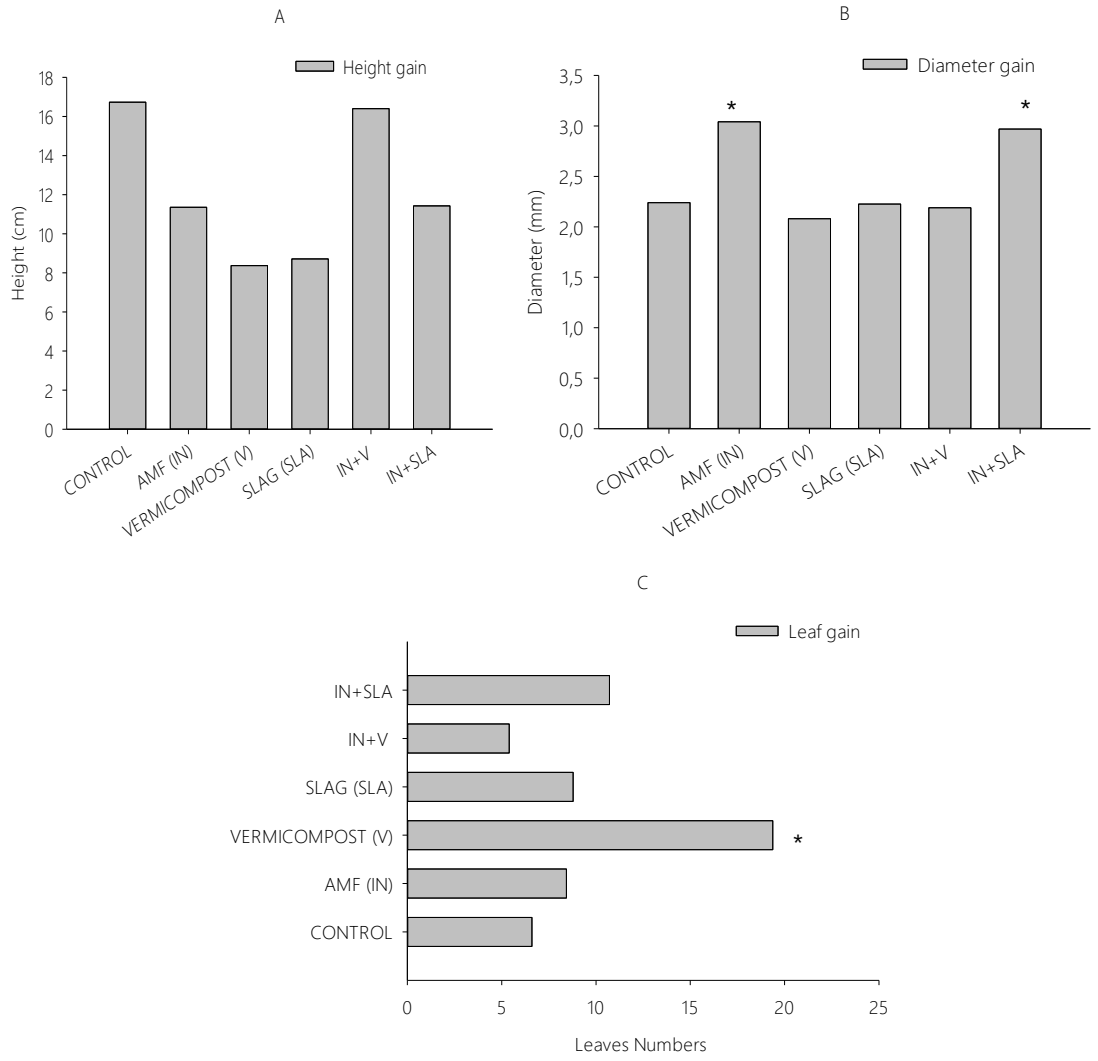
The major gain in size occurred in the treatment with inoculation of IN+V, following by the V, IN and IN+SLA treatments, respectively. The other parameters showed similar behaviors, in which the biggest gain in diameter occurred in the V treatment and the leaves gain in the V treatment, followed by IN+SLA and IN.

