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Arbuscular mycorrhiza fungi and water retention characteristics of a tropical rainforest soil during the dry and rainy seasons

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ABSTRACT

Water relations of arbuscular mycorrhiza fungi (AMF) soils have been compared with the non-AMF soils, and often found that AMF increased soil water retention in cultivated soils. However, little knowledge is available about the influence of AMF on water retention characteristics of rainforest soils. In this study, we evaluated the population and the relationship between AMF of a tropical rainforest soil and water retention characteristics in the dry and rainy seasons. Results showed that AMF population and species abundance increased significantly in the dry season than rainy season. The AMF population was significantly higher ($p<0.05$) at 392.5 spores 100 g^{-1} soil in the dry season, than 297.7 spores 100 g^{-1} soil found in the rainy season. A*caulospora* and *Glumos* sp were dominant in the dry season soils with 106.1 and 78.5 spores 100 g^{-1} soil, respectively, in comparison with 92.3 and 67.7 spores 100 g^{-1} soil in the rainy season soils, respectively. Micro-porosity was significantly higher ($p<0.01$) in the rainy season than dry season, indicating that AMF aided more water retained in the soil during the rainy season. Water retention at field capacity (FC) was significantly higher ($p<0.05$) at 20.3% in dry season. Available water content (AWC) of 9.2% in dry season, indicated tendency of the soil to take in water in dry season than in rainy season. Macro-porosity favoured increase in AMF, while micro-porosity decreased AMF population in the soil. Water content at field capacity (FC) and available water content (AWC) showed significant positive relationships with AMF ($r = 0.741$, $p<0.05$ and $r = 0.814$, $p<0.01$), (respectively). Therefore, AMF could be effective in the maintenance of soil water during the dry and rainy seasons and potentially increased water retention at permanent wilting point for crop use.

Keywords: Arbuscular mycorrizha fungi, tropical soil, field capacity, available water, macro-porosity.

INTRODUCTION

Arbuscular Mycorrhizal fungi (AMF) plays important roles in the functioning of terrestrial ecosystems and on plant development in field conditions (Rillig, 2004). They form mutualistic interactions with a great variety of plants in several ecosystems across the globe (Brundrett, 2009), and produce copious amounts of the glycoprotein glomalin which improve pore spaces in the soil (Rillig, 2004). Although soil aggregation is a complex hierarchical process (Udom *et al*., 2016), concentration of glomalin is tightly correlated with aggregate stability and water retention across many soils (Wright and Upadhyaya 1998; Emam, 2016; Vahter *et al*., 2020; Medeiros *et al*., 2021). The hyphae of AMF are able to connect plant individuals, colonizing more than one root, and forming interactive networks in the soil, which distribute resources to the plant community through their mycelia, (Van Der Heijden and Horton, 2009). They increase the uptake of nutrients in the soil, such as phosphorus (Nazeri *et al*., 2013), and nitrogen (Leigh *et al*., 2009). The mycelium of AMF can maintain soil moisture (Aug´e, 2004), allowing plants to better tolerate drought conditions (Aug´e, 2001). Several studies have reported that AM fungal communities vary along different stages of plant succession (Souza *et al*., 2013), vegetation types (Pagano *et al*., 2013; Silva *et al*., 2014), or ecosystem disturbance intensities (Pereira *et al*., 2014; 2018).

The hyphae of AM fungi grow into the soil matrix to create the skeletal structure that holds primary soil particles together via physical entanglement. They create conditions conducive to formation of micro-aggregates, and they chemically enmesh and stabilize micro-aggregates and smaller macro-aggregates into macro-aggregate structures (Miller and Jastrow, 2000). The number and dimension of the pore spaces between soil particles are important in functional considerations of soil structure, especially from the standpoint of soil water relations. The moisture characteristic of a soil depends on the size and distribution of its pores, or void space. Due to the effect of AM fungi on soil structure, it seems logical to suspect that AM colonization of a soil might affect its water retention characteristics and, in turn, the affinity of soil water to growing plants in dry or wet seasons. AM fungi directly influence growth of a great variety of plant species by increasing nutrient uptake and providing a network of nutrient distribution for the whole plant community.

