Diversity and spore density of arbuscular mycorrhizal fungi in the rhizosphere of Cowpea (*Vigna unguiculata* [L.] Walp.) cultivated in different soils in Senegal

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Keywords: Arbuscular Mycorrhizal fungi, *Vigna unguiculata*, Indicator species, Dek, Dek_Dior and Dior soils

Publication date 30/04/2021, http://m.elewa.org/Journals/about-japs/

1 ABSTRACT

Arbuscular mycorrhizal fungi (AMF) play a significant role in soil structure, plant water and nutrient uptake particularly in poor soils. This work aims to determine the diversity and spore density of AMF in the rhizosphere of cowpea cultivated in three soil types (Dek, Dek_Dior and Dior) collected from two sites (Ouarkhokh and Dya) in Senegal (West Africa). Using morpho-anatomical identification of spores isolated from cowpea rhizosphere, 15 taxa classified in 8 genera (*Gigaspora*, *Racocetra*, *Scutellospora*, *Entrophospora*, *Acaulospora*, *Glomus*, *Sclerocystis* and *Rhizophagus*) and 3 families (*Gigasporaceae*, *Acaulosporaceae* and *Glomeraceae*) were identified. The genus *Glomus* is the most represented followed by *Gigaspora* in the different soil types. The spore density was significantly higher in Dek soil than in Dior soil. This study also revealed that AMF communities were clustered according to sites and soil types, with a clearer separation between Dek soil and Dior soil for Ouarkhokh as well as Dya site. In addition, *Racocetra gregaria* was identified as indicator species for Dya site in the Sudano-Sahelian zone and *Gigaspora* sp. and *Acaulospora* sp. were identified as indicator species for Ouarkhokh site in the Sahelian zone. Meanwhile, *Scutellospora heterogama* was identified as indicator species for Dek soil and *Glomus coronatum* as indicator species for Dek soil and Dek_Dior soil. Future research should focus on these AMF taxa in order to develop highly effective and competitive inoculants for cowpea cultivation in these different soil types and sites.

2 INTRODUCTION

Arbuscular mycorrhizal fungi (AMF) form symbiotic association with more than 80% of terrestrial plants (Smith and Read, 2008). In this symbiotic association, the fungus receives the carbohydrate produced by the plant through photosynthesis and in return, it provides essential minerals and water to the plant. Currently, the AMF diversity is composed of nearly 300 species morphologically described throughout the word (Opik and Davison, 2016). However, the diversity of AMF is poorly studied in sub-Saharan Africa, particularly in Senegal where only few studies have been conducted (Ndoye *et al.*, 2012; Diop *et al.*, 2015; Samba-Mbaye *et al.*, 2020). In Senegal, studies carried out in different agro-systems and on several plant species, including Acacia trees, revealed a low diversity generally not exceeding 10 species distributed in genera *Glomus*, *Gigaspora*, *Scutellospora* and *Acaulospora* (Ndoye *et al.*, 2012; Sène *et al.*, 2012). Previous studies have simply shown that the AM fungal communities are influenced by the physico-chemical characteristics of soil such as texture, organic matter, pH, level of phosphorus and soil moisture (Mohammad *et al.*, 2003; Ndoye *et al.*, 2012; Bhardwaj and Chandra, 2018). Others studies made in agro-systems have highlighted the effects of cultural practices such as tillage, rotations, monocultures and host plant on the AM fungal communities (Carrenho *et al.*, 2002; Jansa *et al.*, 2003; Oehl *et al.*, 2003; Öpik and Moora, 2012). Also, it is well established that the diversity of the AM fungal communities varied in relation to spatial distance and environmental gradients (Davison *et al.*, 2015). A study conducted in Central Europe by Oehl *et al.* (2010) also showed that the communities of AMF varied depending on the soil type, with generalist AM fungal species being encountered in all soil types, while species-specific at a soil type. In this respect, the AMF are considered as good indicators of agricultural soils (Oehl *et al.*, 2011). In Senegal, more than 2/3 of cultivated areas are occupied by Dek, Dek-Dior and Dior soil types (Sarr *et al.*, 2001; FAO, 2002). However, little is known about the diversity of AMF in these different types of soil where crops such as cowpea, groundnut and millet are grown in either monoculture or association. Cowpea (*Vigna unguiculata* [L.] Walp.) is one of the most important legumes in savanna areas of tropical Africa. In Senegal, cowpea is the second legume after the peanut in cropping systems (Sarr *et al.*, 2001). Its leaves, green pods and dry seeds are eaten by people due to its high protein content. In addition, like other legumes, its cultivation contributes to the restoration of soil fertility due to its high potential of biological nitrogen fixation (Graham and Vance, 2003). Like others legumes, cowpea is privileged to form a double symbiosis with nitrogen-fixing bacteria and arbuscular mycorrhizal fungi. Many studies have been conducted on the diversity of nitrogen-fixing bacteria associated with cowpea in Senegal (Krasova-Wade *et al.*, 2003; Krasova-Wade *et al.*, 2006), while only few studies have been done on the diversity and distribution of AMF associated with cowpea. Thus, the objectives of this study were: (i) to determine the diversity and spore density of AMF in the rhizosphere of cowpea cultivated in the three soil types (Dek, Dek-Dior and Dior) collected from two ecological zones in Senegal and (ii) to determine indicator species for the different soil types and ecological zones.

