



Symbiotic compatibility between arbuscular mycorrhizal fungi (autoctone or exotic) and three native species of the Caatinga in different phosphorus levels

João Ricardo Gonçalves de Oliveira^{1*}, Geraldo Milanez de Resende², Nataniel Franklin de Melo² and Adriana Mayumi Yano-Melo³

¹Departamento de Micologia, Centro de Ciências Biológicas, Universidade Federal de Pernambuco, Rua Nelson Chaves, s/n., 50670-420, Recife, Pernambuco, Brazil. ²Embrapa Semiárido, Petrolina, Pernambuco, Brazil. ³Universidade Federal do Vale do São Francisco, Petrolina, Pernambuco, Brazil. *Author for correspondence. E-mail: jrgoliveira@yahoo.com.br

ABSTRACT. The aim of this study was to evaluate three plant species native to Caatinga (*Aspidosperma pyrifolium*, *Ziziphus joazeiro* and *Pseudobombax simplicifolium*) in response to inoculation with two arbuscular mycorrhizal fungi (autoctone: *Claroideoglomus etunicatum* or exotic: *Acaulospora longula*) and phosphate fertilization. The experiment was conducted in a greenhouse with a completely randomized design involving a factorial arrangement of three inoculation treatments (control, *C. etunicatum* or *A. longula*) and 4 levels of single superphosphate (0 - no added P_2O_5 , 12, 24 and 48 mg dm⁻³) in 10 repetitions. Under the conditions of this study, the inoculum of *C. etunicatum*, autoctone to the semi-arid region, showed great compatibility and efficiency in promoting plant growth and nutrient intake when compared to the exotic inoculum of *A. longula*. Plants of *A. pyrifolium* were not responsive to mycorrhization and phosphate fertilization. In soil with low phosphorus content, mycorrhized plants of *Z. joazeiro* and *P. simplicifolium* presented better vegetative development with high shoot dry weight. Mycorrhized plants of *Z. joazeiro* had a proportional increase in the levels of macro- and micronutrients at the phosphorus doses applied. Mycorrhizal symbiosis may have a fundamental role in the development of these species from the Caatinga.

Keywords: Semi-arid, mycorrhiza, endemic species.

Compatibilidade simbiótica entre fungos micorrízicos arbusculares (autóctone ou exótico) e três espécies nativas da Caatinga em diferentes níveis de fósforo

RESUMO. O objetivo do trabalho foi avaliar o desenvolvimento de três espécies vegetais nativas da Caatinga (*Aspidosperma pyrifolium*, *Ziziphus joazeiro* e *Pseudobombax simplicifolium*) em resposta à inoculação com dois fungos micorrízicos arbusculares (autóctone: *Claroideoglomus etunicatum* ou exótico: *Acaulospora longula*) e adubação fosfatada. O experimento foi realizado em casa de vegetação em delineamento inteiramente casualizado em arranjo fatorial com três tratamentos de inoculação (Controle, *C. etunicatum* ou *A. longula*) e quatro doses de superfosfato simples (0 - sem adição de P_2O_5 , 12, 24 e 48 mg dm⁻³), em dez repetições. Nas condições deste estudo, o inóculo de *C. etunicatum*, autóctone da região semiárida, demonstrou maior compatibilidade e eficiência na promoção do crescimento e nutrição das plantas quando comparado ao inóculo exótico de *A. longula*. Plantas de *A. pyrifolium* não foram responsivas à micorrização e adubação fosfatada. Em solo com menor teor de fósforo as plantas de *Z. joazeiro* e *P. simplicifolium* micorrizadas apresentaram melhor desenvolvimento vegetativo, com elevada produção de biomassa seca da parte aérea. Plantas de *Z. joazeiro* micorrizadas tiveram aumento nos teores de macro e micronutrientes proporcional às doses de fósforo aplicadas. Conclui-se que simbiose micorrízica pode ter papel fundamental no desenvolvimento destas espécies nativas da Caatinga.

Palavras-chave: Semiárido, micorriza, espécies endêmicas.

Introduction

The Brazilian semi-arid region covers an estimated area of 982,000 km² distributed in eight northeastern states, in addition to northern Minas Gerais (Silva et al., 2015). This region is home to a unique biome in the world, the Caatinga, which

presents rich plant diversity despite years of intense extrativism for obtaining wood and opening of grazing areas in addition to other agricultural activities. The biome is considered to have high environmental vulnerability (Castelletti, Silva, Tabarelli, & Santos, 2003), which combined with

low water availability, high average temperature and soil nutrient deficiency, characteristics of semi-arid regions (Martínez-García, Armas, Miranda, Padilla, & Pugnaire 2011), place even greater strains on plant development.

Arbuscular mycorrhizal fungi (AMF) are root symbionts of plants that add a new dimension to the soil/plant/microorganism system, directly and indirectly influencing soil nutrient cycling, thus being an important component of ecological plant succession and increasingly important for agriculture, agro-forestry, recovery of degraded areas and conservation of natural ecosystems (Covacevich, Echeverría, & Pagano, 2012).

Certain species of AMF feature great specificity with plant communities (Pagano et al., 2011) playing, according to standard plant succession, an important role in the composition and stability of these communities (Stürmer, Klauberg Filho, Hering de Queiroz, & Mendonça, 2006; Martínez-García & Pugnaire, 2011). Works with native species of AMF in other semi-arid regions have demonstrated great efficiency in their implementation, with advantages that can be extended to the time of transplanting, due to the maintenance of the biological properties of the soil (Barea et al., 2011) including the initial phase of revegetation (Alguacil, Torres, Torrecillas, Díaz, & Roldán, 2011).

Although it has been observed that native plants of the Caatinga present a mycorrhizal responsiveness modulated by the adverse conditions of the environment, such as low nutrient availability, including phosphorus (Sousa, Maia, Menezes, Sampaio, & Garrido, 2008) there are, as yet, few works that list the benefits of this symbiosis on survival and development of native plants in semi-arid regions (Maia, Silva, Yano-Melo, & Goto, 2010) and/or demonstrate the functional role of indigenous isolates from the biome in the development of native plants.

Considering the high diversity of AMF observed in the Caatinga (Goto, Silva, Yano-Melo, & Maia, 2010), optimization of phosphorus supply provided by mycorrhization (Smith & Smith, 2012) and the benefits in promoting the growth of native plants of other semi-arid regions subjected to inoculation with native AMF (Alguacil et al., 2011), this study aimed to test the efficiency of native and exotic mycorrhizal isolates of the Caatinga biome in the development and accumulation of nutrients of three native species (*Aspidosperma pyrifolium* Mart., *Ziziphus joazeiro* Mart. and *Pseudobombax simplicifolium* A. Robyns) in the biome's own soil, supplemented or not with single superphosphate.

