OCCURRENCE AND DIVERSITY OF INDIGENOUS MYCORRHIZAL FUNGI IN DIFFERENT SUDAN SOILS USING SORGHUM [*Sorghum bicolor* (L.) Moench] AS A HOST PLANT

AHMED K. H. MOHAMMED ALI [1], MOHAMED A. M. ADLAN[1], LUBNA M. MUSA[2*]

[1]Soil Microbiology Unit, Plant Nutrition Section, Land and Water Research Centre, Agricultural Research Corporation (ARC), Sudan
[2]Soil and Water Science, Faculty of Agricultural Sciences, University of Gezira, P.O. Box 20, Wad Medani, Sudan

**Corresponding author: lubna_musa@yahoo.com*

ABSTRACT: The mutual relationship between arbuscular mycorrhizal fungi (AMF) and plants is ancient. However, there are some environmental factors, which affect the occurrence and diversity of this relationship. This study was conducted to investigate the indigenous AMF occurrence and diversity indices at six sites (two sites from Gezira, two from Sennar and one from each of Gedarif and North Kordofan States) which represent four geographical locations in the Sudan. Three rhizosphere samples from the root part of the sorghum were taken from each site to estimate soil physical and chemical properties, total spore density, invalid spore percentage and root colonization to evaluate their roles in AMF occurrence and diversity. Results showed that the average total spores density ranged from 418/100 g soil at Gedaref to 1781/100 g soil at North Kordofan. The highest invalid spore percentage was found at Gedaref (21.5%) and the lowest at North Kordofan (12.5%). Root colonization percentage ranged from 11.3% at Gedaref to 32.1% at North Kordofan. There was a highly positive correlation between root colonization percentage and total spore density, invalid spore and sand percentage. A highly negative correlation existed between root colonization and CEC, clay percentage and soil pH on the other hand. Twelve genera and 26 species were morphologically identified, and two species were not identified. Rhizophagus, Glomus, Claroideogloms, Funneliformis, Acaulospora, Scutellospora and Entrophospora were dominant genera at all sites. However, Septoglomus and Ambispora were normally distributed genera and Gigaspora, Scelerocystes and Dentiscutata were rare genera. The diversity index detected a normal diversity and richness except for Gedarif having a lower diversity index, and the situation was reversed for North Kordofan, having a higher diversity index. It is recommended to add AMF inoculums to heavy clay soils to increase spore density.

KEY WORDS: *Mycorrhizal Fungi, Sorghum, Soil, Occurrence, and Indigenous*

1. INTRODUCTION

Arbuscular Mycorrhizal Fungi (AMF) has a mutual relationship with more than 85% of plant species including most of the economic and strategic crops. AMF symbiosis can improve the soil structure and increase host plant tolerance and drought stress, [1]. In this Mutualistic relationship the host plant provides AMF with carbohydrates and in return AMF facilitates several nutrients absorption, such as phosphorus [2,3], nitrogen, potassium,

calcium and magnesium [4], copper [5] and zinc [6]. Colonization of roots by AMF was reported to improve productivity of numerous crops widely cultivated as staple food crop and forage in different Sudanese environments [7-10] and because it is well infected and colonized by AMF, sorghum was used as a host plant in the study. This relationship varies greatly and is affected by various factors including soil type, agricultural practices, and host plant [11]. Different ecological conditions can influence the AMF community in the cultivated soil [12]. When the soil is used for agricultural purposes, it undergoes a series of physical, chemical, and microbiological changes. The most important of which is the ones that affect the root-inhabiting microorganisms also reported that when soil is disturbed or is partially removed, a decrease in the number of mycorrhizal propagules occurs [13-16].

Diversity is the key indicator of the health of an ecosystem and generally it refers to the variety and variability of life on earth as mentioned by the United Nation Environment Programme (UNEP). Therefore, it measures population of different species and variations among them at the ecosystem level. In other words, a wide variety of species will cope better with threats than a limited number of them in large populations. Many AMF species are globally ubiquitous occurring in quite different terrestrial ecosystems [17] while others appear to be restricted to specific ecosystems, land use types, vegetations or climates [18-19]. Several studies documented the occurrences of indigenous AMF [20-21]. Most of these studies found that the predominance of the genus Glomus in several ecosystems. In Africa, AMF research has focused mainly on the agro-ecosystems and pastoral farmland [22-24]. Many of these studies revealed high ratios of novel taxa in the natural tropical ecosystems. However, little is known about the influence of ecological site conditions on AMF community composition in Sudan's soil.

