



Influence of Agrosystems on the Diversity of Mycorrhizae under Plantain Banana Cultivation in the Forest Region of Kisangani (Tshopo Province, DR Congo)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The largest genetic diversity of plantain banana (*Musa* AAB subgroup) is found by DR Congo. Arbuscular mycorrhizal fungi (AMF) are synergistic beneficial organisms with a positive effect on growth vigor. We determined the influence of plantain banana-based agrosystems on the diversity

of AMF in agroforestry and home-garden field systems located in the Kisangani region of DR Congo. Soil samples of the different agrosystems showed a high mycorrhizal frequency (82.5%) with an overall mycorrhizal rate of 33.43%. Vigorous plantain plants are growing in soils that rich in AMF spores whereas non vigorous ones were found in soils that had few AMF spores. There were also significant differences between cultivars, in terms of the number of spores. *Glomus* was the most abundant genus followed by *Gigaspora*, *Acaulospora*, *Scutellospora* and *Entrophospora*. The diversity indices evaluated, richness, abundance and Shannon_H showed non-significant difference between agroforestry and home-garden plantains. However, agroforestry plantains showed a larger Inv-Simpson and Equitability-J index than home-garden plantains. Soil physico-chemical characteristics had an effect on abundance of mycorrhizal genera in all inventoried mycorrhizal taxa.

Keywords: Agrosystems; Kisangani; mycorrhizae; plantain banana; vigor.

1. INTRODUCTION

Plantain bananas are important in different countries in the intertropical zone [1]. For the Democratic Republic of Congo (DRC) plantain is the second most important crop and 3rd largest source of household income, after cassava, rice, and oil palm and its production ranks 10th in the world [2,3]. Plantain is the key to food security in the DRC, its production is increasing over the years, 1,42 million tons per year in 2016 [4] and around 4,86 tons per year in 2020 [5]. The Tshopo Province is the biggest plantain producer with 814,237 tons in 2019, about 16.8% of the total national production [5]. Moreover, Tshopo province had the highest diversity in plantain [6, 7] and the biggest consumption rate [8] in DRC with a consumption of more than 90% [9, 3]. In tropical Africa, the yield of plantain is 4-7 tons per hectare [10] but vary between 5 to 15 tons per hectare per year [11]. To date, yield values of plantains in Tshopo province are still scarce. In Tshopo province, yields of main crops are continually declining due to pests and diseases, poor soil quality, the non-use of sustainable agricultural practices as slash and burn [12]. Moreover, insufficient financial means to purchase mineral fertilizers and insufficient knowledge of good agricultural practices (e.g. compost, use of mycorrhizae, etc.) result in low yields. Plantain requires deep, well-drained soils with a high organic matter content for its development and growth [13]. Plantain production in Tshopo province is often increased at the expense of the forest where the soils are more fertile and where crops are less exposed to pest attacks [14]. Trees present in cultivated fields produce organic matter (litter) contributing to soil fertility but are now increasingly logged as timber and fuelwood due to population expansion leading to soil degradation and deforestation [15]. In the Kisangani region, plantains banana

are often grown as monocultures in homegardens. In other cropping systems (fallow and forest), they are often grown in an intercropping systems with groundnuts, maize, rice, and/or cassava [16].

Several studies demonstrated the beneficial effects of mycorrhizal fungi on crops including plantain [17, 18, 19, 20, 21, 22]. Hence the use of mycorrhizal inocula could contribute to improved soil fertility facilitating the sustainable cultivation of plantain. Mycorrhizae are symbiotic fungi which colonize the roots of plants such as plantain by producing mycelia in and around the roots. The symbiotic relationship facilitates the uptake of water and nutrients by plants, especially minerals which are difficult to assimilate (e.g. zinc, phosphorus) [15].

It becomes necessary to develop new agricultural practices in forest environments including the biofertilization of plantain, while safeguarding the rich biodiversity of the forest in the Kisangani region. The general objective of this study is to determine the influence of agrosystems on the diversity of the Arbuscular Mycorrhizal Fungi (AMF) under plantain to contribute to the development of efficient biofertilizers in the Kisangani region. More specifically this study aims to determine the taxonomic diversity of AMF under plantains according to the agrosystem, to evaluate the influence of AMF on plantain vigor, and to determine the influence of physico-chemical soil parameters on the diversity of AMFs under plantains.