3 MATERIALS AND METHODS

3.1 Study area and location of sampled plots: Soils were collected from two sites: Dya (14°13'60"N and 16°10'0"W) and Ouarkhokh (15°22'60"N and15°13'60"W) located in Senegal in the Sudano-Sahelian zone and Sahelian zone, respectively. The Sudano-Sahelian zone is characterized by about 500 to 900 mm of annual precipitation and an average temperature of 36°C. In contrast, the Sahelian zone is characterized by an annual rainfall ranging from 250 to 500 mm and an average temperature of 38°C. In the studied zones, the vegetation was dominated by *Faidherbia albida, Guiera senegalensis* for tree stratum and *Digitalaria ciliaris*,

Dactilectonium aegyptiaca, *Cenchrus biflorus* for herbaceous stratum in Dya. In Ouarkhokh, the tree stratum is mainly dominated by *Acacia raddiana* and *Balanites aegyptiaca* while the herbaceous stratum is dominated by *Zornia glochidiata*, *Cenchrus biflorus and Eragrostis tremula*. The main crops grown in the two zones are millet, groundnut, cowpea and sorghum.

3.2 Soil sampling: From each site, three soil types (DEK, DEK-DIOR and DIOR) were collected with three replicates each. Thus, a total of 18 plots (9 for each site) were sampled. Soil samples were taken from each site in early July when the growing season began. At each sampling plot, we collected approximately 10 kg of soil in six different points. Soils were taken from the depth of 0-40 cm and homogenized to obtain a composite soil sample for each sampling plot. Each composite soil sample was divided into two parts: one part was used for cowpea cultivation in a greenhouse experiment, and the other part for physicochemical analysis of soil samples.

3.3 Physicochemical analysis of soil samples: Analysis of soil physicochemical parameters was performed at the CEREGE, Aix en Provence (France). The soils were characterized by their granolometry (coarse sand, fine sand, coarse silt, fine silt and clays) and by measuring their cations exchange capacities (Ca, Na, Mg, Mn, K, Al and Fe).

3.4. Greenhouse experiment: Soil samples were sieved (< 2 mm) homogenized and distributed in 1kg pots. Hence, 10 pots were obtained for each composite soil sample. Cowpea seeds of the "Melakh" variety were sown in pots maintained in greenhouse. Cowpea seedlings were watered regularly with tap water to field capacity. After 60 days of culture, the plants were removed and the contents of 10 pots representing the same type of soil were mixed in a composite sample from which 100 g aliquots (with 3 replicates) were taken to determine AM fungal spore density and species richness. Roots were collected to determine mycorrhizal parameters of cowpea plants grown on the different soil types.

3.5 AMF spore isolation, enumeration and identification: AMF spores were extracted from soil by wet sieving and sucrose density gradient centrifugation (Oehl *et al.*, 2003). Spores were counted under a dissecting microscope using up to 40-fold magnification. For identification of morphological characters, spores size and colour were assessed in water under a stereomicroscope and photographed. Spore wall structure and other specific attributes were observed under a microscope on permanent slides prepared according to Azcon-Aguilar *et al.*(2003). The microscope was connected to a computer for digital image analysis. Spore identification was mainly based on morphological features, including size, colour, wall structure and hyphal attachment (Morton and Benny, 1990). Morphotypes were classified to the genus level, and when possible, to the species level. The AM fungal identification was based on current species description and identification manuals (International Culture collection of Arbuscular Mycorrhizal Fungi (http://invam.caf.wvu.edu/fungi/taxonomy/speciesID.htm).