2. MATERIALS AND METHODS

2.1. Geographical and General Sites Description

This study was conducted using samples taken from six sites distributed across different Sudanese environments. The site description was presented in Table 1.

Table 1: General description of the collection sites

Sites	Altitutes and Latitutes	Irrigation system	Soil practices	Soil type
North Kurdofan	13°10'50.14"N 30°13'10.89"E	Rain-fed	Chisel	Loamy sand
Gedaref	14°1'37.49"N 35°21'55.22"E	Rain-fed	Wide level disc harrow (WLDH)	Clay
Sennar	13°19'48"N 33° 22' 12"E	Rain-fed	Level disc harrow (LDH)	Clay
Sennar	13°33'00"N 33° 37' 00"E	Surface irrigation	Level disc harrow (LDH)	Clay
Gezira	14°38'6.22"N 33°49'53.13"E	surface irrigation	Level disc harrow (LDH)	Clay
Gezira	14°38'64.92"N 33°49'22.92"E	Rain-fed	Level disc harrow (LDH)	Clay

2.2. Sample Collection

Three samples of sorghum roots and their rhizosphere soil after harvest were collected from the different mentioned sites (Table 1), with a 1.27 m diameter soil probe to a depth of approximately 15 cm as suggested by Schenck and Pérez [25]. The samples were prepared and analyzed at Microbiology Laboratory, Land and Water Research Center, ARC, Wad Medani, Sudan.

2.3. AMF Spores Extraction

The wet sieving and decanting technique as described by Giovannetti and Mosse [26] was used for extraction of spores using 45, 63, 180 and 250 µm pore size sieves.

2.4. Spores Counting

The spores counting was done using technique clarified by International Culture Collection of Vascular Arbuscular Mycorrhizal Fungi (INVAM), West Virginia University (https://invam.wvu.edu). Two methods of spores counting using dissecting microscope were followed depending on the density of the spores in the petri dish. One of them was the method of direct count for low spores' density; if the spores are three to four in some fields of view and absence of spores in others (25-50% of fields examined). The other was the method of relatively higher spores' density (less than 30 spores per field of view in the microscope).

2.5. Genera Counting and Species Identification

AMF Genera were counted by transferring spore suspension to a test tube (20 mL) prior to mixing using a vortex. About 1 mL of the homogeneous suspension was transferred with a micropipette to a slide glass. Then one drop of Melzer's reagent was added for observing and counting the spores under a light microscope ;10X lens magnification for the general characters of the spores, 40X and 70X lens magnification for identifying spore cell wall layers and spores surface distinguish marks. This step was performed four times and the average was multiplied by the dilution factor (20). After that, the average of the three samples from one site was calculated and dealt with as AMF spore population at that site. Morphological classification was done to the genus level and some spores were identified to species level referring to procedure elucidated by INVAM, based on identification manuals [13, 27].

2.6. Sterilization of the Spores

The spores were soaked for 20 minutes into a sterile streptomycin sulfate solution (200 mg/mL) and then transferred into a 100 mL graduated cylinder. Distilled water was added till the volume reached 100 mL.

2.7. Long Term Storage of the Spores

The sterilized petri dish was filled to its third quarter with the sterile dry sand, then the sterilized spore's suspension was poured over the sand and water was allowed to evaporate from the sand by leaving the cover off. This process took overnight to several days. When the sand was dried, the petri dish was covered and sealed with parafilm and stored at 4º C till further use. This method of storage will last for 5 years according to INVAM.

2.8. Estimation of Root Colonization with AMF

Root samples were preserved in 70% ethanol prior to clearing. Then the roots were cleared and stained using writing ink and vinegar (INVAM) protocol. Then, Grid-line intersect method was used to estimate colonized roots [28].