2. MATERIALS AND METHODS

2.1 Study Sites

This research was carried out in Masako and Simi-Simi near the city of Kisangani. The Masako

site is administratively located in the Lubuyabera sector community, northeast of Kisangani, 14 km along the old Buta road in the vicinity of the Masako Forest Reserve. This reserve covers an area of 2,105 hectares and is located entirely within a large loop of the Tshopo River [23, 24], its geographic coordinates are 00°36'08.4"N and 25°15'59.9"E, with an average altitude of 429 m.a.s.l. The Simi-Simi experimental site is located 15 km from Kisangani, in the western part of the country, in the locality of Linoko, 00°33'04.6"N and 25°05'15.6"E and at 397 m.a.s.l.

2.2 Materials

Eighty root samples of plantains were collected, with three roots of 5 cm per plant collected for root colonization analysis. The rhizospheric soil around the 80 root samples was used to determine the quantity and diversity of mycorrhizal spores. Eight soil samples were collected from the fields at the two sites for physico-chemical analyses. The analyses were done in the soil laboratory of the Kisangani University.

2.3 Methods

2.3.1 Data collection

Eight soil samples were taken from the two sites between 0 cm to 30 cm depth in the plantain fields using the diagonal method [25, 26]. The following physico-chemical soil parameters were measured: particle size by the pipette method, bulk density, pH by potentiometry, available phosphorus by Bray 2 method [27], total nitrogen by Kjeldahl, organic carbon according to the Walkey and Black method, exchangeable acidity by the titrimetric method [28], cation exchange capacity and exchangeable basic cations by saturation with NH_4^+ . All methods are described in detail in [29] and [30].

Agrosystems: Agroforestry is a system using agricultural land in association with trees and crops or livestock to produce agricultural products. Leguminous trees (*Leucaena leucocephala*, *Albizia chineensis*, *Albizia gummifera*, *Albizia laurentii*) in the experimental fields were planted at a spacing of 6 m x 6 m and were 16 years old at Simi-Simi and 8 years old at Masako. Plantain plants were grown in the inter-rows of the leguminous trees, and there were 5 replications of 20 m x 30 m each. The plantain plants (1 year old) were planted at a spacing of

3.5 m x 6 m at both sites. The total number of plantain roots samples collected in agroforestry fields was 40 in total in both sites: 20 from the cultivar Libanga lifombo and 20 from the cultivar Libanga likale; both cultivars are false horn types.

In home-gardens fields, three types of plantains were grown: the French type (4 plants of Litete), false horn (2 plants of Libanga lifombo, 15 plants of Libanga likale) and true horn (3 plants of Adili, and 5 plants of Egbeomabese). Plantain plants were one year old with 6 m x 6 m of spacing.

Forty vigorous plantain plants were selected and characterized by a large diameter taken at 5 cm height, between 15 to 40 cm with 2 to 4 m of height, green foliage, bearing a large bunch with large fingers depending on the cultivar. Forty non-vigorous plantain plants were selected as well and characterized by a medium or small pseudo-trunk, and a diameter taken at 5 cm height, varying between 1 to 14 cm, with a height between 1 to 3 m, the foliage sometimes being yellowish, and sometimes with a small bunch with small fingers [31]. The comparison of vigor was done between plantain plants located in agroforestry and home-garden fields which had the same age of 1 year.

2.3.2 Staining and observation of mycorrhizae

Mycorrhizal spores and root colonization were observed by root staining. This consisted of cell discoloration while preserving the cell walls, which were stained by methylene blue. Young plantain roots were washed with running water, cut to a length of 1-2 cm, and then placed into test tubes with a 10% KOH solution followed by heating in a water bath at 90 °C for 30 min. This process decolorized the tannins and the solution became brown-red [32,33]. The KOH solution was filtered and rinsed with acidified water (1% HCl) for neutralization. Three drops of methylene blue were added, and the solution put back to the water bath of 90 °C for 10 to 15 min, then filtered again and rinsed with distilled water.

For plantain root observation, acidified glycerol was added to discolor the plant root cells but not the mycorrhizal structures. When the root was too thick, it was gently crushed with the back of a pencil [34, 32].

2.3.3 Observation of mycorrhizal spores

The slides were observed under an inverted microscope, each root fragment was carefully

checked along its entire length, at magnifications of 50 and 100x [35].

