Revista Brasileira de Ciências Agrárias
ISSN (on line) 1981-0997
v.13, n.1, e5497, 2018
Recife, PE, UFRPE. www.agraria.pro.br
DOI:10.5039/agraria.v13i1a5497
Protocolo 5497 - 16/06/2017 • Aprovado em 28/10/2017

Arbuscular mycorrhizal fungi in soils of arboreal Caatinga submitted to forest management

Jhuly Ely Santos Pereira[1], Patrícia Anjos Bittencourt Barreto-Garcia[1], Rafael Nogueira Scoriza[1], Orivaldo José Saggin Júnior[2], Vanessa de Souza Gomes[1]

[1] Universidade Estadual do Sudoeste da Bahia. Vitória da Conquista, BA, Brasil. E-mail: jhulyribeiro_@hotmail.com (ORCID: 0000-0001-9793-2696); patriciabarreto@uesb.edu.br (ORCID: 0000-0002-8559-2927); rafaelscoriza@gmail.com (ORCID: 0000-0001-7361-4095); vanessadesousagomes@hotmail.com (ORCID: 0000-0003-2149-2211)
[2] Embrapa Agrobiologia. Seropédica, RJ, Brasil. E-mail: orivaldo.saggin@embrapa.br (ORCID: 0000-0001-9209-9738)

ABSTRACT: The arbuscular mycorrhizal fungi (AMF) community presents a variable tolerance to changes in the medium, to which it responds modifying the number of propagules. For this reason, the study of the effect of different management practices on this community can help to understand the magnitude of the changes caused to the ecosystem. The objective of this study was to evaluate changes in the community of arbuscular mycorrhizal fungi in the soil in an area of arboreal Caatinga submitted to forest management. The study was conducted in Contendas do Sincorá (BA). Three types of forest management (clear-cutting, selective logging based on diameter, and selective logging based on species) and one control area were evaluated. Soil samples were collected at 0-10 cm depth in two periods (five and 10 months after management). AMF spores were present in low density (< 1 spore g^{-1} soil), dry and non-viable, and were generally more abundant in managed areas. Fewer species were observed in the control area. The AMF community showed to be related to the attributes of the soil and sensitive to management practices, demonstrating greater impact under clear cut management.

Key words: AMF community; spore diversity; indicator of sustainability

Fungos micorrízicos arbusculares em solo sob Caatinga arbórea submetida a manejo florestal

RESUMO: A comunidade de fungos micorrízicos arbusculares (FMA) apresenta diferentes tolerâncias a alterações no meio, respondendo a estas mudanças com modificações no seu número de propágulos. Por essa razão, o estudo do efeito de diferentes práticas de manejo sobre esta comunidade pode auxiliar no entendimento da magnitude das alterações ocasionadas no ecossistema. O objetivo deste estudo foi avaliar mudanças na comunidade de fungos micorrízicos arbusculares do solo em área de Caatinga arbórea submetida a manejo florestal. O estudo foi realizado em Contendas do Sincorá (BA). Foram avaliados três tipos de manejo florestal (corte raso, corte seletivo por diâmetro e corte seletivo por espécie) e uma área testemunha. As amostras de solo foram coletadas na profundidade de 0-10 cm, em dois períodos (cinco e 10 meses após a execução do manejo). Os esporos de FMA apresentaram-se em baixa densidade (< 1 esporo g^{-1} de solo), secos e inviáveis e, geralmente, em maior quantidade nas áreas manejadas. Menor número de espécies foi observado na testemunha. A comunidade de FMA mostrou-se relacionada aos atributos do solo e sensível as práticas de manejo, demonstrando maior impacto do manejo corte raso.

Palavras-chave: comunidade de FMA; diversidade de esporos; indicador de sustentabilidade

Introduction

Caatinga is a typical Brazilian biome that covers 11% of the national territory and is one of the largest semiarid areas in the world. It is characterized mainly by a low annual rainfall (much smaller than 1000 mm) and a long dry season. It is composed of arboreal, shrub and herbaceous xerophytic vegetation, usually deciduous and with thorns. It has a wide range of physiognomies and high diversity of species, including cacti and bromeliads (Queiroz, 2009; Costa et al., 2014; Moro et al., 2016).