2.9. AMF Occurrence and Diversity Indices

To elucidate the variances in the AMF populations on different environments, the Shannon Wiener (SW) and Evenness (EV) diversity index were used to provide important information about the diversity in the community of AMF [29]. Furthermore, absolute number of spores (AS), relative spore density (RD), isolation frequency (IF) and importance value (IV) were calculated to evaluate the dominance rarity and commonness of AMF genera [30].

Correlation analysis was used to explain the relationship between spore density and root colonization and the following factors; soil reaction (pH), available phosphorus and cation exchange capacity (CEC) [31].

3. RESULTS AND DISCUSSIONS

3.1. Soil Properties and Climate

The chemical and physical properties of soils are demonstrated in Table 2. Gedaref had the highest soil pH, CEC and clay texture while Gezira and Sennar properties were almost similar. North Kordofan was completely different from the other sites with the lowest pH, and CEC and a loamy sand texture. All of the four sites had a low available phosphorus.

Table 2: Soil properties and climate condition for the selected 6 sites in Sudan

No	Site location	pH	Avg. P [mg/kg]	CEC	Avg. rainfall [mm]	Avg. T [^{o}C]	Clay [%]	Sand [%]
1	Gedaref	8.2	2.6	76	458	37.4	80	4
2	N.K	6.9	1	8	269	35.1	12	82
3	S.I	8.1	2.8	53	367	37.2	62	7
4	S.R	8.1	2.8	53	367	37.2	62	7
5	G.I	8.4	3.8	51	312	37.9	56	12
6	G.R	8.4	3.8	51	312	37.9	56	12

Notes:
N.K= North kordofan; S.I= Sennar Irregated; S.R= Sennar Rain-fed; G.I= Gezira Irregated; G.R = Gezira Rain-fed; Avg. rainfall = average rainfall; Avg. T = Average mean Temperature

3.2. Spores Density

The average total number of spores extracted from different sites is shown in Table 3. The values ranged from 418.3 spore/100g soil at Gedaref to1781 spore/100g soil at North Kordofan. The highest number of spores found in North Kordofan was almost five times higher than those of Gedaref and irrigated sites of Gezira and Sennar. Rain-fed sites of Gezira and Sennar exhibited a little bit higher total number of spores compared to the irrigated sites of Gezira and Sennar. Thus, the sites could be divided into four groups in terms of the total number of spores. These groups are North Kordofan, rain-fed sites of Gezira and Sennar, irrigated sites of Gezira and Sennar and Gedaref. The highest invalid spore percentage was found in Gedaref followed by Gezira and Sennar surface irrigation

then Gezira and Sennar rain-fed irrigation and finally the lowest invalid spore percentage was found in North Kordofan as demonstrated in Table 3.

Table 3: root colonization percentage, total number of spores/100g soil, and invalid spores

No	Site location	Root colonization [%]	Total spores/100 g soil	Average total spores/ site	Invalid spores	Average total invalid spores	Invalid spores [%]
1	Gedaref S1	14.8	455		90		
2	Gedaref S2	16.1	395	418	85	90	21.5
3	Gedaref S3	11.3	405		95		
4	N.K. S1	30.4	1781		250		
5	N.K. S2	31.5	1492	1781	165	223	12.5
6	N.K. S3	32.1	2070		255		
7	S.I S1	18.5	637		108		
8	S.I S2	15.7	572	556	92	94	16.9
9	S.I S3	17.5	459		83		
10	S.R S1	24.5	854		128		
11	S.R S2	21.3	972	864	119	117	13.5
12	S.R S3	25	766		104		
13	G.I S1	15.4	576		103		
14	G.I S2	16.1	647	593	93	99	16.6
15	G.I S3	18.3	556		102		
16	G.R S1	25.5	818		130		
17	G.R S2	23.4	886	812	124	124	15.2
18	G.R S3	26.8	732		117		

Notes: S1= soil sample 1. S2= soil sample 2 S3= soil sample3.