Material and methods

Procedure and experimental design

The experiment was developed under controlled conditions in a greenhouse, using soil (Acrisol) with the following physical and chemical attributes: 672.9, 250.1 and 76.94 g kg⁻¹ of sand, silt and clay, respectively, pH 5.8, electrical conductivity (E.C.) 0.51 dS m⁻¹, phosphorus (P) 6.14 mg dm⁻³, potassium (K) 0.35 cmol_c dm⁻³, calcium (Ca) 1.5 cmol_c dm⁻³, magnesium (Mg) 1 cmol_c dm⁻³, sodium (Na) 0.03 cmol_c dm⁻³, aluminium (Al) 0.1 cmol_c dm⁻³, iron (Fe) 34.1 mg dm⁻³; cationic exchange capacity (CEC) 7.5 cmol_c dm⁻³ and 10.96 g kg⁻¹ of organic matter (O.M.).

The soil was autoclaved three times for one hour at 121°C on three consecutive days, remaining at rest for 15 days. After this period, P in the form of single superphosphate (P₂O₅) was homogenized into the soil according to each treatment of phosphate fertilization and packaged in bags with a capacity of up to 2.5 kg. The experiment was conducted in a completely randomized design with a 3 × 4 factorial arrangement, of which 3 are inoculation treatments (control - not inoculated and inoculated with *Claroideoglomus etunicatum* (Becker & Gerd.) C. Walker & A. Schüssler or with *Acaulospora longula* Spain & Shenck) and 4 levels of phosphorus (0 – no P₂O₅ added, 12, 24 and 48 mg dm⁻³ of P₂O₅), in 10 repetitions. The soil without addition of P represents the natural fertility of the soil (6.14 mg dm⁻³) and in this way the treatments were designated as: P6, P12, P24 and P48.

Preparation of mycorrhizal isolates and seedlings

Isolates of *C. etunicatum* (UNIVASF06) and of *A. longula* (UNIVASF12) were propagated in the greenhouse, in pots containing a previously disinfected sand:soil (1:1 v/v) substrate and having sorghum [*Sorghum bicolor* (L.) Moench.] as host plant for three months. The inoculum produced was evaluated on the basis of the number of glomerospores using the techniques of decanting and wet sieving (Gerdemann & Nicolson, 1963), followed by centrifugation in water and sucrose (40% p/v) (Jenkins, 1964), and counting held in plates (grooved) under a stereomicroscope (40×). Upon counting the glomerospores, it was possible to determine the rate to be used as soil-inoculum, which contained about 200 glomerospores, in addition to fragments of colonized root and mycorrhizal mycelium to be deposited in the vicinity of the plant's roots.

The seedlings of *A. pyrifolium*, *Z. joazeiro* and *P. simplicifolium* were obtained from the germination of

seeds collected in an caatinga area of the Embrapa Semi-arid field station, located in Petrolina, State of Pernambuco, with a geographical coordinate of 09°04'14,8"S, 40°19'04,2" W, and 378 m (altitude). The seeds underwent a fumigation process with sodium hypochlorite (0.05% active chlorine) for 15 minutes followed by washings with distilled water, and seeds of *Z. joazeiro* were also passed through scarification, prior to distribution in trays containing autoclaved vermiculite. Seedlings of the three species with three definitive leaves were then transferred to previously prepared bags with soil in increasing doses of P in their respective inoculation treatment.

Experimental evaluations

The plants were monitored during the entire development phase in the greenhouse. After 120, 135 and 180 days of inoculation, respectively in *P. simplicifolium*, *Z. joazeiro* and *A. pirifolium*, the following parameters were measured: leaf area, shoot dry weight and root dry weight, nutrient content in the aerial part, mycorrhizal colonization and number of glomerospores. For determination of dry weight, samples of leaves and roots were placed in an oven (65°C) until constant weight was reached. After weighing, samples from the shoot were pounded in a Willye-type mill and portions of 0.5 g of sample were mineralized by nitric-perchloride digestion for subsequent determination of the levels of Ca, sulfur (S), Mg, Fe, zinc (Zn), copper (Cu) and manganese (Mn), by atomic absorption spectrophotometry, P and boron (B) by colorimetry, K and Na by emission flame photometry, in addition to nitrogen (N) by digestion of 0.1 g of the sample in sulfuric acid in the presence of a mixture of selenium, copper sulfate and potassium. All analyses followed the methodology described by Silva (1999). Mycorrhizal colonization was estimated by the intersection method of the quadrants (Giovannetti & Mosse, 1980), after diaphanization of the roots with 10% KOH and clearing with 10% H₂O₂, acidification in 1% HCl, and staining with Trypan Blue solution (0.05%) in lactoglycerol (Phillips & Hayman, 1970, modified). The number of glomerospores was evaluated by counting, using the techniques of Gerdemann and Nicolson (1963) and Jenkins (1964) for recovery of spores from the soil. The leaf area was estimated using the Li 3100 device (LI-Cor Inc. Lincoln, Neb., USA) and for determination of the resulting increase of the treatments an adapted formula of Weber et al. (2004) was used:

$$I (\%) = [(Tr - T) T^{-1}] \times 100$$

where:

I (%) = increment;

Tr = average value for the inoculated treatment;

T = average value of the uninoculated treatment.

Following the concepts established by Janos (2007) as to the responsiveness of plants to mycorrhization, this was determined by the formula:

$$MR (\%) = (A-B) \times A^{-1} \times 100$$

where:

A = dry weight of mycorrhized plants;

B = dry weight of unmycorrhized plants; and categorized in terms adapted from the work of Habte & Manjunath (1991) as one of the following: excessively responsive plants (>75%), highly responsive (50-70%), moderately responsive (25-50%), marginally responsive (<25%) or independent (no response to mycorrhization).

Statistical analyses

To satisfy the homogeneity of variance, the data of the number of glomerospores were transformed into log (x + 1) and those of mycorrhizal colonization on arcsine ($\sqrt{x/100}$). The data were subjected to analysis of variance and averages compared by the Tukey test ($p \leq 0.05$) and the significant variables for doses of P were subjected to regression analysis, which were performed using the SANEST program.

Results and discussion

The vegetative growth of plants of *A. pirifolium* was not influenced by the phosphate fertilization and/or inoculation with AMF. On the other hand, the growth of seedlings of *P. simplicifolium* and *Z. joazeiro* presented was influenced by mycorrhizal inoculation and phosphate fertilization, respectively. *P. simplicifolium* seedlings inoculated with *C. etunicatum* (Ce) had a greater number of leaves in relation to the control given only the natural fertility of the soil (P6), while for dry weight, there was an increase both in P6 and P12 using the same mycorrhizal inoculum.