Despite its importance, the Caatinga has been severely affected by anthropic actions such as logging and collection of fuelwood, mineral and vegetal extractivism, livestock farming and extensive agriculture. These practices have led to deforestation and loss of species peculiar to the Caatinga biome, damaging ecological processes that are fundamental to the functioning of the ecosystem (Pagano et al., 2011).

Inadequate exploitation of a little-known and complex ecosystem such as the Caatinga can lead to an irreversible degradation process, which raises a number of concerns about the long-term sustainable use of its resources (Marshall, 2000; Riegelhaupt & Pareyn, 2010; Pagano et al., 2011b). Sustainable forest management (SFM) is one of the alternatives for the sustainable exploitation of the biome, i.e. one with economic, social and environmental benefits.

SFM is defined as a set of interventions implemented in a forest area aimed at the continuous use of forest products and services and, at the same time, the maintenance of its productive capacity (MMA, 2008). In Brazil, SFM in areas of native vegetation is regulated by federal law and is subject to the existence of a sustainable forest management plan (SFMP) previously approved by a competent environmental agency (Brasil, 2012).

The main forest management practice used in the Caatinga for the exploitation of vegetation is clear cutting followed by selective logging (based on species or diameter) (MMA, 2008). However, choosing the most appropriate type of management for a community depends on its resistance and resilience after disturbance, and the purpose for which the wood will be used.

The understanding of the consequences of different management practices on forest ecosystems is only possible through the interpretation of the complex interactions that occur between its above- and below-ground components (Marshall, 2000). Among the soil biological components that are sensitive to changes in the environment are the arbuscular mycorrhizal fungi (AMF). These organisms form symbiotic associations in the roots of host plants and have a stimulating effect on plant growth. In this association, plants supply the fungi with carbon compounds, while fungi benefit the plants by causing greater nutrient and water absorption, besides promoting moisture retention, aggregation and stability of the soil (Souza et al., 2008; Smith & Smith, 2012).

In the Caatinga, the presence of AMF plays an important role in the establishment and maintenance of vegetation (Mello et al., 2012; Sousa et al., 2013), providing constitutes a mechanism for the adaptation of plants to soils with nutrient restrictions. Thus, arbuscular mycorrhizal fungi present variable tolerance to changes in the environment and soil management, responding to these modifications with changes in the number of propagules (Mello et al., 2012). For this reason, the AMF community is usually considered a good soil indicator (Pagano et al., 2011b).

In view of the above, the objective of this study was to evaluate the modifications observed in the arbuscular mycorrhizal fungi community in an area of arboreal Caatinga submitted to different forest management practices. The assumption is that the native AMF community is sensitive to the changes caused by different forest management practices.

Materials and Methods

The study was carried out in the Contendas do Sincorá National Forest (FLONA) (13°55'21'' S and 41°06'57'' W), located in the municipality of Contendas do Sincorá, Southwest region of the state of Bahia. The altitude varies between 295 and 380 m, reachibg 580 m in mountainous areas. The local climate is semi-arid (BSwh) according to Köppen classification, with an average annual temperature of 23°C and precipitation between 596 mm and 678.5 mm, distributed in the months of November to April. The predominant vegetation is arboreal Caatinga in the late successional stage.

The experimental area is part of the Resource Management Zone, as determined in the Management Plan of the conservation unit (CU) (MMA, 2006), which allows the development of research and management programs. The area is divided into four treatments, which correspond to three types of management (executed in May 2015) and an untreated area of Caatinga, as described in Table 1.

Table 1. Description of treatments evaluated in the arboreal Caatinga area in the Southwest of Bahia.

Treatment	Description
Clearcut	Cutting of all tree individuals. This management represents the totalremoval of vegetation.
Selective by DBH	Cutting of all arboreal individuals with a diameter at breast height (DBH) greater than or equal to 5 cm. This management system aims at the use of wood for firewood and coal.
Selective by species	Selective cutting of three species: *Commiphora leptophloeos* (Mart.) J. Gillett, *Jatropha molíssima* (Pohl) Baill and *Pseudobombax simplicifolium* A. Robyns. This management aimsat the use of wood extracted from the Caatinga for a more noble purpose than firewood and coal.
Control	Caatinga without any type of anthropic intervention.