2.3.4 Mycorrhizae rating of plantain roots

The mycorrhization rating was based on a 6-level scale (0 to 5), and each level represented a mycorrhization class. The class scale between 0 and 5 corresponded to the estimation of the proportion of the colonized root part attributed to each of the observed root fragments. The overall mycorrhization result was obtained by averaging over the number of roots observed [36]. The mycorrhization rate was assessed by the following parameters:

- The percentage of mycorrhized roots, also called mycorrhization frequency:

$$F (\%) = (\text{number of fragments roots mycorrhized} / \text{the total number of fragments roots}) \times 100$$
 [37].
- The global intensity of mycorrhization:

$$M (\%) = (95n_5 + 70n_4 + 30n_3 + 5n_2 + n_1) / \text{total number of fragments}$$
 [38].
 With n_5 representing the number of mycorrhized fragments in class 5, n_4 the number of fragments in class 4, etc.

The global intensity of mycorrhization is a better parameter who reflects the degree of mycorrhization [39].

For mycorrhizal spores, the soil samples were taken at a depth of 15 to 20 cm, and at a distance of 10 to 30 cm from the base of the plant.

For AMF spores' assessment, 100 g soil was placed in a beaker, tap water added and the solution vigorously shaken followed by 20" settling of the solution which was then filtered through a 1 mm sieve and the waste discarded. The mixture was shaken again, allowed to settle for 20' and filtered through a 45 µm sieve. The debris was collected with a water jet in another 100 ml beaker and transferred to tubes. The tubes were centrifuged for 2' at 2000 rpm (4 °C). The supernatant was discarded and the tubes were filled with 50 ml of sugar solution and centrifuged for the second time for 20" at 2000 rpm. The supernatant was filtered through a 45 µm sieve with the help of a water jet; the debris was collected in a petri dish for spore observation under a microscope[38]. The families and genera of spores were determined using an identification key based on the shape, size and color of the mycorrhizal spores by [40, 41 and 42].

2.3.5 Data analysis and processing

The data from this study were processed in Microsoft Excel (2013), as well as the R software (Version 3.6.1). This R software helped to verify the correlation between the AMF spores genera from different plantain cultivars, with the soil physico-chemical characteristics. The statistical tests carried out on the environmental and specific parameters include *t* student test, ANOVA test after verification of the normality of the residuals with the Shapiro test, Tukey's test (HSD), the Pearson correlation test and 5 diversity indices: The Richness, Abundance, Inv_Simpson, Shannon_H and Equitability J were calculated.

3. RESULTS

3.1. AMF Spores

Five genera of AMF were identified: *Gigaspora* with a spore size varying between 200 to 360 µm, *Entrophospora* with a spore size varying between 100 to 250 µm, *Acaulospora* with a spore size varying between 100 to 250 µm, *Scutellospora* with spore size varying between 20 to 100 µm and *Glomus* with spore size varying between 60 to 180 µm (Fig. 1).

The mycorrhization frequency was 82.5%, and the overall global mycorrhizal intensity was 33.43%.

3.2 AMF Spores Per Genera

More than half of the spores were of the genus *Glomus* and one third of *Gigaspora*. The other three genera contributed to about 15% of the total amount of AMF spores (Table 1). There was non-significant difference between the two agrosystems.

3.3 Distribution of Mycorrhizal Spores by Cultivar

Table 2 shows that there was a significant difference ($p = 0.00175$) between the plantain cultivars in the mean number of mycorrhizal spores identified from the soil samples on which these cultivars were respectively located. The soils on which the cultivar Litete is found had a higher mean number of AMF spores, followed by those containing Libanga likale, Adili, Libanga lifombo and Egbeomabese, respectively. Among the mycorrhizal genera identified, the genus *Glomus* was the most abundant for all plantain cultivars, the least

Table 1. AMF spores per 100 g of soil and per genera in agroforestry and home-garden

Agrosystems	<i>Glomus</i>	<i>Gigaspora</i>	<i>Acaulospora</i>	<i>Scutellospora</i>	<i>Entrophospora</i>	Total
Agroforestry	34.65±24.08	15.48±11.14	6.13±6.06	3.05±3.49	1.30±1.80	60.60±43.01
Home-garden	46.15±29.62	17.68±14.55	7.15±5.81	2.60±2.67	0.88±1.24	74.45±48.54
Average	40.40±27.44	16.58±12.93	6.64±5.92	2.83±3.10	1.09±1.55	67.53±46.10
P-value	0.1177	0.7424	0.4396	0.7264	0.3817	0.2277