For the plants of *Z. joazeiro* there was an interaction between mycorrhization and phosphate fertilization (Figure 1A-F), with pronounced development due to mycorrhization under smaller doses of P (6 and 12 mg dm⁻³). The leaf area of mycorrhized plants was greater than that observed in

uninoculated plants, increasing linearly with the doses of P (Figure 1D). Similarly, the shoot dry weight in plants associated with *Ce* had a 1515% increment in P6 and 448.12% in P12, whereas in plants inoculated with *A. longula* (*Al*) the increments were 1298.8% in P6 and 342.08% in P12 (Figure 1E).

In relatively smaller proportion, the root dry weight (Figure 1F) also reflected the development of plants, with increment values of 305% in P6 and 136.18% in P12 when inoculated with *Ce*, and 177.67% in P6 and 86.72% in P12 when inoculated with *Al*.

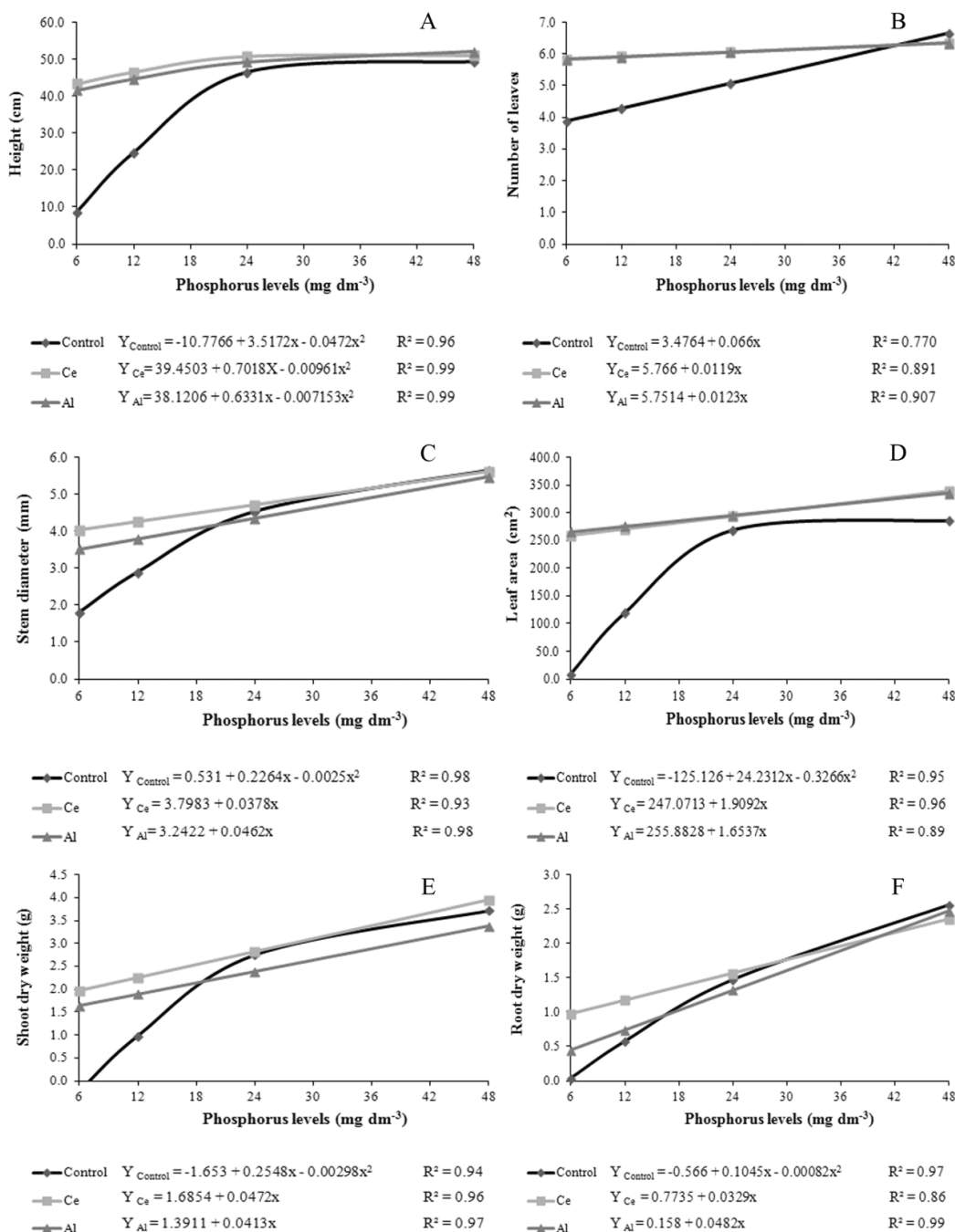


Figure 1. Height (A), number of leaves (B), stem diameter (C), leaf area (D), shoot dry weight (E) and root dry weight (F) of *Ziziphus joazeiro* Mart., inoculated or not with *Claroideoglomus etunicatum* (*Ce*) and *Acaulospora longula* (*Al*), in soil with increasing doses of phosphorus, after 135 days in the greenhouse.

The benefits of mycorrhization for *Z. joazeiro* were more evident when the plants were grown in soils with low availability of P. Similar results were reported to tomato (*Lycopersicon esculentum* Mill.) (Schroeder & Janos, 2004) and peanut (*Arachis hypogea* L. cv. Runner IAC 886) (Hippler & Moreira, 2013). In addition, in other semi-arid regions of the world, such as India and Africa, plants of *Acacia nilotica* Delile var. *cupressiformis* Stewart and *Albizia lebbek* Benth. (Sharma, Bhatia, & Adholeya, 2001), and fruit trees of *Ziziphus mauritiana* Lam. and *Tamarindus indica* L. (Guissou, 2009), respectively,

showed similar results, suggesting that AMF has played an important role for improving the growth of plants in limited availability of P. This relationship could result as much from a decrease in mycorrhizal colonization with increasing levels of P (Smith & Read, 2008) as from a smaller fungal contribution to the translocation of nutrients to the plant due to excessive drain of carbohydrates by the extraradicular mycelium (Sena, Labate, & Cardoso, 2004).

Mycorrhizal colonization and production of glomerospores reduced linearly with the addition of P in the plant species studied (Figure 2).

