ARBUSCULAR MYCORRHIZAL FUNGI IN SUCCESSIONAL STAGES OF CAATINGA IN THE SEMI-ARID REGION OF BRAZIL

FUNGOS MICORRÍZICOS ARBUSCULARES EM ESTÁDIOS SUCESSIONAIS DE CAATINGA NA REGIÃO SEMI-ARIDA DO BRASIL

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ABSTRACT

Caatinga is an exclusively Brazilian biome with areas in accentuated process of desertification. Arbuscular mycorrhizal fungi (AMF) act in plant succession by favoring the establishment of plant species typical of successional stages and by accelerating recovery leading to a climax stage. The objective of the present work was to evaluate the occurrence and diversity of AMF in successional stages of caatinga in the semi-arid region of Paraíba State. Experimental plots (30 x 60 m) were delimited in 2007 in areas corresponding to different caatinga successional stages: early caatinga succession (natural revegetation during the previous 15 years); intermediate (natural revegetation for about 35 years); late (mature caatinga with more than 50 years without major disturbances;) and also in pasture areas fenced and protected to represent the initial phase of succession. Plots of all four stages were implemented with three replicates. Soil and root samples were collected in the experimental plots, from the 0-15 cm soil layer in the dry and in the rainy seasons. All areas presented low infectivity potential suggesting that the introduction of mycorrhizal seedlings may accelerate the process of revegetation of degraded soils in this region. Except for the areas of late stage, the glomalin reservoirs increased along with the advancement of the succession process. Areas in the late stage of succession presented greater richness of AMF species, indicating that the establishment of the vegetation also exerts a significant effect in the fungal community. *Glomus* and *Acaulospora* species were predominant in both seasons, possibly because they are well adapted to semi-arid conditions.

Keywords: soil infectivity; revegetation; mycorrhizal association.

RESUMO

A caatinga é um bioma exclusivamente brasileiro com áreas em acentuado processo de desertificação. Os fungos micorrízicos arbusculares (FMA) atuam na sucessão vegetal favorecendo o estabelecimento das espécies vegetais próprias das etapas sucessionais e acelerando a recuperação para um estádio climax da sucessão. O presente estudo teve como objetivo avaliar a ocorrência e diversidade de FMA em diferentes estádios sucessionais de caatinga no semiárido paraibano. Parcelas experimentais (30 x 60 m) foram demarcadas em áreas representando diferentes estádios sucessionais de caatinga: inicial (revegetação natural nos últimos 15 anos); intermediário (revegetação natural nos últimos 35 anos); tardio (caatinga madura com mais de 50 anos sem severos distúrbios antrópicos); e também em áreas de pasto cercadas e

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INTRODUCTION

Alterations in caatinga region began with the process of land use during the Brazilian colonial period, initially as a consequence of cattle raising associated to rudimentary agricultural practices. Throughout the years, other land use practices were adopted, such as diversification of agriculture, increases in the extraction of wood for coal production and hunting, all of these associated to livestock production, (PESSOA et al., 2008). Due to the systematic character of these activities, combined with increases in land use pressure during the last decades, several areas of the caatinga biome have been severely disturbed. Nowadays, the biome is under an accentuated process of desertification which results in loss of biodiversity, accentuated erosion and loss of soil fertility and water quality due to sedimentation (DRUMOND et al., 2000).

The recovery of soils within these degraded areas may occur through the facilitation of processes of natural plant succession (KAGEYAMA et al., 1994). For Saggin Júnior (1997), effective practices of reforestation with native species depend on their capacity to establish the species under the many sources of stress imposed by the environment, including resource limitation and competition processes. Another problem is that most of the area destined for revegetation has low fertility and low beneficial microorganism inoculum potential for plants (JANOS, 1996).