Table 2. AMF spores per 100 g of soil of different plantain banana cultivars

Cultivars	<i>Glomus</i>	<i>Gigaspora</i>	<i>Acaulospora</i>	<i>Scutellospora</i>	<i>Entrophospora</i>	Total
Adili	42.00±8.49	19.00±2.83	7.00±5.66	3.00± 4.24	0.00±0.00	71.00± 4.24
Egbeomabese	21.80±22.17	5.80±3.96	1.40± 2.07	1.00± 1.41	0.40± 0.55	30.40± 28.85
L.lifombo	26.30±19.06	11.63±8.68	4.41± 4.21	1.67± 2.08	0.81± 1.18	44.81± 32.42
L.likale	49.98±27.01	20.46±14.03	8.29± 6.25	3.73± 3.52	1.34± 1.78	83.80± 45.82
Litete	57.25±47.25	23.00±20.45	8.00±7.16	3.25± 3.4	1.75± 2.22	93.25± 78.35
Average	40.27±27.59	16.61±13.00	6.48±5.79	2.81± 3.11	1.09± 1.56	67.25± 46.33
P-value	0.00199	0.01258	0.01517	0.05674	0.3534	0.00175

Table 3. AMF presence by genus and plantain vigor

Systems	<i>Glomus</i>	<i>Gigaspora</i>	<i>Acaulospora</i>	<i>Scutellospora</i>	<i>Entrophospora</i>	Total
Non_vigorous	31.46±27.36	13.9±14.72	4.85±5.48	2.08±3.15	0.85±1.55	53.13±47.85
Vigorous	48.85±25.29	19.25±10.61	8.08±5.7	3.53±2.94	1.33±1.56	81.03±40.84
Average	40.27±27.59	16.61±13	6.48±5.79	2.81±3.11	1.09±1.56	67.25±46.33
P-value	0.002324	0.003793	0.00786	0.007945	0.09179	0.001537

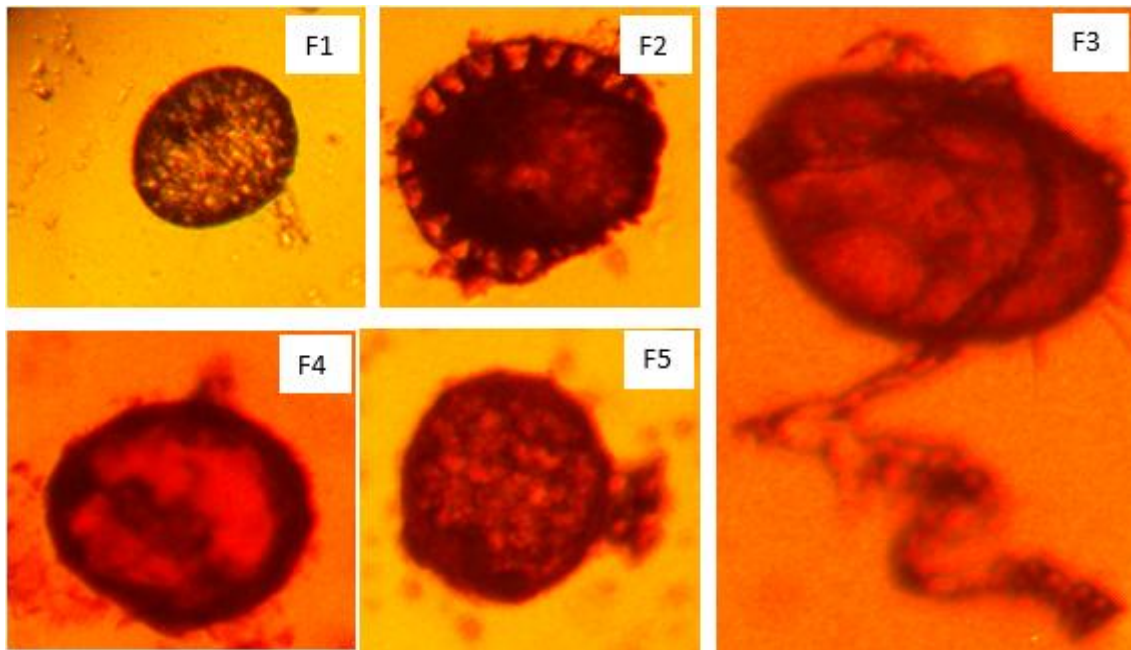


Fig. 1. Mycorrhizal spores of different taxa observed (F1: Gigaspora: shape spherical with hyphae reddish color); (F2: Entrophospora: characterized by reddish- bright color); (F3: Acaulospora: shape subglobular with yellow-reddish color) and (F4: Scutellospora: characterized by amorphous with reddish form); (F5: Glomus: shape spherical ellipsoidal. reddish color)

