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Density and diversity of mycorrhizal propagules in cultivated and contaminated soils under tropical conditions

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Abstract: The intricate relationships between arbuscular mycorrhizal fungi (AMF) and ecosystems underscore their critical role in maintaining soil health and plant productivity, yet environmental factors profoundly influence their abundance and diversity. Therefore, a survey was conducted to know the diversity and density of AMF in three contrasting locations. This study investigated the density and diversity of AMF propagules in cultivated and contaminated soils under tropical conditions across two seasons using wet sieving and sucrose density gradient centrifugation methods, in a survey of three contrasting locations and three soil depths (0-15, 15-30, and 30-45 cm). The results revealed that soil pH ranged from 4.79-6.52 across sites, influencing AMF populations. The spore density was higher in topsoil and decreased with depth, except in secondary forests. Rainy seasons had higher spore densities than dry seasons, with contaminated land exhibiting the highest density. We isolated 27 AMF species from eight genera, with Glomus being the most dominant (40% relative abundance), and varying distributions across seasons (*Septoglomus constrictum* had 12.79% relative abundance in rainy season) and soil depths (*Acaulospora longula* had 9.13% and 19.85% relative abundance at 0-15 cm and 15-30 cm depths, respectively). Soil depth, organic carbon concentration, and pH significantly influenced AMF population, relative abundance, and distribution. Our findings have implications for understanding AMF ecology and managing ecosystems sustainably, highlighting the importance of preserving AMF diversity for maintaining soil health, fertility, and overall ecosystem sustainability.

Key-words: arbuscular mycorrhizal fungi, soil depths, relative abundance, spore density and diversity.

Densidade e diversidade de propagulos micorrízicos em solos cultivados e contaminados sob condições tropicais

Resumo: As complexas relações entre fungos micorrízicos arbusculares (FMA) e ecossistemas destacam seu papel crítico na manutenção da saúde do solo e da produtividade das plantas, no entanto, fatores ambientais influenciam profundamente sua abundância e diversidade. Portanto, foi realizada uma pesquisa para conhecer a diversidade e densidade de FMA em três locais contrastantes. Este estudo investigou a densidade e diversidade de propágulos de FMA em solos cultivados e contaminados sob condições tropicais em duas estações, utilizando métodos de peneiração úmida e centrifugação por gradiente de densidade de sacarose, em uma pesquisa de três locais contrastantes e três profundidades de solo (0-15, 15-30 e 30-45 cm). Os resultados revelaram que o pH do solo variou de 4,79 a 6,52 entre os locais, influenciando as populações de FMA. A densidade de esporos foi maior na camada superficial do solo e diminuiu com a profundidade, exceto em florestas secundárias. As estações chuvosas apresentaram densidades de esporos mais altas do que as estações secas, com terras contaminadas exibindo a maior densidade.Isolamos 27 espécies de fungos micorrízicos arbusculares (FMA) de oito gêneros, com Glomus sendo o mais dominante (40% de abundância relativa), e distribuições variadas ao longo das estações (Septoglomus constrictum teve 12,79% de abundância relativa na estação chuvosa) e profundidades do solo (Acaulospora longula teve 9,13% e 19,85% de abundância relativa nas profundidades de 0-15 cm e 15-30 cm, respectivamente). A profundidade do solo, a concentração de carbono orgânico e o pH influenciaram significativamente a população de FMA, a abundância relativa e a distribuição. Nossos achados têm implicações para entender a ecologia dos FMA e para gerenciar ecossistemas de forma sustentável, destacando a importância de preservar a diversidade de FMA para manter a saúde do solo, a fertilidade e a sustentabilidade geral do ecossistema.

Palavras-chave: fungos micorrízicos arbusculares, profundidades do solo, abundância relativa, densidade de esporos e diversidade.