3.6 Statistical analysis: Soil properties were subjected to a one-way analysis of variance (ANOVA) with soil type (Dek, Dek-Dior and Dior) as factor, and the mean values were compared using Tukey test at the 5% significance level ($P<0.05$), with R (version 3.6.3) software. Percentage of root length colonization by AMF (intensity), frequency of root colonization and spore density were subjected to a two-way analysis of variance (ANOVA; site x soil type), and pairwise comparisons were made when the interaction was significant at $P<0.05$. The α-diversity of AMF communities associated with cowpea in the different soils was assessed by the species richness, and Shannon and Simpson diversity indices that were subjected to a two-way analysis of variance (ANOVA; site x soil type). All data were tested for normality using the Shapiro–Wilk test (Shapiro and Wilk, 1965). Differences in the structure of AMF communities associated with cowpea in the different soils (β-diversity) were assessed by a non-metric multidimensional scaling (NMDS)

based on Bray-Curtis distances using the "metaMDS" function in the "vegan" package (Oksanen *et al.*, 2017). Then, the "envfit" function in the "vegan" package was used to assess the relationships between AMF community structure and soil properties. The permutational multivariate analysis of variance (PERMANOVA) was performed to test significant differences between sites and soil types by using the "adonis" function in the "vegan" package (Anderson, 2001). To determine which AMF taxa characterized soil types or sites, the indicator species analysis was performed using the "multipatt" function in the "indicspecies" package (De Caceres and Legendre, 2009).

4 RESULTS

4.1 Soil properties: The analyses of soils from the two sites showed differences among the three soil types (Table 1). For instance, coarse silt and fine silt contents were higher in Dek soil than in Dior soil. The contents of the exchangeable cations such as Ca and Mg were significantly higher in Dek soil than in Dior soil, while those of Al and Fe were significantly higher in Dior soil than in Dek soil. The contents of the other exchangeable cations (K, Mn and Na), sand and clay were not significantly different among the three soil types (Table 1). Nevertheless, the contents of exchangeable cations K and Mn were higher in the soil collected from Ouarkhokh than in those from Dya, while the clay content was lower in the soil collected from Ouarkhokh than in those from Dya (Table 1).

Table 1: Composition of the three soil types sampled from the two sites (Dya and Ouarkhokh)

		Soil types			Sites
	Dek	**Dek_Dior**	**Dior**	**Dya**	**Ouarkhokh**
Granulometry					
Coarse sand (%)	34.50a	45.50a	35.75a	38.17a	39.00a
Fine sand (%)	49.75a	45.25a	59a	48.50a	54.17a
Coarse silt (%)	7.75a	4.00ab	1.5b	6.00a	2.83a
Fine silt (%)	3,25a	1.75ab	0.75b	2.67a	1.17a
Clay (%)	4.75a	3.50a	3.00a	4,67a	2.83b
Cation exchange capacity					
Al_cec (%)	8.50b	15.75b	41.00a	26.83a	16,67a
Ca_cec (%)	57.50a	49.00a	34,50b	48,17a	45.83a
Fe-cec (%)	1.00b	1.75b	4.75a	2.67a	2.33a
K_cec (%)	7.75a	9.00a	4.25a	3.67b	10.33a
Mg _cec (%)	22.25a	20.50a	12.00b	16.67a	19.83a
Mn_cec (%)	2.00a	2.00a	2.50a	1.00b	3.33a
Na _cec (%)	1.00a	2.00a	1.00a	1.00a	1.67a

Means in the same line followed by the same letter are not significantly different ($P < 0.05$), according to Tukey's HSD. Al = aluminium; Ca = calcium; Fe = iron; K= potassium; Mg = magnesium; Mn = manganese; Na= sodium.

4.2 Spore density and cowpea root mycorrhization: Cowpea root colonization by AMF varied depending on the soil type and site where the soils were collected (Table 2; Fig. 1). The site, soil type and site-soil type interaction had significant effects on the frequency of root colonization ($p < 0.001$, Table 2). For the root length colonized by AMF, we observed a significant effect of soil type ($p = 0.011$, Table 2), and a marginally significant effect of site ($p = 0.050$, Table 2). Hence, for the soil collected from Dya, the frequency of root colonization

and root length colonized by AMF were significantly higher in Dek soil than in Dior soil (Fig. 1). Meanwhile, for the soil collected from Ouarkhokh, there is no statistically significant difference among the three soil types in terms of frequency of root colonization and root length colonized by AMF (Fig. 1).