3.3. Root Colonization and Correlation with Soil Chemical Properties

All plant roots of sorghum were colonized by AMF at all sites (Table 3). The maximum root colonization percentage was observed at North Kordofan and the minimum was found at Gedaref. The root colonization percentage at the rain fed sites of Gazira and Sennar was higher than at their irrigated ones. Roots colonization as shown in Table 4 had a negative correlation with the available phosphorus, soil pH and cation exchange capacity. There was a highly positive correlation between roots colonization, total spore density, and sand percentage. Correlation of total spore density with the soil properties showed a similar pattern to the correlation of root colonization with the same soil properties (Fig. 1).

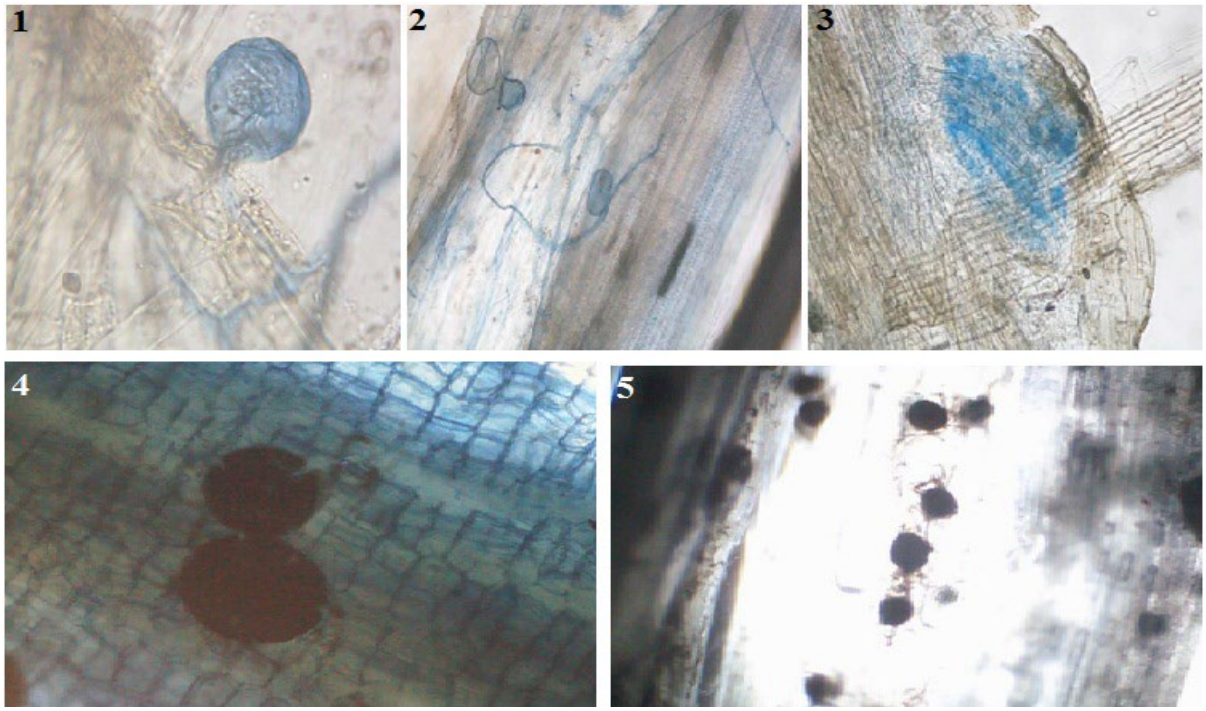

Fig. 1. Exhibit AMF structure inside sorghum roots, (1,2) Vesicles and hyphae (3) arbuscule (4,5) *Rhizophagus intraradices* spores insides root cortex.

Table 4: The correlation between root colonization, RC (%), total spore density (TSD) and invalid spores (IS) with the available phosphorus (AV. P), pH, CEC, clay %, sand %, average precipitation (Avg. P) and average total temperature (Avg.T)

	TSD	**IS**	**AV. P**	**CEC**	**Clay %**	**Sand %**	**Avg. P**	**Avg. T**
RC	0.86	0.80	-0.50	-0.83	-0.82	0.76	-0.72	-0.66
TSD		0.44	-0.72	-0.92	-0.93	+0.92	-0.70	-0.86

3.4. AMF identification

From the roots of the host-plant and its associated rhizosphere soil at the six studied sites, there were twelve genera, twenty-four identifiable species and two unidentifiable spores (Fig. 2).