The role of microorganisms has been highlighted in the process of plant succession and among them are the arbuscular mycorrhizal fungi (AMF). AMF can help plants to establish under arid conditions by increasing nutrient absorption, especially P, improving the aggregation of eroded soils (CARAVACA et al., 2002), and reducing water stress (AUGÉ, 2001). AMF are essential components in ecosystems for revegetation of degraded areas as well as for maintaining soil structure and decreasing desertification risks (CARAVACA et al., 2005).

Plants with mycorrhizae have greater chances of establishing in low fertility soils than the ones that do not have mycorrhizae. These plants demonstrate high competitive capacity, facilitate the revegetation in areas with reduced potential of inoculum and are important for rehabilitation programs of degraded areas (JANOS, 1996). In addition to the effects in the initial growth, the mycorrhizal colonization affects the future successional phases of the species (HERRERA et al., 1991) and the structure of plant communities (MILLER e JASTROW, 1992).

The knowledge of the capacity of plant species to form symbiosis with these fungi is important for the success of the revegetation process (JASPER et al., 1991) and the establishment of highly mycotrophic species throughout time can improve the environment to be revegetated. These improvements during the initial phases of succession can make the soil more adequate for establishing plants of the later phases of the succession. (ZANGARO et al., 2000). The objective of the present study was to evaluate the occurrence and diversity of arbuscular mycorrhizal fungi in successional stages of caatinga area in the semi-arid region of Paraíba state.

MATERIALS AND METHODS

Description of the areas studied

The study was carried out at Tamanduá Farm, in the county of Patos, semi-arid region of Paraíba state, located between 06°59’13” and 07°0’14” south latitude and 37°18’08” and 37°20’38” W longitude, with average altitude of 270 m. The climate is Bsh (semi-arid) in the Köppen classification with average annual temperature of 32,8 °C and precipitation around 600 mm annually. Monthly rainfall was reg-
istered in 2007, the year the experiment was carried out (Figure 1).

The area where the study was conducted was originally covered with caatinga vegetation. However, probably in the beginning of the 20th century most of the region was at some point deforested for agricultural purposes, in particular for the establishment of perennial cotton plantations. During the second half of the 20th century, due to the decline of the cotton cropping system, some of these cultivation areas were gradually replaced by pastures or abandoned, which allowed the regrowth of caatinga through natural succession processes. These land use practices led to the creation of a mosaic of areas with different land cover types at Tamanduá farm, where we establish the present study.

Soil and root samplings were carried out in two periods, characterized as the rainy season (May) and the dry season (November) in 2007. Ten simple samples in each plot, in the 0-15 cm deep layer, were collected. The soil samples were air dried, separated and homogenized and sieved through 2 mm mesh sieves. Thin roots (< 2 mm) were collected from the crops, washed in water and stored in plastic recipients containing alcohol 50% for conservation until the analysis.

Chemical and physical characterization of the soil

The chemical and physical characteristics of the soil (Table 2) were carried out according to methodologies proposed by Embrapa (1997).

Density and viability of spores, identification of AMF species and ecological indices

AMF spores were extracted from 50 g of the samples by the humid sieving technique (GERDEMANN and NICOLSON, 1963). For this,
we used superposed sieves of 50µm, 100µm and 250µm, followed by centrifugation in water (3000 g) and sucrose solution 45% (2000 g) for 3 and 1 minute, respectively (JENKINS, 1964). We then added 5 mL of iodonitrotetrazolium chloride (INT) at 0.1% to the spores extracted from the soil and carried an incubation for 5 days at room temperature for the evaluation of viability according to Walley and Germida (1995). Afterwards, the spores were counted in channeled plates using a stereomicroscope (40x). Spores were considered viable when turned red after reacting with iodonitrotetrazolium chloride (INT) and non-viable when they maintained the original color.