In tropical dry forest, practices such as irrigation, litter transposition and agroforestry systems could affect the AM fungal community (Silva *et al*., 2015). In terms of irrigation agriculture, AM fungi species may have their relative abundance altered by gradients of water availability in the soil (Freitas *et al*., 2014). Teixeira-Rios *et al*. (2018) showed that in semiarid ecosystems, the number of *glomerospores* was higher in the rainy season than in the dry season. However, de Souza *et al*. (2016) reported higher number of *glomerospores* in the dry seasons. Other studies, (Silva *et al*., 2015) reported that very low or very high soil water content decreases total *glomerospores* numbers, while da Silva Barros *et al*. (2019) observed that intermediate level of soil water promoted maximum AM fungi sporulation rates. Additionally, irrigation can lead to an increase in soil salinization in some regions (Banerjee *et al*., 2006), which can be detrimental to the development of AM fungal communities (Juniper and Abbott, 2006). Studies of mycorrhiza and soil water relations have almost always focused on how AM fungi affect the plant. Authors support the idea that AM fungi may increase available water to plants under relatively dry conditions (permanent wilting point potential) (Duan *et al*. 1996; Augé 2001). The studies concluded that AM fungi probably increased the capability of cowpea root systems to scavenge water in drier soil, resulting in less strain to roots and foliage and hence higher transpiration, and shoot water status at low soil water content.

There is increasing interest in the relationships between AM fungi and soil water retention at specific matric potentials and related soil properties, because of the need to conserve soil water for plant use. The most obvious interest and objective in this study was to relate AM fungi to soil water characteristics during the dry and wet periods in a rainforest soil. This is because; the influence of AM fungi on water retention properties of soils remains largely unstudied. Thus, this study would bridge important gap in knowledge and improve our understanding on the role of AM fungi and soil water content in the rainforest soils during the dry and wet seasons.

MATERIALS AND METHODS

The Study Area

The study was carried out in a humid tropical rainforest soil, located at the Forestry Division of the Rivers State University Teaching and Research Farm, in Port Harcourt, southern Nigeria (Latitude 4^{O} 30′N and Longitude 7^{O} 00′E). The climate of the area is of the tropical humid climate, with two seasons (the dry and wet seasons). The dry season is usually shorter, from November to March; while the wet (rainy) season is longer; from Mid-March to October. The mean annual rainfall in the area ranges between 3,000 mm and 4,500 mm, the maximum temperature ranges between 22 and 29 ^{O}C, while relative humidity is between 75 and 95% (FAO, 1984). The soil is sandy clay loam, derived from Coastal Plain Sands of the Niger Delta Region. The sand, silt and clay contents at the 0-30 cm topsoil are 678, 148, and 174 g kg^{-1}, with pH of between 4.4-5.8 (Udom and Adesodun, 2016).

Soil Sample Collection and Laboratory Analysis

Disturbed and undisturbed core soil samples were collected in two seasons: the rainy and wet seasons at 0-15 cm in three randomly selected 30 x 30 m plots within the area. The disturbed soil samples were kept in labeled plastic bags, while the core samples were tied with polythene to prevent moisture loss and crusting. Soil samples for microbial studies were collected with the use of well labeled sterile bottles. All the soil samples were transported to the laboratory for analysis.

Isolation and Extraction of Arbuscular Mycorrhizal Fungi Spores

The Arbuscular Mycorrhizal (AM) fungi spores were separated from soil by wet-sieving and decanting technique as describe by Gerdmann and Nicolson (1963). In this procedure, 50 g of soil sample was mixed in 200 ml of distilled water in a large beaker. After 1 h, the soil suspension was sieved through a 200 µm to 25 µm nest of sieves arranged in a descending order. The process was repeated until the upper layer of the soil suspension was transparent. The retained material on the sieve was washed into a beaker using a stream of water. The AM fungi spores were identified and enumerated using a microscope, by the morphological observation of colour, shape, size, hyphal attachment, spore ornamentation and spore reaction to Meizer’s solution (Schneck and Perez, 1990; Schubler and Walker, 2010).

Particle-size Distribution, Water Retention Characteristics and Porosity

Particle-size distribution was determined by the method of Gee and Or (2002) using 50 g of air-dried soil after dispersion with sodium hexametaphosphate. Soil water retention characteristics (SWRC) were measured with soil cores measuring 6 cm x 5 cm (height x diameter) using pressure chamber with ceramic plates. After saturation, water retention at 0 to -10 kPa was measured by the hanging water column method as described by Wang and Benson (2004). Water retention at -1500 kPa was measured with Pressure Plate apparatus. Water retained at -10 kPa represents water content at field capacity (FC) and water retained at -1500 kPa represents permanent wilting point (PWP) (Cassel and Nielson, 1986). The agronomic moisture states: available water (AW) was calculated according to Braudeau *et al*. (2005) as:

$$AW = FC - PWP \qquad (1)$$

Total porosity was determined with the core samples using the method of Flint and Flint (2002) as:

$$\% \, Total\ porosity = \frac{volume\ of\ water\ at\ saturation\ (cm^3)}{volume\ of\ bulk\ soil\ (cm^3)} \times 100 \quad (2)$$