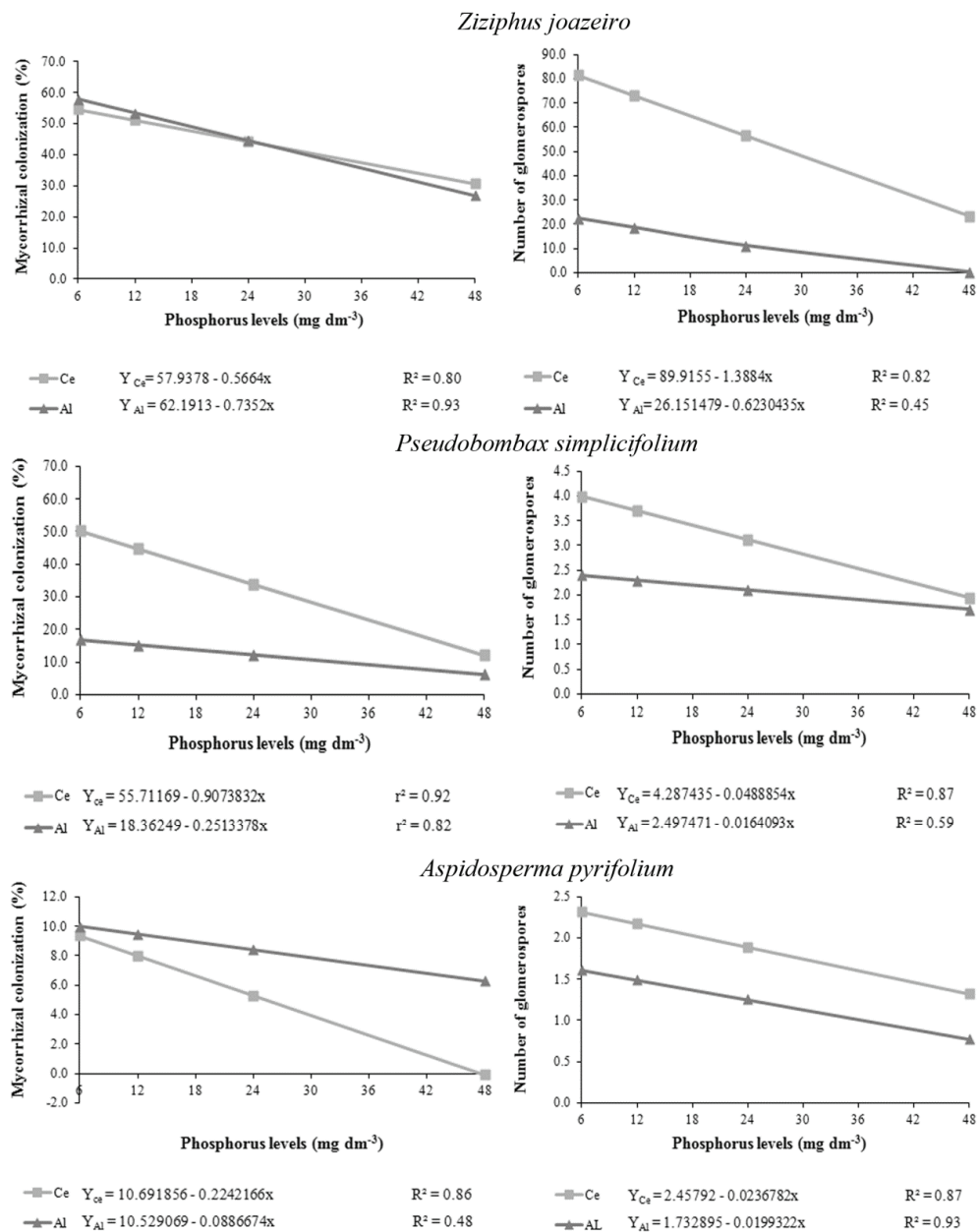


Figure 2. Mycorrhizal colonization and number of glomerospores in *Ziziphus joazeiro* Mart., *Pseudobombax simplicifolium* A. Robyns and *Aspidosperma pyrifolium* Mart., inoculated or not with *Claroideoglomus etunicatum* (Ce) and *Acaulospora longula* (Al) in soil with increasing doses of phosphorus, after 135, 120 and 180 days, respectively, in the greenhouse.

At the lowest concentration of P in the soil, the percentage of mycorrhizal colonization was observed to be low, especially in plants of *A. pirifolium* (9.35% *Ce* and 10% *Al*), showing similar values to those found by Souza, Maia, Sales, and Trufem (2003) under field conditions for the same plant species (7.2 to 18.6%). On the other hand, in plants of *Z. joazeiro* and *P. simplicifolium*, the root colonization by inoculum of *Ce* (54.54 and 50.27%, respectively) and *Al* (57.78 and 16.25%, respectively) reached percentages which provided developing plants with an accumulation of dry weight (Figure 1 and Table 1) and nutrient content (Figures 4 and 5).

According to Martínez-García & Pugnaire (2011), the AMF may exhibit specificity and/or preference for a particular plant host and this relationship can be mediated by the physical and chemical properties of the soil. For plants of *A. pirifolium*, no effect of the mycorrhizal isolates applied could be observed while increasing doses of P were seen to reduce mycorrhizal colonization and the production of glomerospores. In associations consisting of symbiotically cooperative isolates, high doses of P can trigger direction of photosynthates to other fungal activities, such as the increased production of vesicular structures in *G. aggregatum* (= *Rhizoglossum aggregatum*) and glomerospores in *G. custos* (= *Rhizoglossum custos*) (Kiers et al., 2011), in addition to the external mycelium of *G. etunicatum* (= *C. etunicatum*) (Melloni, Nogueira, Freire, & Cardoso, 2000).

Table 1. Number of leaves and shoot dry weight of plants of *Pseudobombax simplicifolium* A. Robyns (Imbiruçu), inoculated or not with *Claroideoglossum etunicatum* (*Ce*) and *Acaulospora longula* (*Al*) in soil with increasing doses of phosphorus (P6, P12, P24 and P48), after 120 days in the greenhouse.

Treatment	Phosphorus levels			
	P 6	P 12	P 24	P 48
Number of leaves				
Control	3.457 b	3.745 a	3.915 a	3.912 a
<i>Ce</i>	4.412 a	4.162 a	4.052 a	4.165 a
<i>Al</i>	4.080 ab	4.080 a	3.830 a	3.580 a
CV% = 12.22				
Shoot dry weight (g)				
Control	0.101 b	0.131 b	0.117 a	0.184 a
<i>Ce</i>	0.280 a	0.280 a	0.237 a	0.177 a
<i>Al</i>	0.143 b	0.148 b	0.113 a	0.100 a
CV% = 44.16				

Means followed by the same letter in the column do not differ by Tukey's test ($P \leq 0.05$).