For the identification of the AMF species, trap cultures were built in which soil samples were diluted in autoclaved sand (1:1) and transferred to

TABLE 1: Density of tree and shrub species (> 3 cm DBH) in four successional stages of caatinga, in Patos, Paraiba.

| Species/Family          | Common name            | Stage¹ |
|------------------------|------------------------|--------|
|                        |                        | P   | E   | I   | L   |
| Apocynaceae            |                        |     |     |     |     |
| *Aspidosperma pyrifolium* Mart. | Pereiro | -  | -   | 3   | 50  |
| Bombacaceae            |                        |     |     |     |     |
| *Pseudobombax marginatum* (A. St.-Hil., Juss.&Cambess.) A. Robyns | Embriratanha | -  | -   | -   | 17  |
| Burseraceae            |                        |     |     |     |     |
| *Commiphora leptophloeo* (Mart.) J.B.Gillett | Imburana | -  | -   | -   | 307 |
| Bignoniaceae           |                        |     |     |     |     |
| *Tabebuia impetiginosa* (Mart. ex DC.) Standl. | Pau d’arco | -  | -   | 3   | -   |
| Cactaceae              |                        |     |     |     |     |
| Cereus jamacaru        | Mandacaru              | -  | 3   | 13  | 7   |
| Capparaceae            |                        |     |     |     |     |
| *Capparis flexuosa* L. | Feijão bravo           | -  | -   | 7   | 3   |
| Combretaceae           |                        |     |     |     |     |
| *Combretum leprosum* Mart. | Mofumbo | -  | -   | 17  | 53  |
| Erythroxylaceae        |                        |     |     |     |     |
| *Erythroxylum pungens* O.E Schulz | -  | -   | -   | 37  |
| Euphorbiaceae          |                        |     |     |     |     |
| *Croton sonderianus* Muell. Arg. | Marmeleiro | -  | 3   | 87  | 3   |
| *Cnidoscolus querocfolius* Pohl | Faveleira | -  | -   | -   | 33  |
| *Jathophia mollissima* (Pohl) Baill. | Pinhão bravo | -  | -   | 10  | 23  |
| Leguminosae            |                        |     |     |     |     |
| *Amburana cearensis* (Allem.) A.C.Smith | Cumaru | -  | -   | -   | 3   |
| *Anadenanthera colubrina* (Vell.) Brenan var. cebil (Griseb.) | -  | -   | -   | 3   |
| Althshul               | Angico                 | -  | -   | 3   | 43  |
| *Caesalpinia pyramidalis* Tul. | Catingueira | -  | 3   | 350 | 440 |
| *Mimosa tenuiflora* (Willd.) Poir. | Jurema preta | -  | 687 | 517 | 40  |
| *Bauhinia cheilantha* (Bong.) Steud. | Mororó | -  | -   | 10  | 13  |
| *Piptadenia stipulacea* (Benth.) Ducke | Jurema branca | -  | -   | 77  | 77  |
| Total density of trees and shrubs | -  | 696 | 1100| 1200|
| Total number of species | -  | 4   | 12  | 16  |

Em que: ¹ (P) = Pasture; (E) = Early caatinga; (I) = Intermediate caatinga; (L) = Late caatinga.
plastic pots with 500 mL capacity using Italian millet (*Panicum miliaceum* L.) as the host plant. After three multiplication cycles, the spores were extracted from the soil and separated according to their morphologic characteristics (color, size and form) and mounted on slides with PVLG (polivinil-lactoglicerol alcohol) and with Melzer + PVLG (1:1; v/v) (MORTON et al., 1993). The identification was done using specialized literature (SCHENCK and PEREZ, 1988).

Species richness of AMF was determined by the number of species occurring in the area. In order to measure the similarity of species between the areas, Sorensen’s coefficient was used according to the following equation: 

\[ S = \frac{2c}{(a + b)} \times 100 \]

whereas 

- \( c \) = number of species common to both areas (1 and 2); 
- \( a \) = number species in area 1 and 
- \( b \) = number of species in area 2. 