1. INTRODUCTION

Soil is a heterogeneous medium for the growth and development of microorganisms, and a complex environment with a great variety of microbial community that co-exists and are balanced by the complex equilibrium of species and the environment (PAUL, 2014). Bacteria, archaea, protozoa, fungi, and algae are some of the many types of microorganisms which can be found in all parts of the ecosphere including ocean, soil, atmosphere, and within the earth's surface (BHATTARAI et al., 2015). Mycorrhizae is a group of fungi that has a symbiotic relationship with plant roots, and they exist within this microbiota. Arbuscular mycorrhizal fungi are obligate fungus that belong to the phylum Glomeromycota, categorised as mycorrhiza-forming fungi. They enhance plant nutrient absorption (SELOSSE and ROUSSET, 2011), improve soil aggregate stability, and plant biomass and yield (LEWANDOWSKI et al., 2013). Mycorrhizal fungi also have impact on plant community structure and biodiversity, and their effects varies depending of their host plants (ÖPIK et al., 2013; BITTEBIERE et al., 2020). Mycorrhizal fungi connect plants through a vast mycelia network in the soil and may effectively absorb nutrients from the soil and transfer them to their host plants in exchange for carbohydrates by extending their complex hyphal network (WIPF et al., 2019). The determination of the positive effects of AMF plants depends on the diversity and abundance of a specific AM species, especially those with extensive hyphal networks (Gigasporoaceae), as well as other species that are capable of protecting against pathogens or can even be parasitic (TKACZ and POOLE, 2015; BERRUTI et al., 2016). Arbuscular mycorrhizal fungi promote phosphorus absorption, increases resistance to root pathogens, and provide protection against abiotic stresses, including drought and metal toxicity (BOROWICZ, 2001; AROCA et al., 2007).

Despite the significant influence of environmental factors on soil microbial communities, arbuscular mycorrhizal fungi (AMF) may still be found in diverse habitats globally, regardless of whether the ecosystem is pristine or degraded. The distribution of AMF is significantly influenced by several characteristics that impact its density and diversity. Climate (KIVLIN et al., 2011), pH (BAINARD et al., 2015), soil depth, soil types (LEKBERG et al., 2007), altitude (GAI et al., 2012), host plants, distribution of plant species (KIVLIN et al., 2011; EMMANUEL et al., 2012), and variations in plant development and location (UHLMANN et al., 2004) are the factors that significantly influence their diversity and richness in a given environment or habitat. The predominant factor influencing the composition and diversity of arbuscular mycorrhizal (AM) fungal species is land use, which includes cultivation, livestock grazing, agroforestry, and the conservation of protected areas (KLIRONOMOS et al., 2004; RENKER et al., 2005). These land use practices impact soil disturbance, plant biomass, and carbon sequestration as a result of grazing and fertiliser application. (SOKA and RICHIE, 2018).

According to D'Souza and Rodrigues (2013), the tilt of the Earth's axis results in seasonal fluctuations in spore density and environmental conditions. These changes have some effects on the makeup of AMF communities. The seasonal changes in biotic and abiotic factors significantly influence mycorrhizal fungal communities, with comprehensive documentation of seasonal fluctuation in these communities (REYES et al., 2019). According to Bainard et al. (2014) the concentration of soil phosphates and soil moisture content are significant variables affecting seasonal fluctuations in the soil AM fungal population. Seasonal fluctuation in the AM fungal population is strongly related to phenological alterations in the host plant (LUGO and CABELLO, 2002; UNUK et al., 2019). Cuenca and Lovera (2010) observed that arbuscular mycorrhizal fungal richness was decreased throughout the plant growth season (dry season) in tropical or subtropical locations compared to the rainy season (plant blooming or fruiting). Santos-González et al. (2007) reported no significant seasonal fluctuation in the composition of the arbuscular mycorrhizal fungus population associated with *Prunella vulgaris* roots in semi-natural grasslands. Hence, the need for better understanding of seasonal changes in AM populations in terrestrial settings.

Currently, limited knowledge exists on the regulations on the diversity of arbuscular mycorrhizal fungal (AMF) communities in some areas; considering the growing significance of mycorrhizal fungal diversity for sustaining ecosystem functionality, a deeper comprehension of the determinants of AMF diversity and its decline is essential. Despite extensive research on the density of arbuscular mycorrhizal fungi (AMF) at different soil depths (SHUKLA et al., 2013; EGBOKA et al., 2022) and the seasonal fluctuations in AM fungal communities (REYES et al., 2019), there has been no investigation into the variation in AMF community composition across natural, disturbed, and contaminated vegetation. Consequently, examining the impact of varying soil conditions and seasons on arbuscular mycorrhizal fungal density and diversity might enhance our comprehension of ecosystem soil health which was the focus of this study.