Table 2: Summary of ANOVA for the effects of site and soil type on the percentage of cowpea root length colonization (intensity) and frequency of cowpea root colonization

Factors tested	Intensity	Frequency
Site	p = 0.050	p = 1.38e-04
Soil	p = 0.011	p = 5.43e-06
Site x Soil	p = 0.131	p = 3.26e-04

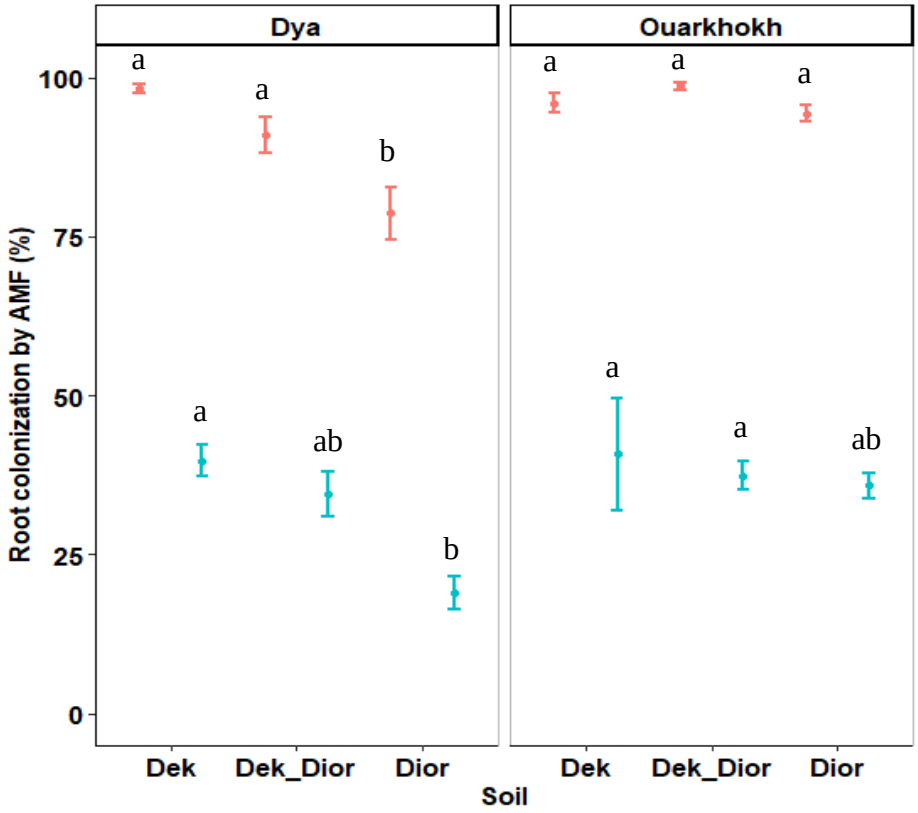

Figure 1: Root colonization (percentage ± SE) by AMF in cowpea plants grown in the three soil types: root length colonized by AM fungi (intensity, in blue) and frequency of root colonization (in scarlet).

On the other hand, ANOVA revealed significant effects of site, soil type and site-soil type interaction on AMF spore density (Table 3). AMF spore density was higher in soils collected from Ouarkhokh than in those collected from Dya ($p < 0.001$). For the soils collected from Ouarkhokh, AMF spore density was lower in Dior soil than in Dek soil and Dek_Dior soil (Fig. 2). While, no significant difference in AMF spore density was detected among the three soil types collected from Dya (Fig. 2)

Table 3: Summary of ANOVA for the effects of site and soil type on the spore density of AMF community associated to cowpea

	Df	SS	MS	F value	Pr(>F)
Site	1	1667780	1667780	34.04	4.49e-07
Soil	2	1150742	575371	11.74	7.06e-05
Site x Soil	2	780067	390033	7.96	0.001
Residuals	48	2351947	48999		

Df = degrees of freedom; SS = sum of squares; MS = mean sum of squares.