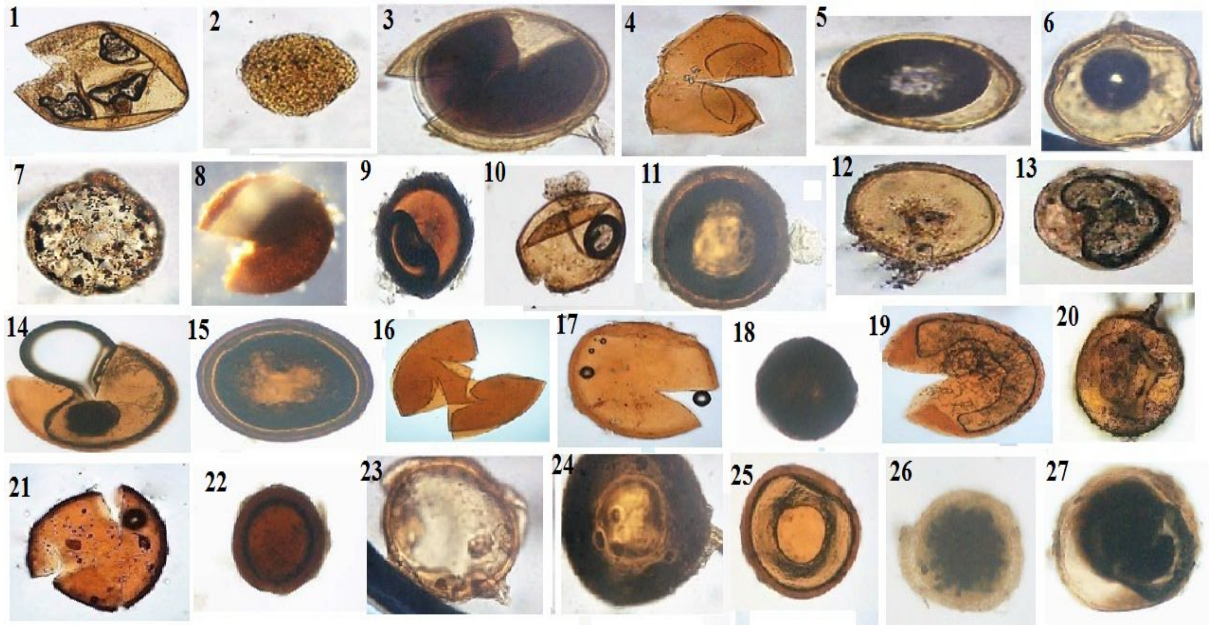

Fig. 2. From 1-5 Acaulospora species:1- delicata 2- denticulata 3- morrowiae 4- scorbiculata 5- spinosa ; 6-*Scelerocystes rubiformes*; 7-*Ambispora gredemannii*; 8- *Entrophospora infrequens;* 9-*Septoglomus deserticola*; 10-*Claroideoglomus claroideum*; 11-*Claroideoglomus etunicatum*; 12-*Funneliformis geosporum*; 13-*Funneliformis mosseae*; 14-*Rhizophagus intraradices*; 15-*Rhizophagus fasciculatus*; 16-*Gigaspora gigantean*; 17-Gigaspora species; 18-*Scutellospora nigra;* 19-*Dentiscutata reticulate*. From 20-25 Glomus species: 20- *G. clarum* 21- *G. macrocarpum*. 22- *G. constructum* 23- *G. microcarpum* 24-*G. multicaule* 25- *G. dimorphicum*. 26 and 27 are unidentifiable species.

3.5. Occurrence indices

As shown in Table 5, the highest absolute number (AS) of spores found in each site was found to be related to the genera Rhizophagus, followed by Glomus, Claroideogloms and Funneliformis. The genera Gigaspora, scelerocystes and Dentiscutata had the lowest AS, and they were found only on the loamy sand soil of North Kordofan.