2. MATERIAL AND METHODS

2.1. Description of Study Sites

This study was conducted at three sites: Botanical Garden, University of Ibadan (Secondary Forest), Crop and Horticultural Science (CHS) Farm, University of Ibadan (Cultivated Land) and defunct Exide Battery manufacturing dumping site, Olodo (Contaminated Land); all located in Ibadan, Oyo State, Nigeria and lie between latitudes 7º27'23.54976"; 7º27'36.49608" and 7º25'55.69392" N, and longitudes 3º53'37.8906"; 3º53'31.56756" and 3º58'56.80884" E, respectively. The region receives around 1200 mm of yearly precipitation, and the rainy season occurs from April to November. The temperature is often elevated, and with an average minimum of 21.9°C and a maximum of 32.5°C annually. The average monthly temperature varies from 24°C to 28°C. Humidity is elevated throughout the early hours with a rapid decrease in the afternoon.

2.2. Sample collection and laboratory analyses

Soil samples were collected from sites in two seasons; in September 2023 (rainy season) and December 2023 (dry season). Three (3) replicate samples were collected in each site. Soil samples were collected using soil auger from three spots at 0-15 cm, 15-30 cm and 30-45 cm depths respectively to make a replicate. The distance between each point within a replicate was 2m apart, while the distance between each replicate within a site was 15m apart. Thus, three (3) composite samples for each depth were collected from each of the sites; with a total of 27 samples per study site within each season. Soil samples were ait-dried at ambient temperature. Each replicate sample was analysed for soil characteristics and population density of arbuscular mycorrhizal fungus.

The hydrometer approach was employed to ascertain particle size distribution (GEE and OR, 2002). A glass electrode pH meter was used to measure the soil pH in a 1:1 soil to liquid suspension. The Walkley and Black wet oxidation method was used to quantify soil organic carbon, and the micro Kjeldahl method, modified by Bremner, was used to assess total nitrogen (HENDERSHOT et al., 1993; UDO et al., 2009). Available phosphorus was quantified colorimetrically via the Bray 1 method, as modified by Olsen and Sommers (1982), while exchangeable cations were extracted using 1N ammonium acetate solution and read with an Atomic Absorption Spectrophotometer (AAS) (UDO et al., 2009; Helmke and Spark, 1996).

2.3. Extraction and Separation of Mycorrhizal Spores

The wet sieve and decanting method was used to extract AMF spores from 50 g of soil samples (Gerdemann and Nicolson, 1963). After being cleansed with tap water, the spores and sporocarps were put into plastic Petri plates. Spore densities were measured as the number of spores and sporocarps per 50 g of dry soil, and they were counted using a 4x stereomicroscope in compliance with INVAM (2006). For morphological identification, viable spores were gathered and prepared on slides using Melzer's reagent (1:1 v/v) and polyvinyl-lactic acid-glycerol (PVLG). Spore features were analysed in relation to species identification on the International Collection Centre for AMF (INVAM) website.

2.4. Data analysis

The variety of AMF species was assessed by the following parameters: species richness, spore count per species, relative abundance, Shannon-Wiener diversity index (SHANNON and WEAVER, 1949), evenness, and Simpson dominance index (SIMPSON, 1949). Diversity indicators were analysed with the methodology established by Hutcheson (1970). Descriptive statistics were used to examine the measured variables using GenStat Discovery Edition 4.0. Data were subjected to analysis of variance (ANOVA), and significant means separated using Duncan's multiple range test.

Table 1. Parameters used to measure AMF diversity

Parameter	Formulae
Spore density	The number of spores in 50 g soil
Relative abundance (RA)	$\frac{\text{Spore numbers of species}}{\text{the total number of identified spore samples}} \times 100$
Shannon-Wiener diversity index (H')	-Σpi In pi
Evenness (E)	H/HMAX
Simpson dominance index (l)	Σ[ni(ni-1)/N(n-1)]

Pi = ni/N, where ni = number of individuals of the species i; N= total number of individuals of all species (SHANNON and WEAVER, 1949). H' = value obtained by Shannon index, where S = total number of species (genera) identified. H'max, or maximum potential diversity, is computed as ln S, where S is the total number of species that have been recognised.