The frequency of occurrence of species was estimated according to the equation: 

\[ F_i = \frac{J_i}{k} \times 100 \]

whereas 

- \( J_i \) = number of samples in which the species occurred; 
- \( k \) = number of total soil samples.

### Soil infectivity

Soil infectivity for the areas was evaluated according to the most probable number technique (MPN) of AMF infective propagules, described by Feldmann and Idczak (1992). A bioassay was carried out for each area (pasture, initial stage, intermediate stage and late stage) and sampling period (rainy and dry). For each area a sample made up of soil (soil-inoculum), homogenized, dried, nonsterile and sieved (0.5 cm Mesh), was used for each plot. Sieved sand (0.5 cm mesh), washed, autoclaved for 1 h at 120°C for three alternating days and oven dried at 105°C, was used as diluting. Soil-inoculum samples were diluted in sand in the following proportions: 1:0; 1:10; 1:100 and 1:1000, and transferred to plastic tubets with capacity of 100g, with five replicates. Two corn (*Zea mays* L.) seeds were sown in each tubet and after germination (± 5 days), only one seedling was kept. Plants were harvested 30 days later and all the root system prepared to verify AMF structures (KOSKE and GEMMA, 1989).

### Quantification of soil proteins related to glomalin

Contents of the easily extractive fractions (EEG) and of total proteins related to glomalin (TG) of the soil were quantified using the Wright e Upadhyaya (1998) method. The EEG fraction obtained from 0.25 g of soil was autoclaved with 2 mL of sodium citrate (20 mM; pH 7.0) for 30 minutes, at 121 °C, and afterwards centrifuged at 10000 g for 5 min. The extraction of the GT was carried out by adding 2 mL of sodium citrate (50 mM; pH 8.0) to the sediment from the EEG extraction followed by autoclaving (121 °C/1 hour), four times, until the

### TABLE 2: Chemical and physical characteristics of the soil in the rainy and dry seasons in four successional stages of caatinga in Patos, PB state.

| Stage | pH | P mg kg⁻¹ | K cmolₑ kg⁻¹ | Na cmolₑ kg⁻¹ | Ca g kg⁻¹ | Mg g kg⁻¹ | C.O. g kg⁻¹ | Granulometry (g kg⁻¹) |
|-------|----|-----------|--------------|--------------|-----------|-----------|-------------|----------------------|
|       | H₂O |            |              |              |           |           |             | sand     | clay     | silt    |
| Rainy Season |     |          |             |              |           |           |             |          |          |         |
| P     | 5.61| 2.72      | 0.25         | 0.12         | 4.31      | 1.37      | 8.37        | 638      | 269      | 93      |
| E     | 5.94| 1.55      | 0.29         | 0.11         | 5.02      | 1.66      | 8.61        | 645      | 239      | 117     |
| I     | 5.79| 1.65      | 0.31         | 0.13         | 3.91      | 1.29      | 14.10       | 668      | 239      | 93      |
| L     | 6.50| 2.62      | 0.29         | 0.11         | 5.22      | 1.36      | 11.62       | 648      | 229      | 123     |
| Dry Season |     |          |             |              |           |           |             |          |          |         |
| P     | 6.08| 4.21      | 0.23         | 0.11         | 3.91      | 1.17      | 13.63       | 638      | 269      | 93      |
| E     | 5.64| 2.11      | 0.32         | 0.09         | 3.97      | 1.36      | 13.23       | 645      | 239      | 117     |
| I     | 5.64| 2.23      | 0.31         | 0.11         | 3.98      | 1.42      | 12.87       | 668      | 239      | 93      |
| L     | 6.68| 2.43      | 0.27         | 0.09         | 5.44      | 1.48      | 12.62       | 648      | 229      | 123     |

In which: 