Isolation Frequency (IF) for Glomus, Acaulospora, Claroideogloms, Entrophospora, Funneliformis, Rhizophagus and Scutellospora was 100% since they were found in all sites. Ambispora and Septoglomus have 83.33% (IF) because they were missed from one site of the six which was Gedaref; Scelerocystes, Dentiscutata and Gigaspora each had 16.67% because they were absent from all sites except North Kordofan. The importance value (IV) demonstrated that Rhizophagus, Glomus, Claroideogloms, Funneliformis, Acaulospora, Scutellospora and Entrophospora as dominant genera since their IV was over 50%, Septoglomus and Ambispora as normally distributed genera as their IV was between 10-50% and Gigaspora, Scelerocystes and Dentiscutata as rare genera since their IV was less than 10%.

3.6. Diversity index

Shannon Wiener diversity index detects a normal diversity and richness for all sites except for Gedaref having lower diversity index. With respect to the Evenness index, the AMF genera were evenly distributed among all sites excluding North Kordofan that had slightly less evenness than the other sites (Table 5).

Table 5: Absolute number of spores identified per Genera (AS), Relative spore density % (RS), Isolation Frequency (IF), Importance Value (IV), Shannon Wiener diversity index (SW) and Evenness (EV) of the different genera at all sites

Genera	N.K	Ged	G.R	G.I.	S.R.	S.I.	A.S	R.D	I.F %	I.V
Glomus	235	48	131	91	157	82	744	17.40	100	58.70
Acaulospora	322	11	59	42	51	35	520	12.16	100	56.08
Ambispora	25	0	23	12	23	7	90	2.10	83.33	42.72
Claroideogloms	255	59	139	68	95	85	701	16.39	100	58.20
Entrophospora	45	25	41	35	53	40	239	5.59	100	52.79
Funneliformis	178	66	118	102	134	64	662	15.48	100	57.74
Gigaspora	108	0	0	0	0	0	108	2.53	16.67	9.60
Dentiscutata	19	0	0	0	0	0	19	0.44	16.67	8.56
Rhizophagus	274	68	105	92	152	89	780	18.24	100	59.12
Scelerocystes	33	0	0	0	0	0	33	0.77	16.67	8.72
Scutellospora	37	51	39	27	54	32	240	5.61	100	52.81
Septoglomus	27	0	33	24	28	28	140	3.27	83.33	43.30
Total spores number/site	1558	328	688	493	747	462	4276			
S.W. Div.Index	2.04	1.84	2.03	2.02	2.01	2.04				
EV	0.82	0.94	0.92	0.91	0.91	0.92				

3.7. Discussion

3.7.1. Spore density

Sporulation among sites varied considerably with Gedaref earning the lowest total spore density, probably due to its high clay percentage. In the fine texture such as clay, some species could not sporulate due to the small size of the micro pores and the swelling and shrinking phenomena of the montmorillonite clay mineral. In addition, the mechanical barrier caused by finer soil texture favors the deposition of suberin on the epidermis of plants [32] which increases resistance to infection by AMF [33-34]. This was demonstrated by the highly negative correlation between total spore density and clay percentage. Gedaref site had a higher CEC, alkaline pH and relatively higher available phosphorus than the other sites. This could be the reason of the limited AMF root colonization and spore density development [35]. A higher CEC indicates higher availability of nutrient elements which resulted in the reduction of AMF infection inside the roots and concurrently spores formation [36-38]. The high soil pH played a rule in decreasing spore density and root colonization as AMF preferred neutral to slightly lower pH soil especially the Acaulospora genera [39]. It was also found that when the phosphorus was low in soils, sorghum secreted strigolactone hormone from roots stimulating AMF to penetrate and spread inside root cortex increasing phosphorus acquisition from soil [40]. However, if the phosphorus was adequate in soil, the plant would reduce strigolactone hormone secretion and consequently reduce the total spore density [41]. The antagonisticrelationships between AMF sporulation

and the above-mentioned soil chemical properties could be explained by the highly negative correlations between AMF total spore density and them.