3. **RESULTS**

3.1. Soil properties of the study sites

Soil pH ranged from 4.80 – 5.83 in secondary forest, 4.79 – 5.13 in cultivated land, and 6.14 – 6.52 in contaminated land (Table 2). The contaminated site had the highest pH level than secondary forest and cultivated lands. The soil organic carbon (OC) was higher at 0-15 cm and decreased with increasing soil depth across all the sites. The total nitrogen (TN) was higher at 30-45 cm at both contaminated and cultivated sites (2.07 and 1.90 g/kg) while the secondary forest's highest TN at 0-15 cm soil depth (2.03 g/kg). Soils at all the sites were different in available phosphorus levels at all the sites with little variation across the three soil depths. The soil exchangeable bases varied at all sites across the three soil depths and the highest total exchangeable bases (TEB) was observed at contaminated land at 0-15 cm (53.8 cmol/kg) soil depth.

Table 2. Soil properties of the study areas

Parameters	S. Forest			Cult.			Con.		
	0-15cm	15-30cm	30-45cm	0-15cm	15-30cm	30-45cm	0-15cm	15-30cm	30-45cm
pH	5.83	4.80	5.83	5.13	5.06	4.79	6.52	6.30	6.14
OC (g/kg)	10.85	6.99	3.32	15.90	8.17	3.77	19.21	8.70	3.85
TN (g/kg)	2.03	1.50	1.33	1.13	1.27	1.90	1.17	1.60	2.07
Avail P (mg/kg)	28.1	24.2	24.2	42.6	19.3	11.2	9.5	9.7	11.1
K^+ (cmol/kg)	15.4	6.6	10.9	26.8	25.0	26.7	41	25.2	28.3
Ca^{2+} (cmol/kg)	4.81	2.82	3.7	3.07	2.53	2.82	9.21	7.23	6.27
Mg^{2+} (cmol/kg)	1.26	1.33	1.81	1.23	1.41	1.42	2.74	1.38	1.58
Na^+ (cmol/kg)	0.90	0.81	0.8	0.82	0.85	0.78	0.64	0.79	0.79
TEB (cmol/kg)	22.4	11.5	17.3	32	29.8	33.2	53.8	34.6	37.0
TEA (cmol/kg)	0.31	0.40	0.35	0.51	36.00	0.35	0.35	0.28	0.35
ECEC	22.7	11.9	17.6	32.5	30.2	33.6	54.1	34.9	37.3
Sand (g/kg)	839.6	855.0	835.4	831.7	792.0	751.8	741.7	702.2	662.5
Silt (g/kg)	35.0	37.0	37.2	33.9	168.3	70.9	88.3	90.1	130.2
Clay (g/kg)	125.4	108.0	127.4	134.4	39.7	177.3	170.0	207.7	207.3

S. Forest (Secondary Forest), Cult. (cultivated Land), Con. (contaminated Land)

3.2. Density of arbuscular mycorrhizal fungi (AMF)

Figure 1 shows the seasonal fluctuations in spore density of arbuscular mycorrhizal fungi across three sites. Spore density varied considerably between seasons and soil depths. The mean spore density was significantly higher in rainy season than in dry season in both contaminated and cultivated lands but there was no significant difference between the two seasons in secondary forest. The spore abundance was highest at 0-15 cm depth regardless of the location and decreased with increase in soil depth in cultivated and contaminated lands (Figure 2). At 0-15 cm and 15-30 cm soil depth, higher number of AMF spores were observed in contaminated land than in secondary forest and cultivated land, but at 30-45 cm, secondary forest had the highest number of AMF spore count than both cultivated and contaminated lands (Figure 2).