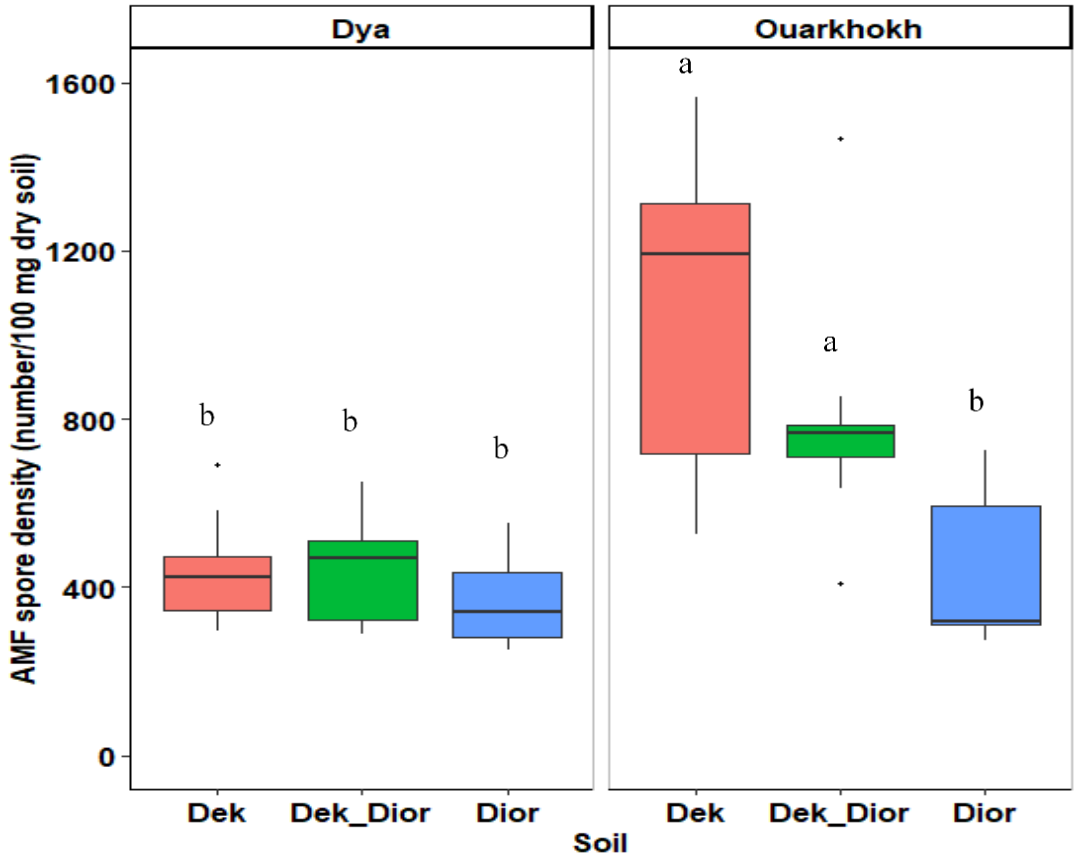

Figure 2: AMF spore density in the three soil types after cowpea cultivation in pots

4.3 Diversity and structure of AM fungal communities: Fifteen (15) AMF morphotypes were recorded from the rhizosphere of cowpea, based on morpho-anatomical features of isolated spores (Photos 1). The identified morphotypes belong to 8 genera (*Gigaspora, Racocetra, Scutellospora, Entrophospora, Acaulospora, Glomus, Sclerocystis and Rhizophagus*) classified in three families (Gigasporaceae, Acaulosporaceae and Glomeraceae). The genus *Glomus* is the most represented and most diversified with 5 morphotypes, representing 33.33% of the total described morphotypes. One of these morphotypes was identified at species level as *Glomus coronatum* (Giovann.) and the remaining four morphotypes were named *Glomus* sp.1, *Glomus* sp.2, *Glomus* sp.3 and *Glomus* sp.4. Among the 4 morphotypes belonging to the genus *Gigaspora,* two were identified at species level as *Gigaspora rosea* (Schenck and Nicolson, Walker and Sanders), one as *Gigaspora margarita* (Becker and Hall), and the remaining was named *Gigaspora* sp. The *Entrophospora* genus was represented by two species, *Entrophospora*

colombiana and *Entrophospora kentinensis*, representing 13.33% of all encountered morphotypes. Two other morphotypes were identified at species level as *Racocetra gregaria* (Schenk and Nicholson) and *Scutellospora heterogama,* respectively. The genera *Acaulospora*, *Sclerocystis* and *Rhizophagus* were each represented by one morphotype. Among them, only the morphotype belonging to the genus *Acaulospora* was identified at species level as *Acaulospora longula.* Those of the two other genera were named *Rhizophagus* sp. and *Sclerocystis* sp. The 15 AMF morphotypes were all found in the three soil types. Furthermore, our analysis revealed that soil type had no significant effect on species richness and Shannon and Simpson diversity indices (Table 4). Meanwhile, a significant effect of site was observed on species richness ($p = 0.017$), but not on the other α-diversity indices (Table 4). Hence, species richness was higher in Ouarkhokh than in Dya, while there are no significant differences in Shannon and Simpson diversity indices between sites and among soil types as well (Table 4). Furthermore, we observed that site and soil type were both important factors structuring AMF communities in cowpea rhizosphere (Table 5; Fig. 3). AMF communities were clustered according to sites and soil types, with a clearer separation between Dek soil and Dior soil for Ouarkhokh as well as Dya site (Fig. 3). In addition, we found that the variation in AMF community structure according to soil type was mainly explained by exchangeable cations (Al, Fe, Ca, Mg, and K) and fine silt (Fig. 3).