Treatments were applied with four replications in 400 m² plots which were randomly distributed, totaling a continuous experimental area of 6,400 m². In each plot, 10 simple soil samples were collected at 0-10 cm depth, to form a composite sample. Soil samplings occurred in October 2015 (05 months after management, end of dry season) and in March 2016 (10 months after management, end of rainy season).

Prior to forest management in the experimental units, the vegetation of the FLONA had not undergone interventions since 1997. Despite this, the area of the CU has a long history of logging for production of charcoal, used to meet the energy needs of mining companies (MMA, 2006). The soil of the experimental area belongs to the Red-Yellow Argisol class with chemical and granulometric characteristics according to Table 2.

For spore counting and identification of AMF species, 50 ml of soil was used to extract spores from arbuscular mycorrhizal fungi using the procedure described for nematodes according to the wet sieving technique (Gerdemann & Nicolson, 1963), supplemented by the adapted methodology of density gradient centrifugation (with water and 40% sucrose) (Jenkins, 1964). Then, with the aid of a stereoscopic microscope, the species were identified using the Schenck & Pérez identification manual (1988), as well as publications and consultation of the AMF international collection website - INVAN (http: //invan.caf .wvu.edu /).

The data obtained were analyzed for homogeneity (Cochran and Barttlet test) and normality (Lilliefors test). In the case of parametric data, the means of the treatments were compared by the Tukey test at 5% of significance. Non-parametric data were compared by the Kruskal-Wallis test at 5%. In addition, a *Cluster* analysis was carried out to evaluate the similarity (Euclidean distance) between treatments. The inter-relationships between soil chemical attributes and the arbuscular mycorrhizal fungi community were analyzed through Pearson correlations at 5%.

Results and Discussion

The total spore density ranged from 8.0 to 37.8 spores in 50 g of soil, which corresponds to less than one spore per gram of soil (< 1 spore g^{-1} soil). Low spore densities were also observed in the Caatinga in Northeast Brazil, as 3 to 5 spores g^{-1} soil (Sousa et al., 2014). According to Bashan et al. (2000), in arid and semi-arid regions, low spore densities are usually associated with the presence of arbuscular mycorrhizal fungi (AMF) species that have low sporulation capacity or critical survival in these environments.

At five months after management, the AMF community had a lower total number of spores in the managed areas than in the unmanaged Caatinga (Table 3). The same result was observed for *Glomus macrocarpum*, which was the dominant species in the community (Table 3). The dominance of the *G. macrocarpum* in the Caatinga can be related to its great adaptive ability (Ceola, 2015) and resistance to natural stress promoted by the climatic and environmental conditions of this biome (Teixeira-Rios et al., 2013; Sousa et al., 2013).

There were also differences in the total number of spores at 10 months after management, but in this case, only selective logging based on species differed from the control, presenting a lower value (Table 3).

Table 2. Accumulated litter and chemical and granulometric characterization of soil under managed and unmanaged arboreal Caatinga.

Treatment	pH	Serap.	P	K	Ca	Mg	H + Al	OC	N	SND	SI	CL
		Mg ha^{-1}	mg dm^{-3}	cmolc dm^{-3}				g kg^{-1}				
Clearcut	6.3	4.9	3.0	0.21	3.8	1.7	1.9	13.4	1.4	200	360	440
Selective by DBH	6.4	5.2	3.0	0.21	3.8	1.8	2.0	11.1	1.5	180	410	410
Selective by species	6.4	4.8	3.3	0.21	4.1	1.7	2.0	12.1	1.3	210	370	420
Control	6.6	9.5	4.0	0.20	4.8	1.9	1.7	12.5	1.8	190	430	380

Serap. = accumulated litter; OC = organic carbon; N = total N; SND = sand; SI = silt; CL = clay.

Table 3. Number of spores and average richness of arbuscular mycorrhizal fungi in Caatinga submitted to forest management and unmanaged Caatinga in the dry and the humid period.