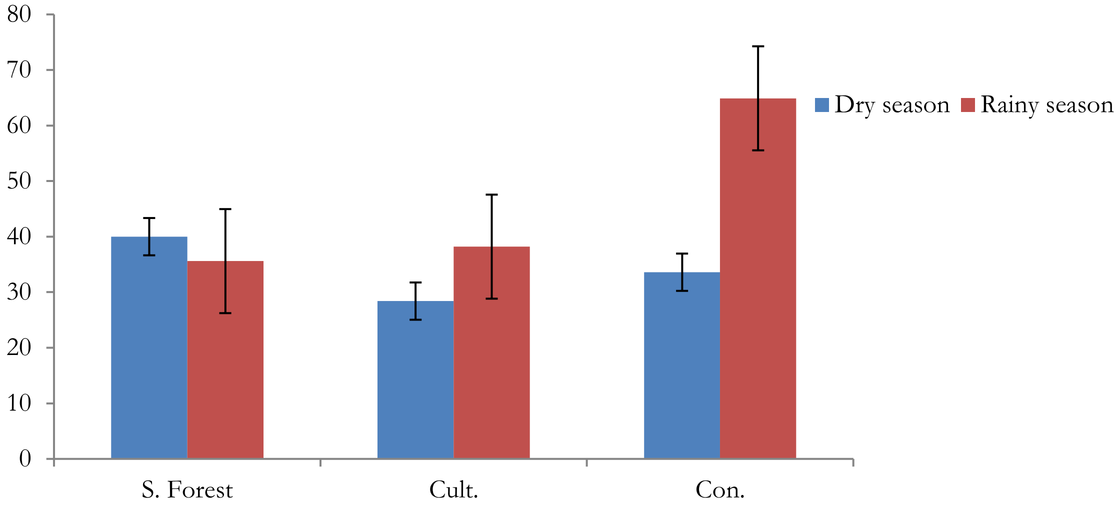

Figure 1. Occurrence of AMF spore in two seasons at different sites.

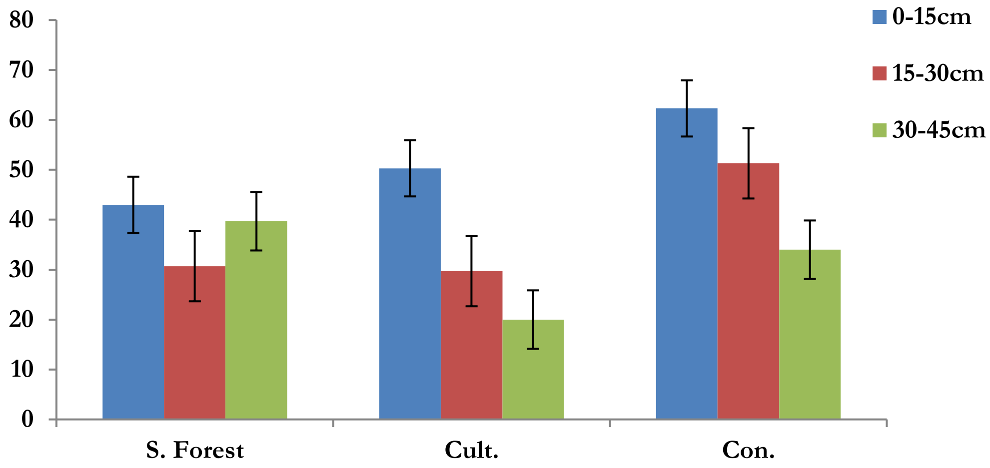

Figure 2. Occurrence of AMF spore at different soil depths at different sites.

Key: S. Forest (Secondary Forest), Cult. (cultivated Land), Con. (contaminated Land)

3.3. Seasonal distribution and relative abundance of AMF species at three sites

A total of 27 AMF species from eight genera were detected (Table 3). The genera include: Acaulospora (4 species), Gigaspora (4 species), Glomus (7 species), Rhizophagus (4 species), Funneliformis (2 species), Pacispora (1 species), Scutellospora (3 species), and Septoglomus (2 species). Some species such as *Acaulospora longula*, and *Scutellospora nigra* were isolated from all the study sites at the two seasons. *Rizophagus clarus, Pacispora boliviana,* and *Septoglomus constrictum* were isolated from all the sites in the rainy season and not in the dry season, while *Rizophagus intraradices was isolated from all the sites only in the dry season. Acaulospora foveata, Acaulospora capsicula, Gigaspora rosea, Glomus maculosum, Glomus spinasum, Glomus sp1, Glomus sp2*, and *Scutellospora pellucida* were isolated from cultivated land only, while *Gigaspora sp1* and *Rhizophagus irregulare* were isolated from the secondary forest only and other species such as *Gigaspora albida, Glomus macrocarporn, Glomus sp3, Rizophagus fasciculata*, and *Funneliformis coronatum* were isolated from contaminated land only. All other species identified in this study occurred in either two or across all three sites at different densities (Table 3).

Acaulospora capsicula, Glomus sp2, Glomus sp3, Rhizophagus fasciculata and *Funneliformis coronatus* were found only in rainy season, while *Acaulospora foveata, Gigaspora sp1, Glomus spinasum* and *Rizophagus irregulare* were recorded in dry season only (table 3). At seasons, the highest relative abundance within AM fungal species in rainy and dry seasons was recorded in secondary forest (S.F); *Septoglomus constrictum* had the highest relative abundance (12.79%) in the rainy season while *Gigaspora margarita* had the highest relative abundance (10.44%) in dry season (Table 3).