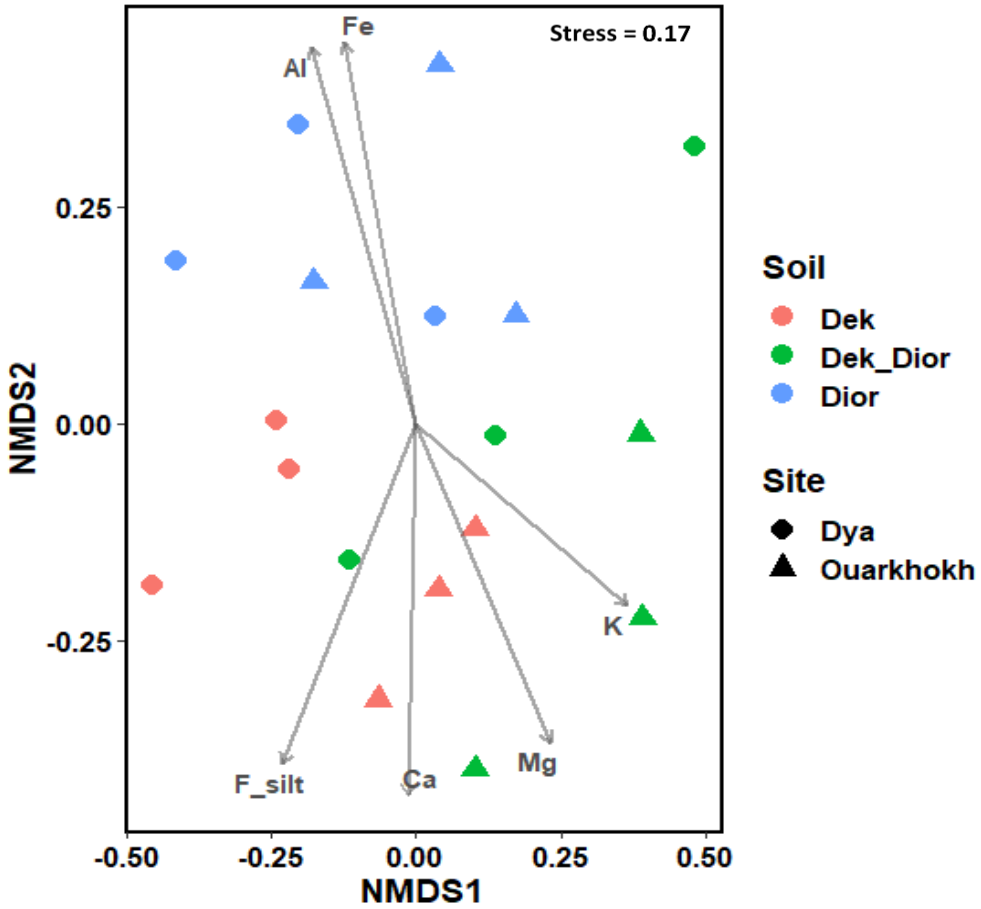

Figure 3: Non-Metric Multidimensional Scale (NMDS) plot depicting the similarity of AMF communities according to sites and soil types, with selected soil properties (arrows) that mainly explained ($P < 0.05$) the variation in AMF community structure.

Table 4: Site and soil type effects on species richness and Shannon and Simpson diversity indices of cowpea associated AMF communities

Site	Soil	Richness	Shannon	Simpson
Dya	Dek	7.000 a	1.361 a	0.658 a
	Dek_Dior	7.333 a	1.427 a	0.720 a
	Dior	7.333 a	1.478 a	0.712 a
Ouarkhokh	Dek	8.333 a	1.621 a	0.760 a
	Dek_Dior	9.000 a	1.527 a	0.692 a
	Dior	7.667 a	1.292 a	0.632 a
Factors tested: Site		p = 0.017	p = 0.519	p = 0.966
Soil		p = 0.397	p = 0.579	p = 0.711
Site x Soil		p = 0.397	p = 0.153	p = 0.211

Means in the same column followed by the same letter are not significantly different ($P < 0.05$), according to Tukey's HSD.