Thus, it can be observed that even in the low fertility of the soil in the area of legal reserve of the Cristalina farm, the *sapucaia* seedlings presented good development, which can be observed by the survival rate that is considered

very good when compared to the low chemical quality of the area soil type, the vermicompost was efficient in the promotion of perennialization of the seedlings in the field. The treatments with SLA and IN did not reflect in better development of the plants.

The treatments IN, IN+SLA and V presented significative difference for both the diameter and number of leaves parameters for *andiroba* in comparison to the control, respectively (Figure 3).

Figure 3. Growth parameters of the *andiroba* seedlings evaluated in the different treatments at 365 days in the field.



AMF = Arbuscular mycorrhizal fungi, A=Height, B= Diameter, C= Leaves Numbers (*) refer to the treatments that presented significant statistical diferrence according to Ferreira (2000).
Source: Elaborated by the author.

The other treatments did not present statistical difference when compared to the testimony for the specie *andiroba*, however, it can be observed that the biological income, the organic fertilizing and the slag associated to the AMF played important role for the seedlings' maintenance in the field.

The growth parameters of the andiroba seedlings were benefited by the AMF symbioses, followed by the vermicompost and the mineral fertilization, these results show that the growth organic inducers play the function of promote the development and survival of the forest specie in adverse conditions of soil fertility, besides to present significative result in combination to both organic and mineral fertilizing (BOFF et al., 2014; SANTOS 2014; FRANCO et al., 2017).

For the *jatobá* specie the growth parameter that presented significative statistic result was the diameter gain, there was no significative difference for the heigh gain and leaves, respectively (Figure 4).

It was observed that the association between IN+V favored the best plant development, highlighting the IN is a "facilitator" of nutrition or vegetal tolerance to the toxicity of the added compounds, the isolated effects of IN, V and SLA in the seedling were low.

Steffen et al. (2011) evaluated the seedlings development of two forest species and got similar results to this experiment, in which the vermicompost associated to the natural fertilizing provided bigger development of the aerial part, it was verified that high doses of isolated vermicompost can delay the development of plants of forest species.

Moreover, the association of mycorrhizal fungi and other substrates favors the plant development by the fact the first improve the absorption area of water and soil nutrients by the plant roots, mainly in soils in which there is low natural fertility, characteristic of degraded area in the present study (MOREIRA, SIQUEIRA, 2006).

Figure 4. Growth parameters of the *jatobá* seedlings evaluated in the different treatments at 365 days in the field.