3.4. Relative abundance of AMF species at different soil depths

Table 3 shows the result of AMF species diversity at different soil depths. Among the 27 AM fungal species that were identified, 21, 15, and 16 species were recorded at 0-15, 15-30, and 30-45 cm soil depths, respectively (Table 4). Some of the AMF species that were identified occurred at specific depths, while some species were found at mostly two soil depths, and few AMF species were isolated across the three soil depths. Species isolated from across the three soil depths (0-15, 15-30, and 30-45 cm) included *Acaulospora mellea, Acaulospora longula, Gigaspora margarita, Rizophagus clarus, Rizophagus intraradices, Funneliformis coronatus, Pacispora boliviana, Scutellospora nigra, Septoglomus constrictum* and *Septoglomus deserticola. Acaulospora capsicula, Gigaspora rosea, Gigaspora sp1, Glomus spinasum, Glomus sp2* and *Rhizophagus irregularre* were isolated from 0-15 cm depths only, *Acaulospora foveata*, and *Rizophagus fasciculata* were the species that were found at 15-30 cm only, and *Scutellospora pellucida, Scutellospora calospora, Glomus sp3*, and *Glomus maculasum* were specific to 30-45 cm depth. All other species identified in this study occurred in two of the three studied depths (i.e either 0-15 and 15-30 cm or 15-30 and 30-45 cm or 0-15 and 30-45 cm). At different soil depths, 0-15 and 15-30 cm had the highest relative abundance and was Acaulospora longula 9.13% and 19.85%, respectively, while at 30-45 cm the highest AM fungal species' relative abundance was *Septoglomus constrictum* (12.63%).

Table 3. Seasonal variation in relative abundance (%) of AM fungi in the selected study sites

Species	Rainy season			Dry season		
	S. F	Cult.	Con.	S. F	Cult.	Con.
Acaulospora foveata	-	-	-	-	3.35	-
Acaulospora mellea	4.41	5.03	-	3.24	3.02	-
Acaulospora capsicula	-	4.19	-	-	-	-
Acaulospora longula	5.44	9.55	5.87	10.00	5.36	3.84
Gigaspora albida	-	-	5.64	-	-	5.87
Gigaspora margarita	6.03	1.68	-	10.44	1.84	-
Gigaspora rosea	-	2.01	-	-	6.03	-
Gigaspora sp1	-	-	-	4.71	-	-
Glomus macrocaporn	-	-	8.92	-	-	3.05
Glomus maculosum	-	3.35	-	-	0.84	-
Glomus melanosporum	-	-	-	4.71	-	2.82
Glomus spinasum	-	-	-	-	3.69	-
Glomus sp1	-	7.87	-	-	3.35	-
Glomus sp2	-	7.04	-	-	-	-
Glomus sp3	-	-	1.35	-	-	-
Rhizophagus clarus	2.94	5.86	3.27	-	3.35	-
Rhizophagus fasciculata	-	-	1.92	-	-	-
Rhizophagus intraradices	-	-	3.72	4.41	3.52	2.26
Rhizophagus irregularis	-	-	-	3.09	-	-
Funneliformis mosseae	-	-	5.30	-	-	4.63
Funneliformis coronatus	-	-	8.01	-	-	-
Pacispora boliviana	1.47	3.02	1.13	2.21	-	1.02
Scutellospora calospora	1.47	-	1.13	4.41	-	2.14
Scutellospora nigra	5.15	4.86	5.87	4.26	1.84	2.03
Scutellospora pellucida	-	2.85	-	-	1.68	-
Septoglomus constrictum	12.79	4.36	4.97	-	0.50	-
Septoglomus deserticola	2.94	-	10.27	5.88	-	1.24

S. F (Secondary Forest), Cult. (cultivated Land), Con. (contaminated Land)

Table 4. Variation in relative abundance (%) of AM fungi at different soil depths