Treatment	*Glomus macrocarpum*	*Gigaspora sp.*	*Glomus clavisporum*	*Archaeospora leptoticha*	*Scutellospora scutata*	Total number of spores	Average richness
5 months after management							
Clearcut	13.00 B	1.25 a	-	0.75 a	0.50 a	15.5 BC	2.00 a
Selective by DBH	9.75 B	0.25 a	-	-	-	10.00 C	1.25 a
Selective by species	21.25 B	0.50 a	0.50	-	0.25 a	22.5 B	1.75 a
Control	36.75 A	0.50 a	-	0.5 a	-	37.75 A	1.75 a
10 months after management							
Clearcut	9.25 BC	1.50	-	0.75 a	-	11.50 AB	2.25 a
Selective by DBH	12.00 AB	-	-	-	-	12.00 AB	1.00 a
Selective by species	7.25 C	-	0.25	0.50 a	-	8.00 B	1.50 a
Control	14.00 A	-	-	0.50 a	-	15.00 A	1.75 a

Similar capital or lowercase letters in the column do not differ from each other according to the Tukey and Kruskal-Wallis test at 5%, respectively.

Despite the differences observed in the two evaluation periods (Table 3), the extracted spores were dry and non-viable. This result indicates that, under the conditions studied, spores are not the main means of propagation of AMF. In other words, considering the importance of mycorrhizal symbiosis for plants, it is probable that other forms of propagules such as mycelia and colonized root fragments responded by greater potential of infectivity of the native AMF communities (Lima et al., 2007; Mello et al., 2012; Pagano et al., 2013). The high incidence of non-viable spores and, at the same time, low spore density may be related to the climatic conditions of the biome, involving periods of drought and increased soil temperature (Lima et al., 2007; Sousa et al. 2013; Silva et al., 2014).

The average richness did not differ between the treatments in any of the two evaluation periods (Table 3). However, a smaller number of species were observed in the unmanaged Caatinga area in relation to clear-cutting and selective logging based on species (Table 3). On the other hand, it is possible that the behavior of the AMF community in terms of infective propagules, as previously discussed, influenced the results because the identification of the species is carried out based on the spores and, thus, some species could have been lacking these propagules in the occasions of the collection.

The variation in the number of spores of the different AMF species evaluated by the *cluster* analysis showed dissimilarity between treatments (Figure 1). In both the five-month and the 10-month period following management, there was differentiation of the clear-cutting (CC) group, which composed the group 1, in relation to the other systems and the control, which composed the group 2 (Figure 1). This evidences that the CC caused a greater impact on the community of mycorrhizal fungi, whereas the selective logging based on DBH and species, which involved partial cuts, favored the maintenance of the original characteristics of the AMF community in the ecosystem.

Clear-cutting was the most invasive among the treatments tested, since it promotes the removal of the entire arboreal component. This procedure completely transforms the vegetation structure, interfering in the microclimate of the forest and modifying the quality and quantity of litter and root exudates (Marshall, 2000). As a consequence of this process, a decrease in root colonization and the number of AMF spores in clear-cutting areas is expected, as observed in this study.

Still according to Figure 1, it can be observed that, five months after management, the control had dissimilar from both selective logging managements. On the other hand, 10 months after management, there was a similarity between the control and selective logging based on DBH. This shows a recovery of the AMF community over time and corroborates the results obtained by Marshall (2000), who observed that, despite the immediate impact caused by logging, the affected organisms and biological processes are able to gradually recover over time.

Significant correlations were found between the number of AMF spores and some edaphic attributes at 10 months after management (Table 4). Among these, clay content was negatively associated with the number of spores of the species *Glomus macrocarpum*. This result is in disagreement with Lekberg et al. (2007), who reported a higher occurrence of the Glomeraceae in more clayey soils. On the other hand, this may be related to the fact that the *Glomus* genus has a high adaptability to different soil conditions, as previously discussed.

Table 4. Pearson correlation coefficients of spore number and average richness of AMF versus accumulated litter and organic carbon (OC), total nitrogen (N) and soil clay content in the Caatinga area, at 10 months after forest management.