Table 5: Summary of permutational analysis of variance (PERMANOVA) based on Bray-Curtis distance to test the effects of site and soil type on the structure of AMF community associated to cowpea

	Df	SS	MS	F.Model	R^2	Pr(>F)
Site	1	0.364	0.364	3.910	0.162	0.004
Soil	2	0.470	0.235	2.529	0.209	0.005
Site x Soil	2	0.296	0.148	1.593	0.132	0.116
Residuals	12	1.116	0.093		0.497	
Total	17	2.246			1.000	

Df = degrees of freedom; SS = sum of squares; MS = mean sum of squares; *F* model = *F* statistics; R^2= partial R-squared, based on 999 permutations.

Using indicator species analysis, we identified *Racocetra gregaria* as indicator taxon for Dya site, while *Gigaspora* spp. and *Acaulospora* sp. were identified as indicator taxa for Ouarkhokh site (Table 6). Yet, *Scutellospora heterogama* was identified as indicator taxon for Dek soil, and *Glomus coronatum* as indicator taxon for Dek and Dek_Dior soils (Table 6).

Table 6: Significant indicator AMF species for different sites and different soil types

Categories	AMF species	IndVal	p-value
Site			
Dya	*Scutellospora gregaria*	0.561	0.008
Ouarkhokh	*Gigaspora* sp.	0.502	0.040
Ouarkhokh	*Acaulospora* sp.	0.404	0.002
Soil			
Dek	*Scutellospora heterogama*	0.485	0.005
Dek + Dek_Dior	*Glomus coronatum*	0.697	0.004

5 DISCUSSION

The techniques of morpho-anatomical characterization are mainly based on morphological traits such as spore size, colour and mode of hyphae attachment and the anatomical features such as the number and diameter of the layers making up the membrane's spores. Nowadays, this type of characterization remains very used in AMF

diversity studies (Wang *et al.*, 2019; Vieira *et al.*, 2020). The use of those techniques allowed us to identify 15 AMF morphotypes in the rhizosphere of cowpea cultivated in soils collected from two sites in Senegal. These AMF morphotypes belong to 8 genera (*Gigaspora*, *Racocetra*, *Scutellospora*, *Entrophospora*, *Glomus, Acaulospora*, *Sclerocystis* and *Rhizophagus*) classified in three families (*Gigasporaceae*, *Acaulosporaceae* and *Glomeraceae*). The genus *Glomus* is the most represented in all sites. This distribution of the genus *Glomus* is comparable to previous observations made in Senegal (Diop *et al.*, 2015; Samba-Mbaye *et al.*, 2020), Brazil (Teixeira *et al.*, 2017; Vieira *et al.*, 2018), Morocco (Sellal *et al.*, 2016) and China (Song *et al.*, 2019). The *Glomus* species have frequently been found in many ecosystems particularly in disturbed habitats, such as agricultural landscapes (Oehl *et al.*, 2003; Alguacil *et al.*, 2008) and in restored semi-natural grasslands (Schnoor *et al.*, 2011). The abundance of *Glomus* in disturbed habitats has been related to its high capacity to sporulate (Oehl *et al.*, 2003), to colonize new roots from AMF root fragments (Klironomos and Hart, 2002) and to easily form anastomoses (Giovannetti *et al.*, 1999). This study shows, overall, that cowpea root colonization and AMF spore density are significantly higher in Dek soil than in Dior soil. These results are consistent with those of Diop *et al.* (2015) who had shown, using molecular tools, that cowpea roots from Dek soil were more mycorrhizal and more associated with a higher number of AMF taxa than those from Dior soil. The fact that cowpea root colonization and AMF spore density were higher in Dek soil than in Dior soil could be explained by differences in soil properties. Yet, our results showed that exchangeable cations (Ca, Mg, K, Al and Fe) and fine silt were the main factors explaining the variation in AMF community structure according to soil type. Interestingly, previous studies have shown that the soil moderate levels of calcium (Ca), magnesium (Mg) and potassium (K) significantly stimulate root colonization (Zhang *et al.*, 2017; Melo *et al.*, 2019; Liu *et al.*, 2019). This is generally correlated with a strong AMF sporulation (Sivakumar, 2013) due to a strong connection of the hyphae to the carbon source, which is used for the spore production (Douds and Schenck, 1990). In this respect, Jarstfer *et al.* (1998) established a relationship between the level of Ca in leaves, root colonization and the number of AMF spores produced. They have shown that a low Ca content in the leaf tissues leads to decrease in root colonization from 30% to 10% and the number of spores produced from 1200 to 200 spores. Calcium is mainly involved in the establishment of symbiosis by promoting the permeability of root cells by an oscillation of its cytosolic concentration (Parniske, 2008). Besides Ca availability, Mg deficiency in soil considerably reduces the concentrations of chlorophylls (Zhang *et al.*, 2015), which suggests a negative effect on photosynthesis and thereby on the amount of carbon allocated to AMF. For potassium, it is described as a stimulating element of mycorrhization and a minimum of K from the soil is often a prerequisite for mycorrhization (Zhang *et al.*, 2017). However, the effect of K depends not only on its own availability, but also on the availability of other exchangeable ions such as Ca and Mg (Ardestani *et al.*, 2011; Melo *et al.*, 2019). On the other hand, studies carried out on the effect of soil chemical properties on root colonization and AMF sporulation, had shown a negative correlation between soil Al and Fe levels and root colonization by AMF (Oliveira and Oliveira, 2010; Cao *et al.*, 2016). Our results are also consistent with those of Zhao *et al.*, (2017) and Silva-Flores *et al.* (2019), who had shown a positive correlation of silt and clay contents with AMF spore density. Nevertheless, other edaphic factors such as pH (Zhu *et al.*, 2020), the level of phosphorus (Song *et al.*, 2019) and nitrogen in soil (Zhu *et al.*, 2020) could also contribute to differences in cowpea root colonization and AMF spore density among soil types and between sites. On the other hand, the AMF indicator species were determined for the different soil types and sites where the soils were collected. Indeed, AMF are increasingly seen as promising candidates for bioindicators of soil quality, management history and soil pollution