Species	0-15cm	15-30cm	30-45cm
Acaulospora foveata	-	2.99	-
Acaulospora mellea	2.79	10.30	0.89
Acaulospora capsicula	2.69	-	-
Acaulospora longula	9.13	19.85	11.03
Gigaspora albida	7.73	-	5.34
Gigaspora margarita	3.44	8.66	7.65
Gigaspora rosea	5.16	-	-
Gigaspora sp1	3.44	-	-
Glomus macrocaporn	7.20	5.82	-
Glomus maculosum	-	-	4.45
Glomus melanosporum	2.69	4.78	-
Glomus spinasum	2.36	-	-
Glomus sp1	5.05	-	3.56
Glomus sp2	4.51	-	-
Glomus sp3	-	-	0.36
Rhizophagus clarus	3.11	8.96	2.67
Rhizophagus fasciculata	-	2.54	-
Rhizophagus intraradices	4.62	1.64	8.90
Rhizophagus irregularis	2.26	-	-
Funneliformis mosseae	5.80	5.07	-
Funneliformis coronatus	3.22	3.28	3.38
Pacispora boliviana	1.93	2.84	4.45
Scutellospora calospora	-	-	12.28
Scutellospora nigra	7.09	10.60	6.58
Scutellospora pellucida	-	-	4.80
Septoglomus constrictum	7.73	2.54	12.63
Septoglomus deserticola	8.59	10.15	8.36

S. F (Secondary Forest), Cult. (cultivated Land), Con. (Contaminated Land)

AMF species richness and diversity

The highest richness of AM fungal species occurred in the dry season and secondary forest, with a range of 9 to 11 during the rainy season and 10 to 12 during the dry season (Table 5). The Shannon-Wiener index was high during the dry season compared to the rainy season, although the rainy season exhibited the maximum dominance of AM fungus species. The values of AM fungal species evenness at both seasons were the same with little variation among sites (Table 5).

In terms of soil depth, AM fungal species richness ranged from 15-21 and the highest level of the species richness was at 0-15 cm (21) soil depth (Table 6), there was a little variation in Shannon-Weiner's index among soil depth. The highest AM fungal species dominance was observed at 30-45 cm (0.933), while the highest value of species evenness was at 15-30 cm (Table 6).

Table 5. AMF species diversity at different seasons and environments

Location	Species richness	Shannon -Weiner's index (H)	Simpson dominance index (*λ*)	Evenness (D)
Rainy season				
Secondary forest	9	0.349	0.934	0.159
Cultivated land	11	0.355	0.924	0.148
Contaminated land	11	0.355	0.781	0.148
Dry season				
Secondary forest	12	0.367	0.845	0.148
Cultivated land	11	0.355	0.924	0.148
Contaminated land	10	0.366	0.891	0.159

Table 6. AMF species diversity at three soil depths

Depths	Species richness	Shannon -Weiner's index (H)	Simpson dominance index (*λ*)	Evenness (D)
0-15cm	21	0.363	0.815	0.119
15-30cm	15	0.363	0.904	0.134
30-45cm	16	0.350	0.933	0.126

4. **DISCUSSION**

Although numerous studies have investigated the density of arbuscular mycorrhizal fungi (AMF) at different soil depths (SHUKLA et al., 2013; EGBOKA et al., 2022) and the seasonal variations in AM fungal communities (SHUKLA et al., 2012; REYES et al., 2019), none have examined the differences in AMF community composition across natural, disturbed, and contaminated ecosystems. Consequently, examining the impact of varying soil conditions on arbuscular mycorrhizal fungal density and diversity at different seasons is essential to our understanding of ecosystem soil health.

The percentage composition of the textural structure of the soil samples collected from the study sites showed that all the three had the same textural class (sandy loam). Though, textural class of soil are known to be influenced by climatic and environmental conditions and also by parent material (BRADY and WEIL, 1999), the different sites in this study were not significantly different. Hence, the comparison of the results with reference to mycorrhizal propagules cannot be confounded by soil physical characteristics.

The organic carbon content was highest at a soil depth of 0-15 cm and declined as the soil depth increased, and it is consistent with the findings of Gaudinski et al. (2000) and Wynn et al. (2005), who observed a decline in soil organic matter with increase in soil depth. The concentrations of cations (K, Ca, Mg, and Na) and available phosphorus were higher at a soil depth of 0–15 cm in comparison to deeper layers. This aligns with the findings of Brady and Weil (2002) which indicated that cations were mostly abundant in topsoils enriched with organic matter and associated with diverse organic components at different stages of decomposition, hence facilitating the continuous release of cations. The effective cation exchange capacity (ECEC) diminished with increasing soil depth, and a reduction in ECEC values correlates with a drop in organic matter content (OYODELE et al., 2008; OLADOYE, 2015).