Plants of *Z. joazeiro* and *P. simplicifolium* were not shown to be responsive to the highest dose of P applied (P48), independent of the mycorrhizal inoculum used (Figure 3).

However, at smaller doses of P, it was noted that the responsiveness of the plants to mycorrhization varied with the inoculum used. In soil with natural fertility (P6) and P12, plants of *Z. joazeiro*

mycorrhized by *Ce* and *Al* went from overly responsive to marginally responsive and non-responsive, respectively at P24. Plants of *P. simplicifolium* were categorized as highly responsive to mycorrhization up until the dose of P24, especially when the inoculum used was *Ce*, but when mycorrhized by *Al* the species presented moderate responsiveness at P6 and marginal responsiveness at P12.

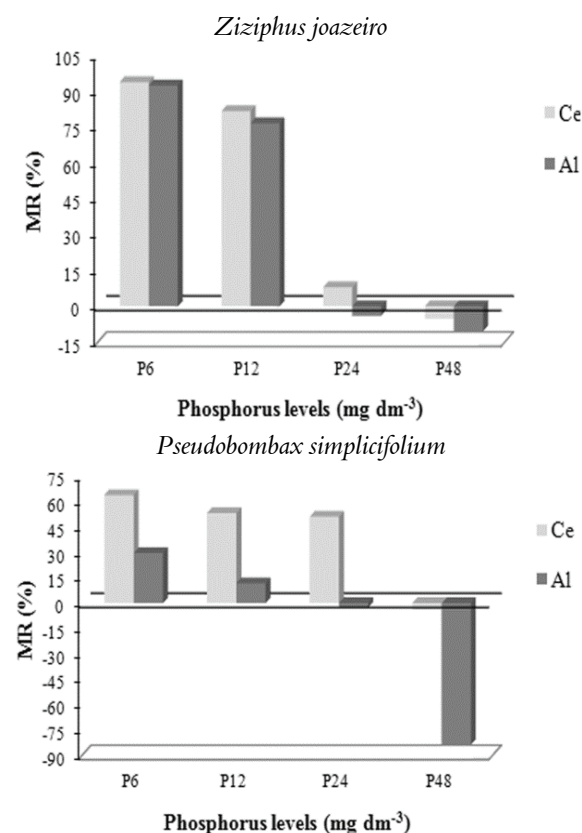


Figure 3. Mycorrhizal responsiveness (MR) of plants of *Ziziphus joazeiro* Mart. (Juazeiro) and *Pseudobombax simplicifolium* A. Robyns inoculated or not with *Claroideoglossum etunicatum* (*Ce*) and *Acaulospora longula* (*Al*), in soil with increasing doses of phosphorus, after 135 and 120 days, respectively, in the greenhouse.

In soils of semi-arid regions, nutrient deficiency is common and the climatic factors may contribute to making this environment severe and unfavorable to the growth of plants, making AMF highly important to the plant community (Martínez-García et al., 2011). Considering the results of responsiveness of plants of *Z. joazeiro* and *P. simplicifolium*, AMF possibly play an important role in the development of these species, especially at the natural fertility of soil of the Caatinga. Considering the adaptation of *Z. joazeiro* to the hydric deficiency and high evaporation of the Brazilian semi-arid region, studies must be conducted to verify whether

AMF contribute to drought-tolerance and by what mechanisms this might occur, in order to optimize the development of this species and reduce extractivist pressure.

Macro and micronutrient content were determined only for plants of *Z. joazeiro* as the shoot dry weight production in the other species studied was insufficient for analysis (Figures 4 and 5). There was similarity between the treatments only in the S content (Figure 4E), which showed a linear increase

with the addition of P to the soil. According to Malavolta (2006), there is an intrinsic relationship between S and P, it being likely that increased P availability in soil is related to the response observed to the content of S obtained by plants of *Z. joazeiro*. Working with a large number of tree species, Carneiro et al. (1996) were able to observe the same relationship in S content, principally in the species less responsive to the combined addition of P and mycorrhizae.