(Jansa *et al.*, 2014). In this study, *Racocetra gregaria* was identified as indicator taxon for Dya site located in the Sudano-Sahelian with annual precipitation ranging from 500 to 900 mm and an average temperature of 36°C. *Gigaspora* sp. and *Acaulospora* sp. were identified as indicator taxa for Ouarkhokh site located in the Sahelian zone characterized by an annual rainfall ranging between 250 and 500 mm and an average temperature of 38 °C. Regarding the soil type, *Scutellospora heterogama* was identified as indicator species for Dek soil, which had higher levels of Ca and Mg than Dior soil. Vieira *et al.* (2018) also found *Scutellospora* sp. as an indicator species of gallery forest soils characterized by high levels of Ca, Mg and K. Our results also revealed *Glomus coronatum* as indicator species for Dek soil and Dek_Dior soil. By working on several types of ecosystems such as shrubs, forests, grasslands and arable land, Zhao *et al.* (2017) also found that only taxa belonging to *Glomus* served as indicator species for all these ecosystems. This ability of *Glomus* species to adapt to several ecosystems is due to its capacity to produce a large number of spores and fragments of hyphae, which can colonize and spread widely on plant roots (Öpik *et al.*, 2006).

6 CONCLUSION

The results obtained in this study showed that the cowpea plant is naturally associated with a range of AM fungi. Fifteen taxa classified in 8 genera (*Gigaspora*, *Scutellospora*, *Acaulospora*, *Glomus*, *Racocetra, Entrophospora*, *Rhizophagus and Sclerocystis*) and in three families (*Gigasporaceae*, *Acaulosporaceae* and *Glomeraceae*) were identified in the rhizosphere of cowpea cultivated in three soil types collected from two sites. *Glomus* is the most represented genus followed by *Gigaspora* in the different soils. Our results also revealed that AMF communities were clustered according to sites and soil types, with a clearer separation between Dek soil and Dior soil for Ouarkhokh as well as Dya site. In addition, the study revealed *Racocetra gregaria* as indicator species for Dya site in the Sudano-Sahelian zone and *Gigaspora* sp. and *Acaulospora* sp. as indicator species for Ouarkhokh site in the Sahelian zone. Meanwhile, *Scutellospora heterogama* was identified as indicator species for Dek soil and *Glomus coronatum* as indicator species for Dek soil and Dek_Dior soil. Future research should focus on these AMF taxa in order to develop highly effective and competitive inoculants for cowpea cultivation in these different soil types and sites.

7 ACKNOWLEDGEMENTS

We thank the project AUF (Agence Universitaire de la Francophonie) and Agence Nationale Française de la Recherche (SolAO) for funding this work and the LSTM host laboratory (Laboratoire des Symbioses Tropicales et Méditerranéennes, Montpellier, France) for their contribution. We Thanks also to the producers of Dya and Ouarkhokh who gave us the experimental plots.

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