- \( P \) = Pasture; 
- \( E \) = Early caatinga; 
- \( I \) = Intermediate caatinga; 
- \( L \) = Late caatinga.
supernatant did not present a brownish-red coloring, characteristic of glomalin. The supernatant from the TG extraction was centrifuged (10000g/5 minutes). An aliquot of 50 µL of the supernatant together with 2.5 mL of the comassie brilliant blue dye G-250, were used for the quantification of the contents of the EEG and TG. Bovine serum albumin was used as standard. Glomalin carbon (G-C) was estimated from the total glomalin, considering that the carbon represents 43.1% of the molecule and expressed in mg g soil⁻¹. The percentage of the contribution of glomalin to the total carbon of soil was calculated by the ratio glomalin carbon (G-C)/total carbon in the soil (C-S).

Mycorrhizal colonization

The percentage of mycorrhizal colonization was determined using the split-plate intersect method (Giovannetti and Mosse, 1980), after processing of the roots, which consisted in their clarification with KOH (10%) for 24 hours, at room temperature, followed by alkaline H₂O₂ treatment for 45 minutes, and with HCl (1%) for 3 minutes and coloring with Tryptan blue (0.05%) (Koske e Gemma, 1989). One-hundred colored root segments were separated for visualization of fungal structures (arbuscles, vesicles and hyphae) using a stereomicroscope (40x).

Statistical analysis

Results were submitted to analysis of variance and averages compared by the Scott and Knott test at 5% probability, using the SISVAR software package. Data of spore density and percentage of mycorrhizal colonization were transformed to \((x + 0.5)^{1/2}\) and \(\arcsin(x/100)^{1/2}\), respectively.

RESULTS AND DISCUSSION

In general, the areas presented low total spore density varying from 198 and 275 spores in 50 g of soil (4 and 5 spores g of soil⁻¹) in the rainy period and from 145 to 210 spores in 50 g of soil (3 to 4 spores g of soil⁻¹) in the dry period (Table 3). Low spore densities of AMF were also observed in studies carried out in semi-arid areas of the northeastern region of Brazil (SOUZA et al., 2003) and in other areas of the world (MOHAMMAD et al., 2003; SHI et al., 2007). According to Bashan et al.

| Stage  | DS (50 g⁻¹ of soil) | RC (%) | MPN (cm⁻³ of soil) |
|--------|---------------------|--------|-------------------|
|        | Viable  | Non viable | Total |
| P      | 46aA    | 228aA     | 275aA | 30,4 bB | 52 |
| E      | 23bA    | 183bA     | 205bA | 38,2aB | 180 |
| I      | 39aA    | 201aA     | 240aA | 28,8bB | 140 |
| L      | 28bA    | 170bA     | 198bA | 27,9bB | 95  |
| CV(%)  | 11,80   | 10,06     | 9,57  | 17,95  | -   |

Rainy Season

| Stage  | DS (50 g⁻¹ of soil) | RC (%) | MPN (cm⁻³ of soil) |
|--------|---------------------|--------|-------------------|
|        | Viable  | Non viable | Total |
| P      | 10aB    | 135bB     | 145bB | 37,5bA | 95  |
| E      | 10aB    | 178aA     | 188aA | 44,5aA | 40  |
| I      | 9aB     | 193aA     | 202aA | 36,3bA | 44  |
| L      | 7aB     | 203aA     | 210aA | 36,7bA | 20  |
| CV(%)  | 11,80   | 10,06     | 9,57  | 17,95  | -   |

Dry Season

In which: ¹ (P) = Pasture; (E) = Early caatinga; (I) = Intermediate caatinga; (L) = Late caatinga. Results followed by similar letters do not differ statistically by the test of Scott e Knott at 5% probability. Small letters compare stages in each season and capital letters compare the same stage in two seasons.

TABLE 3: Density of (DS) viable and non viable spores, root colonization (RC) e most probable number (MPN) of infective propagules in four successional stages of caatinga, in the rainy and dry seasons in Patos, Paraíba state.