	Litter	OC	N	Clay
Glomus macrocarpum	**0.79***	-0.21	**0.91***	**-0.78***
Gigaspora sp.	-0.33	**0.77***	-0.26	0.73
Glomus clavisporum	-0.38	-0.12	-0.60*	0.20
Archaeospora leptoticha	0.08	**0.95***	-0.05	0.34
Scutellospora scutata	0.00	0.00	0.00	0.00
Total number of spores	**0.82***	0.10	**0.93***	-0.65
Average richness	0.13	**0.98***	0.07	0.35

* Significant correlations at 5% probability of error

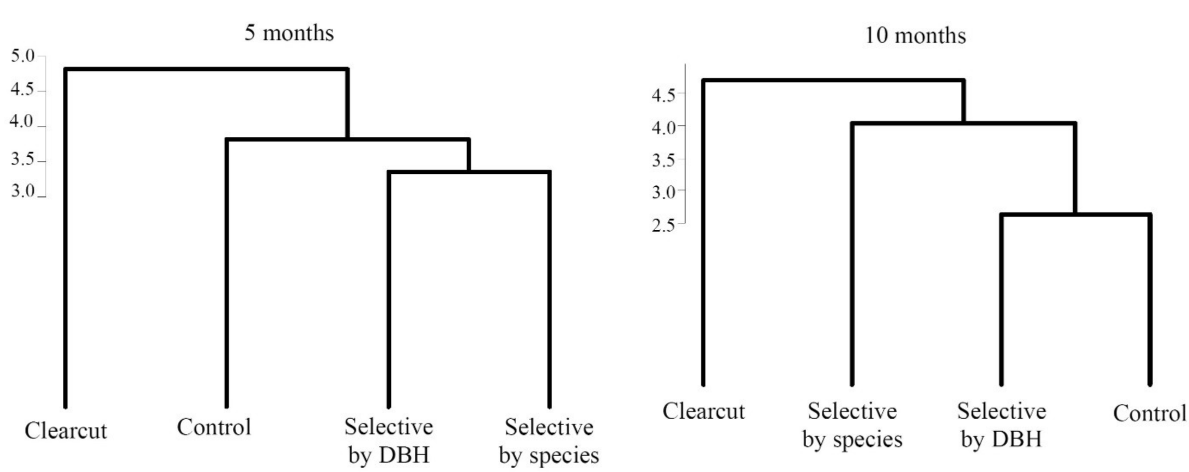

Figure 1. Dendrogram of similarity between Caatinga areas under three types of management and unmanaged Caatinga, based on the composition of AMF species.

Furthermore, accumulated litter and total N content of the soil correlated positively with the total number of spores and the number of spores of *Glomus macrocarpum* (Table 4). There was also a positive correlation between organic C in the soil (CO) content and average richness and number of spores of the species *Gigaspora* sp. and *Archaeospora leptoticha* (Table 4). These correlations evidenced the strong influence of soil organic matter (SOM) availability on the AMF communities and their diversity of species, conditioning the average richness.

Ceola (2015) also observed a significant relationship between CO content and the composition of arbuscular mycorrhizal fungi communities. According to Braghirolli et al. (2012), the fungi are abundant components of the soil biota and, therefore, the MOS, which explains the correlations observed in the present work. Additionally, the structures formed by these fungi can contribute significantly to the amount of C fixed in the soil.

The results obtained in this study reveal that forest management causes short-term changes in the mycorrhizal community and that this presents a capacity of recovery over time. Nevertheless, future studies should be carried out to evaluate the influence of the time of management in the dynamics of AMF in Caatinga areas.

Conclusions

The community of arbuscular soil mycorrhizal fungi (AMF) is sensitive to the changes caused by forest management.

The different managements cause changes in the AMF community, with a greater impact of clear-cutting. Despite this, the mycorrhizal community proved to be capable of recovering over time.

Literature Cited

Bashan, Y.; Davis, E.A.; Carrillo-Garcia, A.; Linderman, R.G. Assessment of VA mycorrhizal inoculum potential in relation to the establishment of cactos seedlings under mesquite nurse-trees in the Sonoran Desert. Applied Soil Ecology, v.14, n.2, p.165-175, 2000. https://doi.org/10.1016/S0929-1393(00)00050-0.