Gedaref uses wide level disc harrow as land preparation practices. This exposed the rhizosphere soil with their AMF hyphal network and spores to the sun's damaging ultraviolet rays [42] and replaced it with the surface soil which was already poor in AMF spores. Such sort of disturbance would decrease AMF sporulation as elucidated by [43]. There was an obvious imparity between Gedaref having the highest average annual precipitation during the period of 2001 to 2016 and the other sites, but this did not have a direct effect on AMF sporulation, and this was observed on the insignificant negative correlation with precipitation.

Unlike Gedaref, North Kordofan revealed the highest total spore density, clarified by the enormous shift in soil texture toward loamy sand soil. In this coarser texture some species with spore size bigger than 180 µm can thrive [44]. This was confirmed by the highly positive correlation of total spore density with sand percentage. The loamy sand soil had a small clay percentage concurrently decreasing soil pH and CEC values and increasing AMF sporulation and that was established by the highly negative correlation with CEC, pH and available phosphorus. North Kordofan uses no tillage as land preparation practices, and it has no disturbance effect on the rhizosphere soil thus AMF hyphal network and spores leading-up to the vast raise in total spore density [45].

The increase in sporulation at Gezira and Sennar surface irrigation sites compared to Gedaref site could be explained by the decrease in the clay percentage and its associated chemical properties values. Nevertheless, the increased sporulation at Gezira and Sennar rain-fed sites in favor of Gezira and Sennar surface irrigation sites was obvious. Hence, they were similar in their soil texture and chemical properties and using the level disc harrow in the land preparation practice. The only two noticeable differences between the two groups of sites were the intensity of the land preparation as the irrigated sites had three steps plowing, leveling, and ridging which resulted in more soil disturbance than the. The second difference was the irrigation regime. So, the differences between the two groups could be attributed to the intensity of the land preparation combined with the irrigation regime. The LDH plow exposed the rhizosphere soil and AMF spores to the soil surface then the horizontal flow of water from the surface irrigation facilitates the wash away of the surface exposed spores with runoff water. On the other hand, rain-fed irrigation facilitates infiltration of the exposed spores with vertical drops of the rainwater to the rhizosphere area back again. No citation is found to support this speculation, but all factors were fixed between the two sites except for the irrigation regime, this could support the theory.

3.7.2 Root colonization

As a host plant, sorghum was known for its high susceptibility and consequently colonization by AMF [46]. In this study, the colonization was generally low in all sites and higher at North Kordofan. This could be due to the high temperature prevailing in all sites. Biermann and Linderman [47] demonstrated that at 38°C there was a reduction in AMF spore germination and root colonization. This was shown by the highly negative correlation between total spore density and the average mean temperature, which in turn would have affected the AMF root colonization. This could be again seen in the negative correlation between root colonization percentage and average mean temperature.

The positive correlation between root colonization and spores' density was not in agreement with Leal et al. [48] who found lack of correlation between root colonization and total spore density. His justification to that some AMF species rely more on extensive formation of hyphal networks instead of survival through spores' formation as primary infective propagules [49]. Nevertheless, in this study the highly positive correlation between root colonization and total spore density could be ascribed for using sorghum poaceae family as a single host plant model which is known for their prolific production of spores. In addition, soil practices exposing AMF hyphae to the damaging ultraviolet ray of the sun, AMF hayphae could not withstand these circumstances for long period. So, over the years, AMF tends to rely more on spores as survival mechanism. Moreover, all the root colonization had a correlation with the soil chemical and physical properties similar to that of the spore's density and this will support the highly positive correlation between total spores' density and root colonization percentage.