TABELA 3: Densidade de esporos (DS) viáveis e não viáveis, colonização radicular (RC) e número mais provável (MPN) de propágulos infectivos em quatro estádios sucessionais de caatinga nos períodos chuvoso e seco, em Patos, Paraíba.
(2000), these low densities can be attributed to the presence of species with low sporulation capacity in those environments.

During the rainy period, the pasture areas and the intermediate stage of succession had the greatest density of viable (46 and 39 spores in 50g of soil, respectively) and non viable spores (228 and 201spores in 50 g of soil), respectively, not differing statistically. No significant difference was observed between the areas in regard to density of viable spores in the dry period. In this period, pasture areas had lower non viable spore density (135 spores in 50 g of soil) than the other areas.

The density of AMF spores in the rhizosphere is usually related to the aggregated form in which the spores are encountered in the soil, and to the distribution, morphology and physiological age of roots. It also depends on other factors such as rainfall, temperature, insulation period and AMF species (BRUNDRETT et al., 1996).

Reduction in the density of viable spores occurred in all areas (up to 78%) in the dry period in comparison to the rainy period. It is possible that these results are related to the increase in soil temperature during this period; a factor that does not favor the maintenance of viable spores in the soil (BENDAVID-VAL et al., 1997). In addition, according to Lima et al. (2007), although the INT presented consistent results in the bioassays carried out, factors such as size, wall permeability, metabolic activity and level of maturity of spores can affect test results. With the exception of the pasture areas, total spore density and non viable spores did not differ significantly in the areas between the two sampling periods.

The percentage of mycorrhizal colonization of plant species varied from 28 to 38% in the rainy season and from 36 to 44% in the dry season, in agreement with the values observed in other areas of caatinga (SILVA et al., 2001; SOUZA et al., 2003; MERGULHÃO et al., 2007). Plant species in the initial succession stage had the greatest percentage of mycorrhizal colonization in both sampling seasons (rainy 38% and dry, 44%). Other studies have also demonstrated that the dependence and the responsiveness to the mycorrhizal association was greater in arboreal species in the initial stages of succession and decreased toward the climax stages (ZANGARO et al., 2002; ZANGARO et al., 2003; AIDAR et al., 2004; ZANGARO et al., 2007).

The small nutrient reserves in the seeds and mainly the rapid growth rate and the great demand for minerals, common within pioneer and early secondary species, may lead to P deficiency in the aerial parts, increasing AMF colonization in those species. Among the late secondary and climax species, the high amount of nutrients in its seeds and the low growth rate and low demand for minerals and may be some of the reasons why these species present low mycorrhizal colonization (ZANGARO et al., 2002).

All the areas had higher mycorrhizal colonization of plant species in the dry season (reaching 31%) than in the rainy season, which possibly can be a strategy of the AMF to avoid water stress conditions. Root colonization and sporulation are crucial AMF survival strategies under adverse conditions (HART e READER, 2002).

In the rainy season, the areas in the initial stage of succession had a greater number of infective propagules than the in other areas (180 propagules cm\(^{-3}\) of soil). However, in the dry season, a higher number of infective propagules was registered in the pasture areas (95 propagules cm\(^{-3}\) of soil). Except for the pasture areas, there was a decrease in the number of infective propagules in the dry season.

In general, a low number of AMF infective propagules in the areas was observed, varying from 29 to 100 infective propagules cm\(^{-3}\) of soil in the rainy season and 11 to 53 infective propagules cm\(^{-3}\) of soil in the dry one, in agreement with observations by Caravaca et al. (2005) in semi-arid regions of the Mediterranean region.

The EEG content in the areas varied from 1.17 to 1.66 mg g soil\(^{-1}\) for the rainy season and from 1.25 to 1.62 mg g of soil \(^{-1}\) for the dry season (Table 4). Bird et al. (2002) observed comparatively low EEG concentrations in semi-arid regions of America, not exceeding 0.6 mg g soil\(^{-1}\). Although the mechanisms which regulate glomalin production are still not well understood (PURIN e RILLIG, 2007), it is believed that soil characteristics, climatic conditions, presence and type of vegetation and fungal species may influence the concentrations of glomalin in the soils.