Table 4. Diversity indices of AMF in agroforestry and home-garden

Agrosystems	Richness	Abundance	Inv_Simpson	Shannon_H	Equitability_J
Agroforestry	4.80± 0.63	242.4± 124.86	0.59± 0.05	1.10± 0.11	0.71± 0.06
Home-garden	5.00± 0.00	288.9± 127.75	0.53± 0.05	1.00± 0.10	0.62± 0.06
Average	4.90± 0.45	265.65± 125.24	0.56± 0.05	1.05± 0.11	0.67± 0.07
P-value	0.3681	0.4212	0.03101	0.06302	0.005957

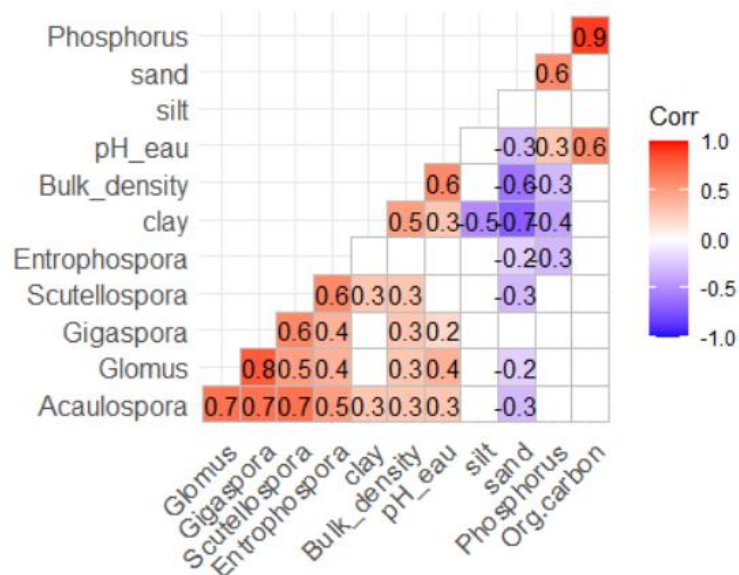


Fig. 2. Correlation matrix between soil variables and AMF taxa

abundant being the genus *Entrophospora*. For each mycorrhizal spore's genus, plantain cultivars were significantly different from each other in terms of mean spore number, except for the genera *Scutellospora* and *Entrophospora* ($p > 0.05$).

3.4 Repartition of AMF Spores

AMF spores were more abundant in vigorous growing plantains than less vigorous plantains. This was the case for all AMF genera with exception for *Entrophospora* (Table 3).

3.5 Diversity index of AMF in agroforestry and home-garden systems

Among the five diversity indices evaluated, richness, abundance and Shannon_H showed no significant difference between agroforestry and home-garden plantains. However, agroforestry plantains showed a larger Inv-Simpson and Equitability-J index than home-garden plantains (Table 4).

3.6 Influence of Soil Physico-chemical Parameters on Mycorrhizal

All AMF genera, except *Entrophospora*, were positively correlated with bulk density, and all AMF genera, except *Entrophospora* and *Scutellospora*, were positively correlated with the pH. Only *Acaulospora* and *Glomus* were negatively correlated with sand and only *Acaulospora* and *Scutellospora* were positively correlated with clay content (Fig. 2). However, all these correlations, despite being statistically significant, remain weak.

4. DISCUSSION

4.1 Diversity and Abundance of AMF per Agrosystem

This study revealed high mycorrhizal frequency (82.5%) in both agrosystems (home-garden and agroforestry), and high mycorrhizal rate (33.43%) under plantain plants roots. The mycorrhizal genera identified were *Glomus*, the most abundant, followed by *Gigaspora*, *Acaulospora*, *Scutellospora*, and *Entrophospora*. The results of this study corroborate with those observed by [43] in a study carried out in the Niligiri Biosphere of the Western Ghats in South India. The authors mention that among the 56 species of AMF identified during the pre-monsoon season and

the 67 species identified in the post-monsoon season the species *Glomus fasciculatum* was the most abundant, followed by *G. geospora* and *G. mosseae*. [33], found a mycorrhizal rate of 40.75% in the Kisangani Forest region. Studies carried out under experimental conditions on various other crops have shown high mycorrhization rates [44, 45, 46, 47, 48] which are in agreement with the results observed in this study. However, it should be noted that in all these studies inoculation was used, which was not the case in our study. In addition, studies on mycorrhizae in the Kisangani region are rare. Differences between colonization rate in different studies could be explained by the variability of studied crops, cropping system used, crop age and season.