Macro-porosity (pore size > 5µm) was calculated as:

$$\% \, Macro-porosity = \frac{volume\ of\ water\ drained\ at -10\ kPa\ (cm^3)}{volume\ of\ bulk\ soil\ (cm^3)} \times 100 \quad (3)$$

$$\% \, Micro-porosity = \% \, Total\ porosity - \% \, macro-porosity \quad (4)$$

Moisture content at field capacity was measured at -10 kPa when all pores > 5µm had drained by gravity.

Statistical Analysis

Statistical analyses of the data were performed using the SAS software (SAS, 2016). The data was subjected to T-test of paired comparison of differences between soil parameters in dry and wet season at $p \leq 0.05$ probability (Gomez and Gomez, 1984). Possible differences in the composition of AM fungi species between the dry and wet season were explored by test of pair comparison analysis. A linear regression analysis was used to evaluate how the water retention at various pressure potentials was influenced by the abundance of AM fungi. A correlation test between all predictive variables was used to verify possible relationships among the measured parameters at 5% probability.

RESULTS

Arbuscular Mycorrhiza Fungi Abundance, Species Richness and Diversity

In both seasons, a total of eight arbuscular mycorrhiza fungi morphology were observed, which belong to eight different genera viz: G*lomus*, A*caulospora*, G*igaspora*, P*araglomus*, *Rhizophagus*, A*rchaecospora*, D*entiscutata*, and C*lariodeoglomus* (Table 1). Arbuscular mycorrhiza spore abundance varied between the dry and rainy season (Table 1). Total number of spores was significantly higher ($p<0.05$) in the dry season (392.5 spores 100 g^{-1} soil), than the value of 297.7 spores 100 g^{-1} soil obtained in the rainy season. In both seasons, the highest spore number was recorded for A*caulospora* sp. with 106.1 and 92.3 spores 100 g^{-1} soil in dry and rainy season, respectively. This was followed by G*lumos* sp. with 78.5 and 67.7 spores 100 g^{-1} soil for dry and rainy season. The lowest spore numbers were recorded for G*igaspora* sp. with values of 1.8 and 0.3 spores 100 g^{-1} soil, respectively in dry and rainy season (Table 1). The abundance of the eight genera was in the order of A*caulospora* > G*lomus* > A*rchaecospora* > C*lariodeoglomus* > R*hizophagus* > P*araglomus* > D*entiscutata* > G*igaspora* in both the rainy and dry seasons.

Total Porosity, Pore-size Distribution and Water Retention Characteristics of the Soil

The effects of dry and rainy season aeration properties, measured by the pore-size distribution and water retention characteristics are shown in Table 2. Total porosity was significantly higher ($p<0.05$) in the rainy (49.2%), than the dry season. Macro-porosity (aeration pores) was 21.6% for dry season and 19.7% for rainy season. Micro-porosity (capillary pores) was significantly higher ($p<0.01$) in the rainy season than dry season. Water retention at field capacity (FC) was significantly higher ($p<0.05$) at 20.3% at dry season, and non-significant different ($p>0.05$) at permanent wilting point (PWP) (Table 2). Available water content (AWC) was higher at 9.2% in dry season.

Table 1: Effects of season on arbuscular mycorrhiza population of the rainforest soil

Season	Glomus	Acaulos	Gigaspo	Paraglo	Rhizosp	Archaeo	Dentisou	Clariode	Totspore
Dry	78.5[a]	106.1[a]	1.8[a]	42.0[a]	42.3[a]	44.2[a]	35.1[a]	42.5[a]	392.5[a]
Rainy	67.7[a]	92.3[a]	0.3[a]	42.0[a]	35.3[a]	5.7[b]	28.6[a]	29.1[b]	297.7[b]

Means with same letters within columns are not significantly different P<0.05.