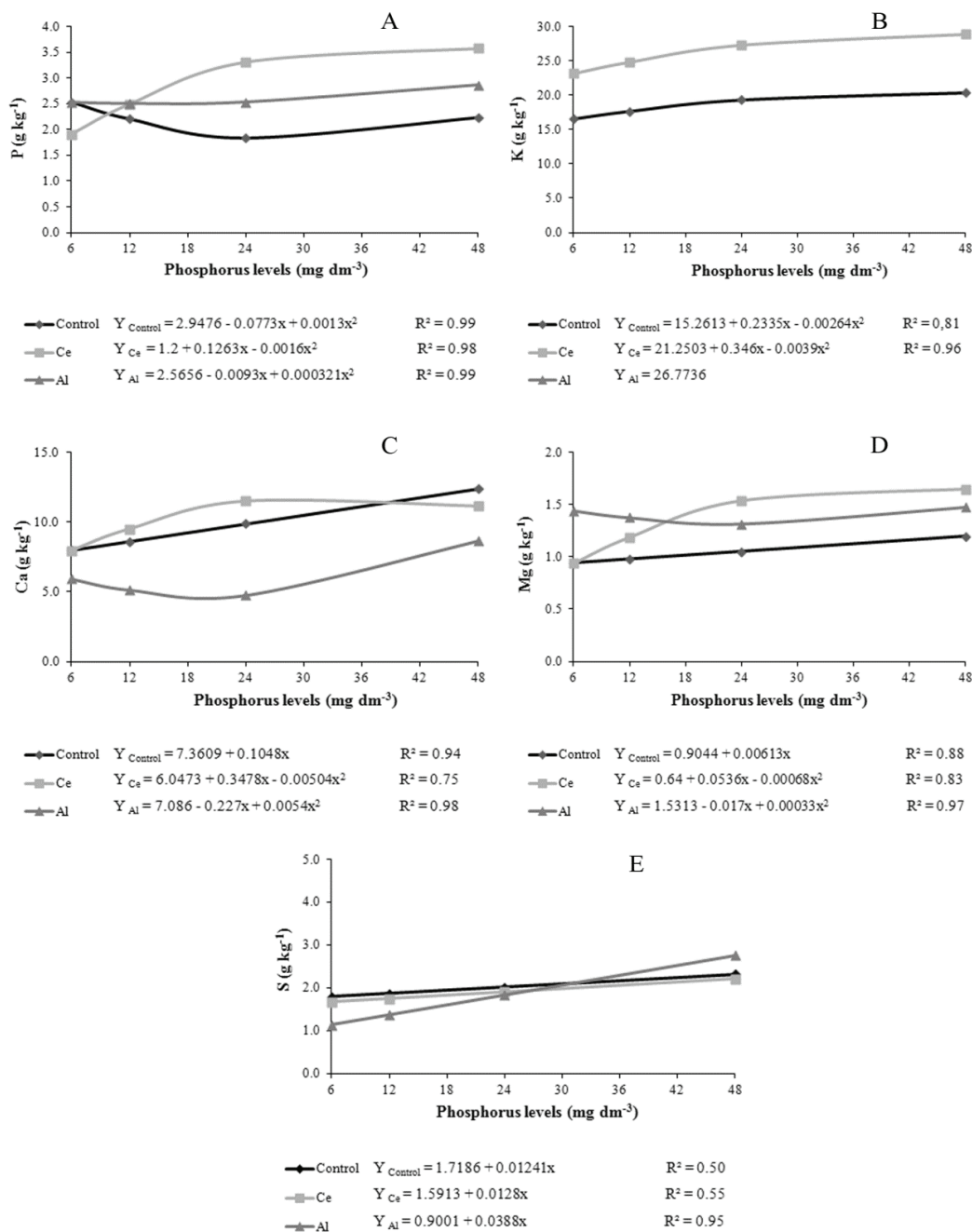


Figure 4. Macronutrient content (P, K, Ca, Mg, and S in g kg⁻¹) in the aerial part of plants of *Ziziphus joazeiro* Mart., inoculated or not with *Claroideoglomus etunicatum* (Ce) or *Acaulospora longula* (Al), in soil with increasing doses of phosphorus, after 135 days in the greenhouse.

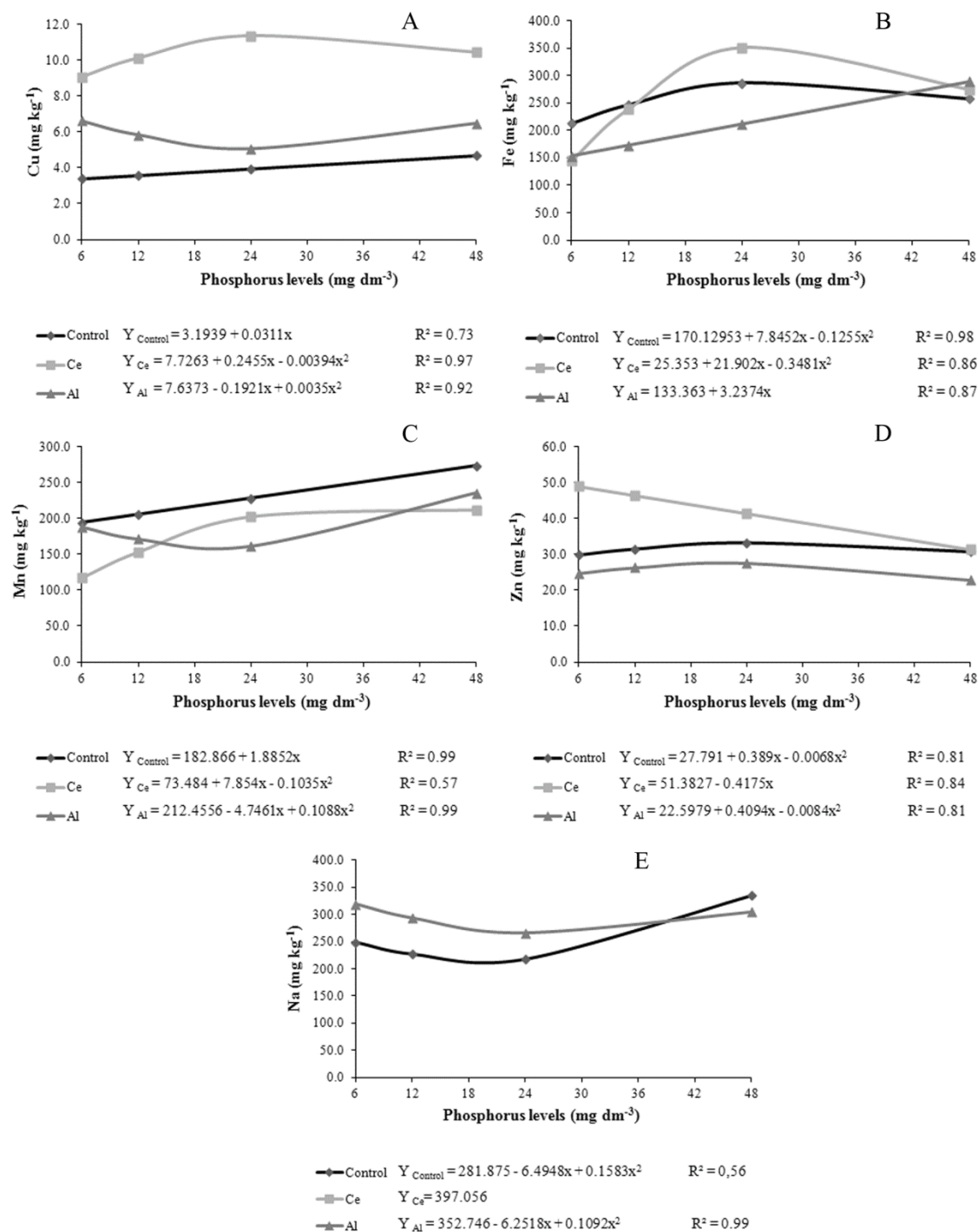


Figure 5. Micronutrient content (Cu, Fe, Mn and Zn in mg kg⁻¹) and Na (mg kg⁻¹) in the aerial part of plants of *Ziziphus joazeiro* Mart., inoculated or not with *Claroideoglomus etunicatum* (Ce) or *Acaulospora longula* (Al), in soil with increasing doses of phosphorus, after 135 days in the greenhouse.

Some studies have indicated an interaction between content of Zn and shoot dry weight in 60% of the inoculated treatments (Pouyu-Rojas, Siqueira, & Santos, 2006). In plants of *Z. joazeiro* mycorrhized by Ce, this relationship has not yet been established, having instead a decrease in this micronutrient

(Figure 5D), but not affecting the shoot dry weight (Figure 1E) and root dry weight (Figure 1F) of the plant, particularly at higher doses of P added to soil.

The other macro- and micronutrients showed specificity in relation to the dose of P and/or inoculum of AMF for accumulation, with the

addition of P exerting a differential effect on the isolates of AMF. Non-inoculated plants of *Z. joazeiro* showed a linear increase in the levels of Ca, Mg, Cu and Mn with the addition of P to the soil (Figure 4C and, D, 5A and C). For levels of K, Zn and Fe, the quadratic model was observed with maximum absorption at 44.22; 31.25 and 28.6 mg dm⁻³ of P₂O₅, respectively (Figure 4B, 5B, and 5D), in addition to P and Na, respectively, with minimal absorption at 29.73 and 20.51 mg dm⁻³ of P₂O₅ (Figure 4A and 5E).