Braghirolli, F.L.; Sgrott, A.F.; Pescador, R.: Uhlmann, A.; Stürmer, S.L. Fungos micorrízicos arbusculares na recuperação de florestas ciliares e fixação de carbono no solo. Revista Brasileira de Ciência do Solo, v.36, n.3, p. 733-743, 2012. https://doi.org/10.1590/S0100-06832012000300005.

Brasil. Lei n. 12.651, de 25 de maio de 2012. Dispõe sobre a proteção da vegetação nativa; altera as Leis nos 6.938, de 31 de agosto de 1981, 9.393, de 19 de dezembro de 1996, e 11.428, de 22 de dezembro de 2006; revoga as Leis nos 4.771, de 15 de setembro de 1965, e 7.754, de 14 de abril de 1989, e a Medida Provisória no 2.166-67, de 24 de agosto de 2001; e dá outras providências. Diário Oficial da União, n.102, seção 1, p.10-11, 2012. http://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/l12651.htm. 12 Jun. 2017.

Ceola, G. Biogeografia e diversidade de fungos micorrízicos arbusculares em cenários contrastantes de uso do solo e de regime hídrico. Santa Catarina: Universidade do Estado de Santa Catarina, 2015. 166p. Tese Doutorado. http://hdl.handle.net/10316/30795. 05 Jun. 2017.

Costa, T.L.; Sampaio, E.V.S.B.; Sales, M.F.; Accioly, L.J.O.; Althoff, T.D.; Pareyn, F. G.C.; Albuquerque, E.R.G.M.; Menezes, R.S.C. Root and shoot biomasses in the tropical dry forest of semi-arid Northeast Brazil. Plant Soil, v.378, n.1, p.113-123, 2014. https://doi.org/10.1007/s11104-013-2009-1.

Gerdemann, J.W.; Nicolson T.H. Spores of mycorrhizal endogone species extracted from soil by wet-sieving and decanting. Transactions of British Mycological Society, v.46, n.2, p.235-244, 1963. https://doi.org/10.1016/S0007-1536(63)80079-0.

Jenkins, W.R. A rapid centrifugal-flotation technique for separating nematodes from soil. Plant Disease Report, v.48, p.692, 1964. http://garfield.library.upenn.edu/classics1980/A1980KJ72900001.pdf. 12 Jun. 2017.

Lekberg, Y.; Koide, R.T.; Rohr, J.R.; Aldrichwolfe, L.; Morton, J.B. Role of niche restrictions and dispersal in the composition of arbuscular mycorrhizal fungal communities. Journal of Ecology, v.95, p.95-105, 2007. https://doi.org/10.1111/j.1365-2745.2006.01193.x.

Lima, R.L.F.A.; Salcedo, I.H.; Fraga, V.S. Propágulos de fungos micorrízicos arbusculares em solos deficientes em fósforo sob diferentes usos, da região semi-árida no nordeste do Brasil. Revista Brasileira de Ciência do Solo, v.31, p.257-268, 2007. https://doi.org/10.1590/S0100-06832007000200008.

Marshall, V.G. Impacts of forest harvesting on biological processes in northern forest soils. Forest Ecology and Management, v.133, p.43-60, 2000. https://doi.org/10.1016/S0378-1127(99)00297-2.

Mello, C.M.A.; Silva, I.R.; Pontes, J.S.; Goto, B.T.; Silva, G.A.; Maia, L.C. Diversidade de fungos micorrízicos arbusculares em área de Caatinga, PE, Brasil. Acta Botanica Brasilica, v.26, n.4, p.938-943, 2012. https://doi.org/10.1590/S0102-33062012000400023.

Ministério do Meio Ambiente - MMA. Manejo sustentável dos recursos florestais da Caatinga. Natal: Secretaria de Biodiversidade e Florestas, Departamento de Florestas, 2008. 28p.

Ministério do Meio Ambiente - MMA. Plano de Manejo Floresta Nacional Contendas do Sincorá**.** Volume I: Informações Gerais sobre a Floresta Nacional. Brasília: Instituto Brasileiro de Meio Ambiente e dos Recursos Naturais Renováveis, 2006. 132p.