Table 2: Effect of dry and rainy seasons on pore-size distribution and water retention characteristics of the rainforest soil at 0-15 cm topsoil

Soil properties	Dry season	Rainy season	t-values
Total porosity (%)	33.4	49.2	3.61*
Macro-porosity (%)	21.6	19.7	1.37ns
Micro-porosity (%)	11.8	29.5	4.82**
Field capacity (%)	20.3	15.2	3.46*
Permanent wilting point (%)	11.1	10.1	0.73ns
Available water (%)	9.2	5.1	3.11*

*Significant at p<0.05, **Significant at p<0.01, ns-non significant at p>0.05

The water release pattern in Fig. 1 showed a relatively gradual release pattern for both seasons, with the soil releasing about 29% and 30% of the moisture between saturation (0 kPa) and field capacity (-10 kPa) in dry and rainy seasons, respectively. The amount of water retained use (AWC) between FC and PWP was 37.5% in dry season and 60% in rainy season (Fig.1). Volumetric water content at saturation (0 kPa), field capacity (-10 kPa), and permanent wilting point (-1500 kPa) were 0.31, 0.22, and 0.16 cm^3 cm^{-3}, respectively, in dry season and 0.34, 0.24, and 0.15 cm^3 cm^{-3}, respectively, in rainy season (Fig. 1).

Relationships between Arbuscular Mycorrhiza Fungi and Soil properties

In Table 3, Arbuscular mycorrhiza fungi showed a negative significant linear relationship with micro-porosity (r = -0.611, p<0.05), accounting for 37.3% of this relationship, and a positive linear correlation with macro-porosity (r = 0.706, p<0.05), accounting for 49.8% of the relationship. Water content at FC and AW showed significant positive relationships with AMF (r = 0.741, p<0.05 and r = 0.814, p<0.01), respectively. The model: AMF = 2.031 + 0.749(AW), can best be used to predict increase in AW content with increase in the population of AMF and its effect on the maintenance of soil moisture content during the dry and rainy seasons.

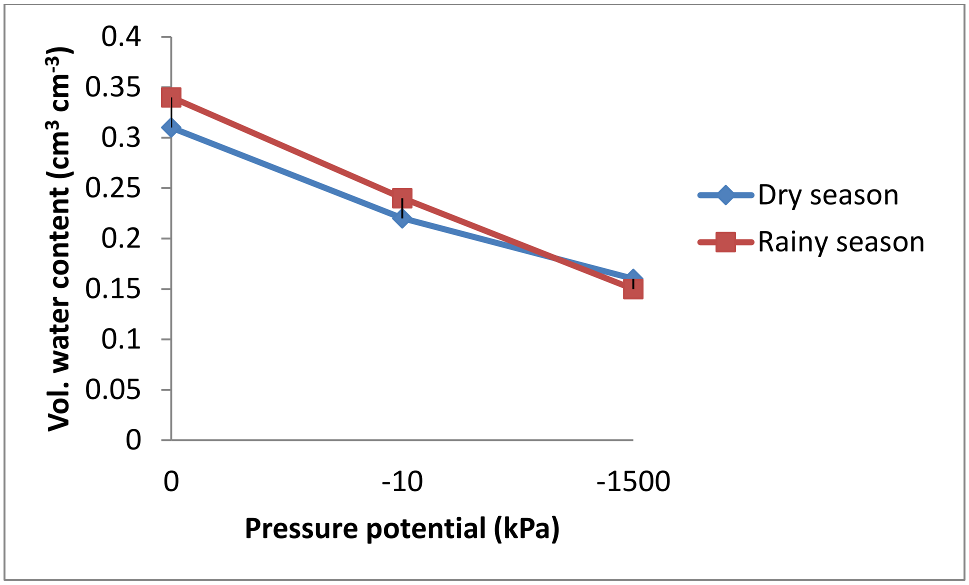

Fig. 1. Water retention characteristics curves of the rainforest soil at 0-15 cm topsoil during the dry and rainy seasons

Table 3: Relationships between arbuscular mycorrhiza fungi and soil properties (N=12)

Regression equation	R^2	R	P
Micro-porosity = 0.539 + 1.251(AMF)	0.373	-0.611	*
Macro-porosity = 1.551 + 1.046(AMF)	0.498	0.706	*
AMF = 2.212 + 0.943(FC)	0.549	0.741	*
AMF = -1.014 + 1.261(PWP)	0.527	-0.726	*
AMF = 2.031 + 0.749(AW)	0.663	0.814	**
AMF = 0.591 + 2.164(Sand)	0.561	0.749	*
AMF = 1.069 + 0.283(Silt)	0.294	-0.542	Ns
AMF = 0.547 + 1.109(Clay)	0.492	-0.701	*

R^2–Coefficient of determination, R – Coefficient of correlation, AMF- arbuscular mycorrhiza fungi, FC- field capacity, PWP- permanent wilting point, AW- available water, *Significant at p < 0.05, **Significant at p < 0.01, ns- non-significant at p>0.05.