In plants mycorrhized by *Ce*, the macro- and micronutrients showed quadratic behavior with the addition of P, except for the content of Zn which decreased linearly with the increase in P dosage, a fact probably related to precipitation in zinc phosphate (Mengel & Kirkby, 2001). It is estimated that the maximum absorption for contents of P, K, Ca and Mg would be, respectively, at 39.46; 44.36; 34.5 and 39.26 mg dm⁻³ of P₂O₅ and for the micronutrients Cu, Fe and Mn at 31.15; 31.46 and 38.31 mg dm⁻³ of P₂O₅.

On the other hand, it is estimated that plants mycorrhized by *Al* have maximum absorption of Zn at 24.36 mg dm⁻³ of P₂O₅, showing a linear increase only in Fe content with added P. It is estimated that the concentrations of P, Ca, Mg, Mn, Cu and Na in plants mycorrhized by *Al* would have the minimum absorption in 14.53; 22.52; 25.30; 21.81; 27.44 and 28.62 mg dm⁻³ of P₂O₅ respectively.

Pouyu-Rojas et al. (2006) verified that although P is a key element for the nutritional status of plants, differences in compatibility between the symbionts could not be neglected in their work. The application of an inoculum of *G. etunicatum* (= *C. etunicatum*), isolated from a coffee agroecosystem, promoted benefits in the development of 13 out of 16 tropical tree species, however there was no nutritional benefit to any species studied (Pouyu-Rojas et al., 2006). On the other hand, the *Ce* inoculum applied in plants from *Z. joazeiro* promoted further development and supply of nutrients in the aerial part, confirming the efficiency attributed to isolates of the species used and also the compatibility between the symbionts (Munkvold, Kjoller, Vestberg, Rosendahl, & Jakobsen, 2004). It should be noted that the source of the isolate may influence efficiency, because the isolated from *C. etunicatum* (Univasf 06) used in this experiment, coming from soil cultivated with banana trees in the semi-arid region (Yano-Melo, Trufem, & Maia, 2003), was more effective than the exotic isolate of *A. longula* (Univasf 12), which came from an area of Atlantic forest. In the same way as noted by Barea et al. (2011), the use of AMF isolates native to the

region where it is intended to apply them, proves to be an interesting strategy for greater efficiency in promoting development and nutritional intake of plants.

Conclusion

The inoculum of *Claroideoglossum etunicatum*, autoctone to the semi-arid region, proved to be more compatible and efficient in promoting plant growth and nutrient intake when compared to the exotic inoculum of *Acaulospora longula*.

Plants of *A. pyrifolium* are not responsive to phosphate fertilization nor mycorrhization for its vegetative development, but in plants of *Z. joazeiro* and *P. simplicifolium*, AMF possibly play an important role in the development of these species, especially at the natural fertility of soil of the Caatinga.

Mycorrhizal colonization and glomerospore production, independent of the host and inoculum used, reduces linearly with the addition of phosphorus to the soil.

Acknowledgements

To CNPq (# 562637/2010-9) for the financial aid and award of a doctoral scholarship (Oliveira, J.R.G.) and PQ grant (Yano-Melo, A.M.). To the Embrapa Semi-arid fieldstation for the use of its facilities. To the whole team of the Microbiology Laboratory of the Univasf/CCA and Biotechnology of the Embrapa Semi-arid field station, especially the students: Alan da Cunha Honorato, Jessica Coelho Valeriano and Tamires Dália Ferreira for their support and commitment.

References

- Alguacil, M. M., Torres, M. P., Torrecillas, E., Díaz, G., & Roldán, A. (2011). Plant type differently promote the arbuscular mycorrhizal fungi biodiversity in the rhizosphere after revegetation of a degraded, semiarid land. *Soil Biology & Biochemistry*, 43(1), 167-173.
- Barea, J. M., Palenzuela, J., Cornejo, P., Sánchez-Castro, I., Navarro-Fernández, C., López-García, A., ... Azcón-Aguilar, C. (2011). Ecological and functional roles of mycorrhizas in semi-arid ecosystems of Southeast Spain. *Journal of Arid Environment*, 75(12), 1292-1301.
- Carneiro, M. A. C., Siqueira, J. O., Davide, A. C., Gomes, L. J., Curi, N., & Vale, F. R. (1996). Mycorrhizal fungi and superphosphate on growth of tropical woody species. *Scientia Forestalis*, (50), 21-36.
- Castelletti, C. H. M., Silva, J. M. C. Tabarelli, M., & Santos, A. M. M. (2003). The remains of Caatinga? A preliminary estimate. In J. M. C. Silva, M. Tabarelli, M. T. Fonseca, & L. V. Lins (Org.), *Biodiversity*