Moro, M. F.; Lughadha, E. N.; Araújo, F. S.; Martins, F. R. A Phytogeographical metaanalysis of the semiarid Caatinga domain in Brazil. The Botanical Review, v.82, n.2, p 91–148, 2016. https://doi.org/10.1007/s12229-016-9164-z.

Pagano, M.C.; Cabello, M.N. Mycorrhizal interactions for reforestation: constraints to dryland agroforest in Brazil. ISRN Ecology, v.2011, Article ID 890850, 2011. https://doi.org/10.5402/2011/890850.

Pagano, M.C.; Utida, M.K.; Gomes, E.A.; Marriel, I.E.; Cabello, M.N.; Scotti, M.R. Plant-type dependente changes in arbuscular mycorrhizal communities as soil quality indicator in semi-arid Brazil. Ecological Indicadors, v.11, n.2, p.643-650, 2011b. https://doi.org/10.1016/j.ecolind.2010.09.001.

Pagano, M.C.; Zandavalli, R.B.; Araújo, F.S. Biodiversity of arbuscular mycorrhizal in three vegetation types from the semiarid of Ceará State, Brazil. Applied Soil Ecology, v.67, p.37-46, 2013. https://doi.org/10.1016/j.apsoil.2013.02.007.

Queiroz, L.P. Leguminosas da Caatinga. Feira de Santana: UEFS, 2009. 914p.

Riegelhaupt, E.M.; Pareyn, F.G.C.A questão energética. In: Gariglio, M.A.; Sampaio, E.V.S.B.; Cestaro, L.A.; Kageyama, P.Y. (Orgs.). Uso sustentável e conservação dos recursos florestais da Caatinga. Brasília: Serviço Florestal Brasileiro, 2010. p. 65-75

Schenck, N.C.; Perez, Y. Manual for the identification of vesicular-arbuscular mycorrhizal fungi. Gainesville: Synergistic Publications, 1988. 255p.

Silva, I.R.; Mello, C.M.A.; Ferreira Neto, R.A.; Silva, D.K.A.; Melo, A.L.; Oehl, F.; Maia, L.C. Diversity of arbuscular mycorrhizal fungi along an environmental gradient in the Brazilian semiarid. Applied Soil Ecology, v.84, p.166-175, 2014. https://doi.org/10.1016/j.apsoil.2014.07.008.

Smith, S.E.; Smith, F.A. Fresh perspectives on the roles of arbuscular mycorrhizal fungi in plant nutrition and growth. Mycologia, v.104, p.1–13, 2012. https://doi.org/10.3852/11-229.

Sousa, C.S.; Menezes, R.S.C.; Sampaio, E.V.S.B.; Lima, F.S.; Oehl, F. Arbuscular mycorrhizal fungi in successional stages of caatinga in the semi-arid region of Brazil. Ciência Florestal, v.24, n.1, p.137-148, 2014. https://doi.org/10.5902/1980509813331.

Sousa, C.S.; Menezes, R.S.C.; Sampaio, E.V.S.B.; Lima, F.S.; Oehl, F.; Maia, L.C. Arbuscular mycorrhizal fungi within agroforestry and traditional land use systems in semi-arid Northeast Brazil. Acta Scientiarum – Agronomy, v.35, n.3, p.307-314, 2013. https://doi.org/10.4025/actasciagron.v35i3.16213.

Souza, F.A.; Silva, I.C.L.; Berbara, R.L.L. Fungos micorrízicos arbusculares: muito mais diversos do que se imaginava. In: Moreira, F.M.S.; Siqueira, J.O.; Brusssard, L. (Eds.). Biodiversidade do solo em ecossistemas brasileiros. Lavras: Universidade Federal de Lavras, 2008. p. 483-536.

Teixeira-Rios, T.; Souza, R.G.; Maia, L.C.; Oehl, F.; Lima, C.E.P. Arbuscular mycorrhizal fungi in a semi-arid, limestone mining-impacted area of Brazil. Acta Botanica Brasilica, v.27, n.4, p.688-693, 2013. https://doi.org/10.1590/S0102-33062013000400006.