The relationship between AMF and water content at permanent wilting point (PWP) was negative (r = -0.726, p>0.05), accounting for 52.7% of the relationship. The relationship between AMF and silt fraction was negative and non-significant (r = -0.542, p>0.05). The AMF showed significant positive linear model with sand content (r = 0.749, p<0.05), and a significant negative linear relationship with clay content (r = -0.701, p<0.05), indicating that AMF increases with decrease in clay content of the rainforest soil, and accounted for 49.2% in the model.

DISCUSSION

Arbuscular mycorrhiza fungi (AMF) spores, numbers, species richness and diversity were significantly higher in the dry season than rainy season. This result is consistent with the report of Silva *et al*. (2015) who found higher spore numbers of AMF in dry season than rainy season in different soils of a rainforest in Mexico. It is also possible that low moisture condition during the dry season increased the soil aeration which consequently increased the AMF (Souza *et* *al*., 2013). A*caulospora* and G*lomus* sp. were the most dominant AMF genera in the soil, which further confirmed previous studies (Snoeck *et al*., 2010; Zerihun *et al*., 2013). Earlier studies also showed that Glomus species were widely found and distributed in different soils regardless of intensity of disturbance of the ecosystems, while A*caulospora* sp. was dominant in least disturbed ecosystems (Snoeck *et al*., 2010). This fact is being justified in this study by the significantly higher population of A*caulospora* and G*lomus* sp. found in this tropical rainforest known for minimal disturbances.

The significantly higher total and micro-porosity found in the rainy season was not surprising, because increase in fine-particle fraction following soil detachment by rainfall impact usually lead to increase in micro-porosity of soils (Udom and Kamalu, 2016). In tropical rainforest, with aggressive annual rainfall intensity, the soil is usually prone to detachment of silt-clay fractions which can increase the total and micro porosity of tropical soils (Udom and Benwari, 2018). The significant increase in water content at field capacity (FC) and permanent wilting point (PWP) in the dry season was interesting in discussing the role of biological activities in increasing soil macro-porosity and consequently, the aeration capacity of the soil (Udom and Adesodun, 2016; Vahter *et al*., 2020). Similarly, the high water retention at saturation (0 kPa) of the soil in wet season was in agreement with the reports of Augé (2001) and Silva *et al*. (2015), who obtained higher soil water retention in soils due to the mycorrhizal activities. The higher water retention at 0 kPa and -10 kPa in wet season is also possible as water adsorption on the clay surfaces tend to decrease in wet soils than dry soils (Udom and Nuga, 2014; Silva *et al*., 2015).

The significant positive linear model between macro-aggregates and AMF can be discuss as the direct positive role of AMF hyphae in breaking the soil, creating gap for soil air diffusion, and possibility of increasing the macro-pores (Nobel and Cui, 1992; da Silva Barros, *et al*., 2019). Further, the negative relationship between micro-porosity and AMF have been discussed in the studies of Augé (2001); Vahter *et al*. (2020) and Medeiros *et al*. (2021), indicating that the higher the clay content, the fewer would be the population of AMF in the soil. This was related to the low aeration capacity usually associated with the capillary (micro) porosity (Udom *et al*., 2018). The positive correlation between AMF and AWC and FC is consistent with the previous reports of Silva *et al*. (2015), who reported positive relationships between AMF and AWC and water content at FC by creating surfaces for water adsorption in the soil. The inverse relationships between AMF and silt and clay fraction is in agreement with Udom and Benwari (2018) who reported a negative relationship between fungi and silt and clay content of a tropical soil after applications of poultry manure.

CONCLUSION

Conclusions drawn from this study are that: *arbuscular mycorrhiza* fungi (AMF) population was significantly higher in the dry season than rainy season. The A*caulospora* and G*lomus* were dominant species and abundant in both the dry and rainy season, with marginal increase in the dry season than rainy season. Total porosity was higher in the rainy season due to creation of fine-particle fractions through breakdown of macro-aggregates by the impact of high rainfall common in the rainforest, which also increased the micro-porosity of the soil. Water content at field capacity (FC) and permanent wilting point (PWP) increased in the dry season. Available water capacity of the soil was 37.5% in dry season and increased to 60% in the rainy season. Water retention at field capacity showed field correlated positively with AMF. Thus, AMF increased water retention at field capacity and permanent wilting point and reduced the tendency of rainforest soils to dry up quickly after rainfall.

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