3.7.3 Occurrence of AMF

Sampling of the AMF spores for the identification, genera count and occurrences of AMF at the six sites was done from the field directly and no trap culture was made. The use of this approach was supported by De la Providencia et al. [50] who revealed that field samples are far more sensitive in detecting shifts in AMF community composition among land uses than the trap cultures. Also, pots as trap cultures usually offer a finite space for root growth which limit root colonization and then sporulation of AMF in a mixed diverse community. Not only that but also a certain threshold of root colonization must exist for each AMF species to trigger sporulation [51]. Finally, trap environment may favor fungal genotypes that are capable of rapid roots colonization to produce enough mycelium biomass for trigging sporulation. Therefore, the above aspects may restrict morphotypes abundance and richness in trap cultures reducing the number of species in traps relative to field conditions as reported in several studies from different ecosystems [13,52]. Identification of the genera and species was done according to INVAM. It displayed the presence of 12 genera and 26 species in the six sites.

Occurrence indices referred to Rhizophagus, Glomus, Claroideoglomus and Funneliformis as dominant genera, and that is due to their small spores' size (45-80 μm) which enable them to adapt to most of the soil conditions, especially clay soils with small size pores. In addition, Rhizophagus has the aptitude to produce spores inside and outside the roots as reported by INVAM. This trick of producing spores inside the roots made them resilient to soil disturbances and other destructive factors. Gigaspora, Scelerocystes and Dentiscutata were rare genera because they transmit their generation mostly on the sporulation more than the hyphal network, which might make them vulnerable to any soil disturbances. In addition, their large spore size (greater than 250 μm) did not fit well with small size of soil pores and cannot tolerate shrinking and swelling phenomena of the montmorillonite clay mineral. This might contribute to the damage of the hyphal networks and spores [48,52]. The two genera Ambispora and Septoglomus were normally distributed among all sites excluding Gedaref. Their disappearance in Gedaref could be attributed to its very high clay percentage and CEC.

In general, North Kordofan has the highest AMF occurrences among the six sites and Gedaref has the lowest; the two sites are rain fed areas but have major variations in soil chemical and physical properties and land practices. Velázquez and Sidney [53] mentioned that AMF prefers the less disturbed and deficient soil in nutrients.

3.7.4 Diversity

Shannon Wiener diversity index revealed a normal diversity and richness among the five sites except for Gedaref that had a lower index less than two. This might be due to the absence of five genera and low spore number of Acaulospora.

With respect to the Evenness index, the AMF genera were evenly distributed among all sites excluding only North Kordofan. This might be due to the presence of high numbers of Acaulospora genera and the presence of Gigaspora, scelerocystes and Dentiscutata; which could be clarified by historical influences like dispersion [54] and speciation which played a critical role in shaping AMF community composition [55]. Considering the divergence of North Kordofan geographical location from the other sites and where its soil matrix disparity is Nubian sandstone, and the other sites are Blue Nile alluvial deposits.

4. CONCLUSION AND RECOMMENDATION

This study of AMF occurrence and diversity was conducted relying on sorghum as a host plant model since it is widely cultivated in Sudanese different environments and because of its high susceptibility to AMF colonization as well. Subsequently, the results could exhibit the following conclusions:

i. All the studied sites contained AMF spores and colonized in different intensity. The lowest total spore density and colonization were found at Gedaref then the spore density and colonization increased at Gezira and Sennar irrigated sites, then Gezira and Sennar rain-fed and lastly at North Kordofan that achieved the highest total spore density and root colonization.

ii. Total spore density had a negative correlation with soil CEC, soil pH, available phosphorus and clay content and a positive correlation with sand content. The situation was similar for the root colonization percentage and invalid spore number, but the case was inversed for invalid spore percentage.

iii. North Kordofan had all of the 12 AMF genera noticed in the study. However, the genera Gigaspora, Scelerocystes and Dentiscutata were not detected in the other sites; in addition, the genera Septoglomus and Ambispora were not seen in Gedaref site.

iv. Occurrences of the genera among sites revealed that Rhizophagus, Glomus, Claroideogloms, Funneliformis, Acaulospora, Scutellospora and Entrophospora were dominant, Septoglomus and Ambispora were normally distributed and Gigaspora, Scelerocystes and Dentiscutata were rare.

v. Gedaref had the lowest diversity index among the sites. And North Kordofan had the lowest evenness.

It is recommended to add AMF inoculums to heavy clay soils to increase spore density. Further studies are needed to evaluate the effect of AMF genera and species found on the studied sites on crops yield.

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