Except for the areas in the late succession stage, the EGG, TG and G-C contents increased with the process of vegetation succession in both sampling seasons. In a coastal area, Souza (2008) also verified that the concentration of EEG increased during the revegetation process, being 6.50 mg g soil\(^{-1}\) in an area without vegetation; 7.66 mg g soil\(^{-1}\) in an area revegetated 16 years before and
11.34 mg g soil\(^{-1}\) in the undisturbed native coastal vegetation. Plant species in the initial stages of succession have large demand for nutrients, resulting in great photosynthetic capacity (LUSK et al., 2008) and therefore may increase the amount of photosynthetic compounds transferred to the AMF (LINCH e HO, 2005), possibly favoring glomalin production.

Regardless of the area, the EEG, TG and G-C contents did not differ significantly between the two sampling seasons. Glomalin is a relatively stable biomolecule in soils (WRIGHT e UPADHYAYA, 1998), not presenting many seasonal variations. The G-C / C-S ratio did not differ significantly among the areas in both sampling seasons. The sampling seasons were only significantly different in their G-C/C-S ratio in the initial succession stage.

Sixteen species distributed in the Glomus (6), Acaulospora (5), Ambispora (1), Scutellospora (1), Racocetra (1), Entrophospora (1) and Gigaspora (1) genera, were registered (Table 5). AMF diversity in arid regions can be underestimated even when trap cultures are used in order to better detect species richness (STUTZ et al., 2000). It is possible that the AMF richness is greater than registered, considering that the multiplication of spores in culture pots, although helping in the recovery of some fungi, may not enable the complete recovery of all spores present in the soil due to the fact that sporulation depends also on the host plant (BEVER et al., 1996). Furthermore, the sporadic production of spores by some AMF and the presence of not feasible spores hinder the identification and better description of the species encountered (SOUZA et al., 2003).

*Glomus intraradices* and *G. glomerulatum* like species were exclusive from the pasture area whereas *R. fulgida* and *S. aurigloba* were registered only in the area of the initial stage of succession. *G. ambisporum* was only observed in the intermediate stage of succession and Acaulospora appendicula, E. infrequens and G. margarita were encountered only in the area of late stage of plant succession. Different host plant species create their own habitats surrounding their roots, leading to the establishment of distinct AMF species (CARRENHO et al., 2001).

*Glomus macrocarpum* was encountered in all areas in both sampling seasons. Aidar et al. (2004) also verified the occurrence of *G. macrocarpum* in all succession stages in an Atlantic forest in the south-

### TABLE 4: Quantification of easily extractable glomalin (GEE), total glomalin (GT), glomalin carbon (C-G) and ratio of glomalin carbon (C-G)/ soil carbon (C-S), in four succession stages of caatinga in the rainy and dry seasons, in Patos, Paraiba state.

| Stage | GEE (mg g soil\(^{-1}\)) | GT (mg g soil\(^{-1}\)) | C-G | C-G/C-S (%) |
|-------|----------------|----------------|-----|-------------|
| **Rainy Season** | | | | |
| P | 1,21bA | 2,18bA | 0,94bA | 11,38aA |
| E | 1,35bA | 2,78aA | 1,20aA | 15,54aA |
| I | 1,66aA | 2,91aA | 1,25aA | 13,04aA |
| L | 1,17bA | 2,25bA | 0,97bA | 8,41aA |
| **Dry Season** | | | | |
| P | 1,34bA | 2,58aA | 1,11aA | 8,21aA |
| E | 1,49aA | 2,78aA | 1,20aA | 9,13aB |
| I | 1,62aA | 2,97aA | 1,28aA | 9,62aA |
| L | 1,25bA | 2,07aA | 0,89aA | 6,75aA |
| **CV(%)** | 19,35 | 27,34 | 27,31 | 31,11 |

In which: \(1\) (P) = Pasture; (E) = Early caatinga; (I) = Intermediate caatinga; (L) = Late caatinga. Results followed by similar letters do not differ statistically by the test of Scott e Knott at 5% probability. Small letters compare stages in each season and capital letters compare the same stage in the two seasons.
Arbuscular mycorrhizal fungi in successional stages of caatinga in the semi-arid...