Seasonal variations were observed in the spore density in this investigation. In both contaminated and cultivated land, the mean number of spores was much higher during the rainy period than during the dry period. Shukla et al. (2012) attributes these variations in both seasons to the moisture content of the soil, Weather conditions in the rainy seasons are usually more conducive to biological communities' growth and metabolic processes than dry season. The AMF spore density was high at a soil depth of 0-15 cm across all locations and diminished with increasing soil depth in both cultivated and polluted areas. The reduction in AMF spore density with increasing soil depth in cultivated and contaminated lands is similar to the findings of Shukla et al. (2013). This may be attributed to the soil organic matter concentration and the susceptibility of fungi to diminished oxygen availability in deeper soil strata (VERMA et al., 2010).

Glomus was the dominating genus, followed by Acaulospora. Gigaspora and Rhizophagus. The prevalent presence of Glomus species aligned with the observations of Dare et al. (2013), who noted the dominance of Glomus in Ibadan. Various study reports have documented the domination of Glomus throughout multiple habitats and climatic environments, indicating their exceptional adaptability to diverse environmental conditions (GAI et al., 2006; EMMANUEL et al., 2010). Furthermore, Nandjui et al. (2013) and Dare et al. (2013) similarly identified the genus Acaulospora as the second most prevalent genus behind Glomus in terms of species abundance. The findings indicated that *A. longula, A. mellea, Gigaspora albida, Gigaspora margarita, Rhizophagus clarus, Rhizophagus intraradices, Pacispora boliviana, Septoglomus deserticola, Septoglomus constrictum*, and *Scutellospora niga* exhibited considerable frequency in their occurrences. Oehl et al. (2003) referred to these AMF species as "AMF generalists". Certain AMF species were ubiquitous across all the soil depths, but others were unique to particular depths; for instance, *Scutellospora pellucida, Scutellospora calospora, Glomus sp3*, and *Glomus macolasum* were isolated from the 30-45 cm soil depth. Thus, concerning spore formation, these species seems to be suited for deeper soil depths (OEHL et al., 2005). The occurrence of *Scutellospora pellucida* in deeper soil layers has been suggested to be due to reduced soil disturbances (OEHL et al., 2005). However, few AMF species specifically occurred only at either secondary forest, cultivated or contaminated lands, this could be due to variations in nutrient elements and ECEC at different sites.

In addition, the influence of sampling time on species richness and the composition of arbuscular mycorrhizal fungal communities was similarly observed. Seasonal fluctuation is recognised as a determinant influencing AMF species groupings and individual species, since certain species may sporulate year-round, while others are restricted to specific seasonal circumstances, illustrating the varied sporulation techniques across species as sporulation is a stage in the fungal lifecycle, and as not all species persist in the same phase throughout the year, this leads to seasonal fluctuations in AMF populations. Both beneficial and unfavourable environmental conditions can induce sporulation as a survival mechanism in fungi (VELAZQUEZ et al., 2013; SILVA et al., 2014).

The findings demonstrated that AMF is prevalent in soils with high organic carbon levels and increased soil pH. The population, relative abundance, and distribution of arbuscular mycorrhizal fungi (AMF) at the studied sites varied based on soil depth, soil organic carbon content, and soil pH. Spore density was higher in the topsoil regardless of location and declined with increasing soil depth, except for secondary forest. The rainy season exhibited a greater spore concentration compared to the dry season, with the maximum spore density found on contaminated land, surpassing that of cultivated land and secondary forest. Some AMF species occurred at all locations and soil depths that were investigated. AMF species such as *Glomus maculosum, Glomus sp3, Scutellospora calospora*, and *Scutellospora pellucida* were specifically identified from deeper soil depths (30-45 cm).

4. CONCLUSIONS AND RECOMMENDATION

This study highlights the diversity and distribution of arbuscular mycorrhizal fungi (AMF) in typical tropical ecosystems, with varying patterns across seasons, soil depths, and land use types. Notably, topsoil (0-15 cm) exhibited higher spore density and diversity, while the rainy season showed increased spore densities. Contaminated land had unexpectedly high spore densities, suggesting potential AMF adaptation or resilience. To build on these findings, future research should focus on exploring the functional roles of AMF in these ecosystems, investigating the mechanisms behind AMF adaptation to contaminated environments, and developing targeted conservation strategies. Consequently, prioritizing topsoil conservation, accounting for seasonal variations, and promoting sustainable land use practices are crucial for maintaining AMF diversity and ecosystem sustainability in this typical tropical region.

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