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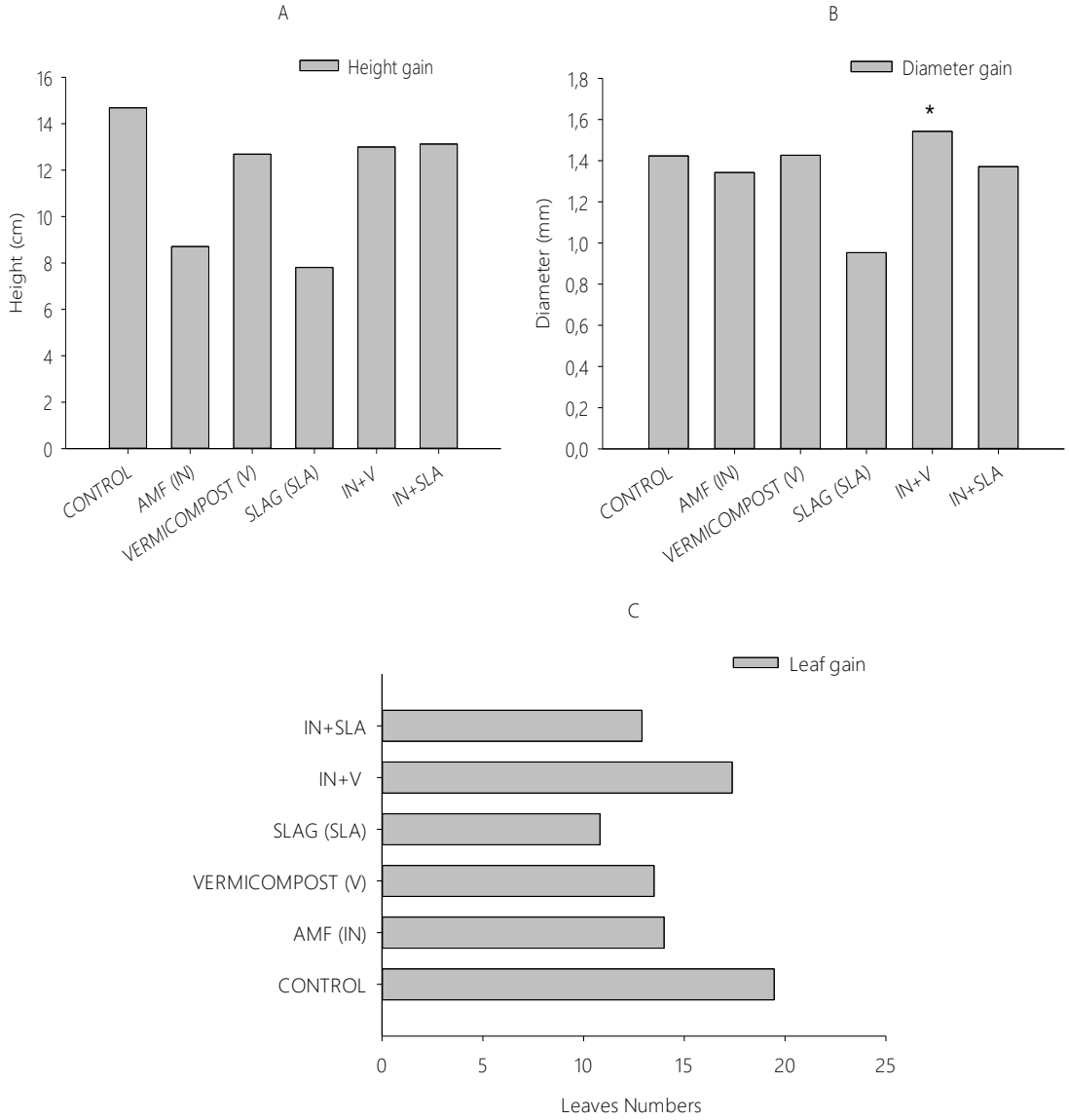

AMF = Arbuscular mycorrhizal fungi, A=Height, B= Diameter, C= Leaves Numbers (*) refer to the treatments that presented significant statistical diferrence according to Ferreira (2000).
Source: Elaborated by the author.

Besides to promote the improvement in the nutritional aspects of plants, the fungi help the plant to acquire bigger survival capacity to long dry or raining periods and to the pest attacks, expanding their initial ability of growth and stabilization (HENTZ et al., 2011). Thus, it can be stated that the association of organic fertilizing +

mycorrhizal potentialized the waited effects in the present study.

In degraded areas as in the Cristalina farm, with shallow soils, plinthite presence and low fertility, the mycorrhizal fungi action was efficient promoting bigger taxa of seedlings survival and bigger development, corroborating Siqueira and Moreira (1996) study, which got similar results.

In spite the slag, isolated analyzed, showed low potential in the development of the studied seedlings, researches prove that the use of this subproduct in bigger quantities can promote the better development of some species and can intensify the absorption and the nutrients supply by the plants due to its corrective power (PRADO et al., 2003).

Sousa Junior (2010) evaluated the effects of steel slag application in relation to its Si accumulation in the sugar cane aerial part and the study showed the soil correction using this product increased the Si content disponible in the soil and the leaves content of sugar cane

Moreover, it is worth to highlight that the slag did not interfere in the action of the mycorrhizal fungi promoting the plants of this treatment the third major growth rate of development, represented in the seedlings height at 365 days after planting in the field. It is important stand out the necessity of continuation of new studies as this one, which are important to the recuperation of legal reserve areas and for the restoration and maintenance of the Amazon biome.

CONCLUSION

The isolated utilization of vermicompost, mycorrhizal fungi and steel slag did not promote significative improvement in seedlings development of *sapucaia*, *andiroba* and *jatobá*. For these species is recommended the association between mycorrhizal fungi + slag or mycorrhizal fung + vermicompost.

The species inoculated with *Glomus clarum* and *Glomus etunicatum* added of vermicompost constitute a model and technology of efficient production

to contribute with recuperation of degraded areas, in the studied conditions, in the legal reserve area.

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