TABLE 5: AMF species in four different succession stages of caatinga in semi-arid Northeast Brazil, in the rainy and dry seasons, in Patos, PB state.

| AMF Species                        | P  | E  | I  | L  | RF (%) |
|------------------------------------|----|----|----|----|--------|
| *Acaulospora excavata* Ingleby, Walker & Manson | X  | X  | X  | X  | 50     |
| *Acaulospora foveoreticulata*      | X  | X  | X  | X  | 100    |
| *Acaulospora longula* Spain & N.C.Schenck | X  | X  | X  | X  | 50     |
| *Acaulospora mellea* Spain & N.C. Schenck | X  | X  | X  | 25  |
| *Acaulospora scrobiculata* Trappe  | X  | X  | X  | X  | 75     |
| *Ambispora appendicula* (Spain, Sieverd. & N.C. Schenck) C. Walker | X  | -  | -  | -  | 25     |
| *Entrophospora infrequens* (Hall) Ames & Schneider | X  | 25  |
| *Glomus ambisporum* G.S. Sm. & N.C. Schenck | X  | 25  |
| *Glomus claroideum* N.C.Schenck & Smith | X  | X  | X  | X  | 75     |
| *Glomus etunicatum* Becker & Gerdemann | X  | X  | X  | X  | 50 100 |
| *Glomus glomerulatum-like* Sieverd | X  | -  | -  | -  | 25     |
| *Glomus intraradices* N.C.Schenck & G.S.Sm | X  | 25  |
| *Glomus macrocarpum* Tulasne & Tulasne | X  | X  | X  | X  | 100    |
| *Gigaspora margarita* Becker & Hall | X  | -  | -  | -  | 25     |
| *Racocetra fulgida* Koske & C. Walker) Oehl, F.A. Souza & Sieverd | X  | -  | -  | -  | 25     |
| *Scutellospora auriglobosa* (Hall.) C. Walker & Sanders | X  | 25  |
| Total of species                   | 5  | 5  | 6  | 7  | 4      |

In which: 1 (P) = Pasture; (E) = Early caatinga; (I) = Intermediate caatinga; (L) = Late caatinga. Season2: (R) = Rainy; (D) = Dry; AMF = Arbuscular mycorrhizal fungi; RF = Relative frequency.

Glomus and Acaulospora species were found in all areas and in both seasons always in larger number than the other genus. These genera are also dominant in other semi-arid regions (TAO e ZHIWEI, 2005; GAI et al., 2006; LI et al., 2007). The predominance of small spores, such as those from Glomus and Acaulospora, can be a selective adaptation to water stress (BODDINGTON e DODD, 2000) but it must be considered that these genera include a large number of species. Picone (2000) reported that small spores are more frequent and present less seasonal variation than larger spores. Tao e Zhiwei (2005) considered that Glomus and Acaulospora species seem more adapted to hot arid environments.

CONCLUSIONS

The areas in the early and intermediate stage of succession had low infectivity potential, suggesting that the introduction of mycorrhized seedlings...
may accelerate the process of revegetation of degraded soils in this region.

The areas in the late stage of succession had high AMF species richness, indicating that the establishment of the vegetation exerts a positive effect in the fungal community;

*Glomus* and *Acaulospora* species were predominant in the areas in both seasons, possibly due to the fact that they were adapted to the semi-arid conditions.

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