- Caatinga: priority areas and actions for the conservation*, (p. 91-100). Brasília, DF: Ministério do Meio Ambiente, Universidade Federal de Pernambuco.
- Covacevich F., Echeverría, H. E., & Pagano, M. C. (2012). Arbuscular mycorrhizal fungi: Essential belowground organisms for earth life but sensitive to a changing environment. *African Journal of Microbiology Research*, 6(27), 5523-5535.
- Gerdemann, J. W., & Nicolson, T. H. (1963). Spores of mycorrhizal *Endogone* species extracted from soil by wet sieving and decanting. *Transactions of the British Mycological Society*, 46(2), 235-244.
- Giovanetti, M., & Mosse, B. (1980). An evaluation of techniques for measuring vesicular arbuscular mycorrhizal infection in roots. *New Phytologist*, 84(3), 489-500.
- Goto, B. T., Silva, G. A., Yano-Melo, A. M., & Maia, L. C. (2010). Checklist of the arbuscular mycorrhizal fungi (*Glomeromycota*) in the Brazilian semiarid. *Mycotaxon*, 113(4), 251-254.
- Guisso, T. (2009). Contribution of arbuscular mycorrhizal fungi to growth and nutrient uptake by jujube and tamarind seedlings in a phosphate (P)-deficient soil. *African Journal of Microbiology Research*, 3(5), 297-304.
- Habte, M., & Manjunath, A. (1991). Categories of vesicular-arbuscular mycorrhizal dependency of host species. *Mycorrhizae*, 1(1), 3-12.
- Hippler, F. W. R., & Moreira, M. (2013). Mycorrhizal dependence of peanut plants on phosphorus levels. *Bragantia*, 72(2), 184-191.
- Janos, D. P. (2007). Plant responsiveness to mycorrhizas differs from dependence upon mycorrhizas. *Mycorrhiza*, 17(2), 75-91.
- Jenkins, W. R. (1964). A rapid centrifugal-flotation technique for separating nematodes from soil. *Plant Disease Report*, 48(41), 692.
- Kiers, E. T., Duhamel, M., Beesetty, Y., Mensah, J. A., Franken, O., Verbruggen, E., ... Bücking E. (2011). Reciprocal rewards stabilize cooperation in the mycorrhizal symbiosis. *Science*, 333(6044), 880-882.
- Maia, L. C., Silva, G. A., Yano-Melo, A. M., & Goto, B. T. (2010). Arbuscular mycorrhizal fungi in the Caatinga biome. In J. O. Siqueira, F. A. Souza, E. J. B. N. Cardoso, & S. M. Tsai (Eds.), *Mycorrhiza: 30 years of research in Brazil*, (p. 311-339). Lavras, MG: Universidade Federal de Lavras.
- Malavolta, E. (2006) *Manual de nutrição mineral de plantas*. São Paulo, SP: Agronômica Ceres.
- Martínez-García, L. B., Armas, C., Miranda, J. D., Padilla, F. M., & Pugnaire, F. I. (2011). Shrubs influence arbuscular mycorrhizal fungi communities in a semi-arid environment. *Soil Biology & Biochemistry*, 43(3), 682-689.
- Martínez-García, L. B., & Pugnaire, F. I. (2011). Arbuscular mycorrhizal fungi host preference and site effects in two plant species in a semiarid environment. *Applied Soil Ecology*, 48(3), 313-317.
- Melloni, R., Nogueira, M. A., Freire, V. F., & Cardoso, E. J. B. N. (2000). Phosphorus levels and arbuscular mycorrhizal fungi on growth and mineral nutrition of *Citrus limonia* (L.) Osbeck. *Revista Brasileira de Ciências do Solo*, 24(4), 767-775.
- Mengel, K., & Kirkby, E. A. (2001). *Principles of plant nutrition* (5th ed.). Dordrecht: Kluwer Academic Publishers.
- Munkvold, L., Kjoller, R., Vestberg, M., Rosendahl, S., & Jakobsen, I. (2004). High functional diversity within species of arbuscular mycorrhizal fungi. *New Phytologist*, 164(2), 357-364.
- Pagano, M. C., Utida, M. K., Gomes, E. A., Marriel, I. E., Cabello, M. N., & Scotti, M. R. (2011). Plant-type dependent changes in arbuscular mycorrhizal communities as soil quality indicator in semi-arid Brazil. *Ecological Indicators*, 11(2), 643-650.
- Phillips, J. M., & Hayman, D. S. (1970). Improved procedures for clearing and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. *Transactions of the British Mycological Society*, 55(1), 158-161.
- Pouyu-Rojas, E., Siqueira, J. O., & Santos, J. G. D. (2006). Symbiotic compatibility of arbuscular mycorrhizal fungi with tropical tree species. *Revista Brasileira de Ciência do Solo*, 30(3), 413-424.
- Schroeder, M. S., & Janos, D. P. (2004). Phosphorus and intraspecific density alter plant responses to arbuscular mycorrhizas. *Plant and Soil*, 264(1), 335-348.
- Sena, J. O. A., Labate, C. A., & Cardoso, E. J. B. N. (2004). Physiological characterization of growth depression in arbuscular mycorrhizal citrus seedlings under high P levels. *Revista Brasileira de Ciência do Solo*, 28(5), 827-832.
- Sharma, M. P., Bhatia, N. P., & Adholeya, A. (2001). Mycorrhizal dependency and growth responses of *Acacia nilotica* and *Albizia lebeck* to inoculation by indigenous AM fungi as influenced by available soil P levels in a semi-arid afisol wasteland. *New Forest*, 21(1), 89-104.
- Silva, F. C. (1999). *Handbook chemical analysis of soils, plants and fertilizers*. Brasília, DF: Embrapa Comunicação para Transferência de Tecnologia.
- Silva, P. C. G., Moura, M. S. B., Kiill, L. H. P., Brito, L. T. L., Pereira, L. A., Sá, I. B.... Guimarães Filho, C. (2015). Characterization of the Brazilian Semi-Arid region: natural and human factors. In I. B. Sá, & P. G. Silva (Eds.), *Brazilian Semi-Arid: Research, Development and Innovation* [E-book] (Chapter 1, 1st ed., p. 17-54), Brasília, DF: Embrapa Informação Tecnológica.
- Smith, S. E., & Read, D. J. (2008). *Mycorrhizal symbiosis*. San Diego, CA: Academic Press.
- Smith, S. E., & Smith, F. A. (2012). Fresh perspectives on the roles of arbuscular mycorrhizal fungi in plant nutrition and growth. *Mycologia*, 104(1), 1-13.
- Souza, R. G., Maia, L. C., Sales, M. F., & Trufem, S. F. B. (2003). Diversity and infectivity potential of arbuscular mycorrhizal fungi in an area of 'caatinga' in the Xingó

- Region, State of Alagoas, Brazil. *Revista Brasileira de Botânica*, 26(1), 49-60.
- Sousa, C. S., Maia, L. C., Menezes, R. S. C., Sampaio, E. V. S. B., & Garrido, M. S. (2008). Arbuscular mycorrhizal fungi in the northeastern semi-arid. In R. S. C. Menezes, E. V. S. B. Sampaio, & I. H. Salcedo (Org.), *Soil fertility and biomass production in the semiarid* (p. 255-280). Recife, PE: UFPE.
- Stürmer, S. L., Klauberger Filho, O., Hering de Queiroz, M., & Mendonça, M. M. (2006). Occurrence of arbuscular mycorrhizal fungi in soils of early stages of a secondary succession of Atlantic Forest in South Brazil. *Acta Botanica Brasilica*, 20(3), 513-521.
- Weber, O. B., Souza, C. M., Gondin, D. F., Oliveira, F. S., Crisóstomo, L. A., Caproni, A. L., & Saggin-Júnior, O. (2004). Inoculation of arbuscular micorrhizal fungi and phosphate fertilization on dwarf cashew seedlings. *Pesquisa Agropecuária Brasileira*, 39(5), 477-483.
- Yano-Melo, A. M., Trufem, S. F. B., & Maia, L. C. (2003). Arbuscular mycorrhizal fungi in salinized and surrounded areas at the São Francisco Submedium Valley, Brazil. *Hohenaea*, 30(2), 79-87.

Received on September 12, 2016.

Accepted on January 10, 2017.

License information: This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.