4.2. AMF Spores Number in Agrosystems

This study revealed that home-garden fields presented a higher mean number of mycorrhizal spores than the agroforestry fields, but the differences were not-significant. However, [32] found significant differences between three agrosystems (forest, fallow and home-garden) in terms of spore numbers. The home gardens were characterised by a higher proportion of nitrogen, phosphorus, organic matter, exchangeable bases, cation exchange capacity, exchangeable acidity (0.23%, 17.45ppm, 5.65%, 3.21 meq/100g, 1.64 meq/100g, 8.23 meq/100g respectively). This indicates a better soil fertility in the home gardens due to household waste, kitchen ashes, livestock excrement, accumulated around the tufts. The mineralization of the whole enriched the soil with nutrients. The allows physico-chemical condition of the soils requires that the home-gardens which supports be maintained for several years [49], the AMF spore multiplication in the soil. In home gardens plantain was planted in permanent system of culture, very diversified, in association with other crops, with non-incinerated elsewhere [9]. This research confirms the effects found [32, 49, 9] on the agrosystem effects on AMF spores.

4.3 AMF spore Genus and Plantain Cultivars

The soils on which the cultivar Litete is growing, had a higher number of AMF spores, followed by those containing Libanga Likale, Adili, Libanga lifombo and Egbeomabese, respectively. There was a significant difference between the plantain cultivars. The genus *Glomus* was the most abundant for all plantain banana cultivars, the

least abundant being the genus *Entrophospora*. [50] points out that the family genus *Glomus* is the most abundant and the best studied one. [33] identified in the Kisangani Forest region, 4 mycorrhizal genera with *Glomus* (54.96%) as most abundant and widespread, followed by *Gigaspora* (27.84%), *Acaulospora* (10.50%) and *Scutellospora* (6.71%). In a study realized on coffee and cardamom in India, [43] identified a large number of the AMF spore where the species *Glomus fasciculatum* were the most abundant, followed by *G. geosporum* and *G. mosseae*. Furthermore, [51] mention a particularity of plantain, that because of the constraints of multiplication, the growth phases of each plant, although synchronous during the juvenile phase of the plantation, reach increasing degrees of heterogeneity as the generations progress. [33] revealed in the Kisangani Forest region the cultivar effects on the AMFs spores with means of AMF spore's number, whose Libanga likale (36.79 ± 32.99 spores), Tala lola (33.07 ± 31.56), Libanga lifombo (32.05 ± 23.39 spores), and Akoto (22.56 ± 21.95); those less represented were Egbeomabese, Libanga liabokaykay, Libanga noir and Pita 21. Statistical analyses showed a significant difference for spore density in relation to the cultivars (Akoto, Libanga lifombo, Libanga likale and Tala lola (p -value <0.001)).

4.4 Abundance and Diversity of Mycorrhizal Spores in Vigorous and Non-vigorous Plantain plants

In both agrosystems (home-garden and agroforestry) vigorous plantain plants performed well in terms of mycorrhizal abundance and taxa compared to non-vigorous plantain plants. Differences were significant between the first four genera (*Glomus*, *Gigaspora*, *Acaulospora* and *Scutellospora*), and a non-significant difference for the last genus (*Entrophospora*). [32] found in forest, fallow and home garden agrosystems in the Kisangani Forest region, more mycorrhizal spores in the soil where vigorous plantain plants were growing than in soil with non-vigorous plants. However, it is difficult to assess separately the mycorrhizal influence on the vigor of harvested plantain fruits, especially since [50] mentioned that the strains that colonize plantain roots are not the most important for yield. This was confirmed by other studies [52, 53 and 54]. [55] and [56] have confirmed that mycorrhizae are essential partners in the soil-plant-microorganism relationship and some plants cannot live and grow normally without their

fungal symbiont on which they are highly dependent for growing. In this research, the control of soil fertility level was not observed with rigor, because the home-garden plantain fields were located in rural local conditions. These results confirm by [32] on AMF spores.

4.5 Edaphic Parameters

The correlation between soil physico-chemical elements and mycorrhizal spore genera showed positive and negative effects on all the taxa inventoried. All these correlations were statistically significant. In a study realized in Lubumbashi-DRC, [57] found that soils with a low pH showed a higher mycorrhizal colonization rate, 53% at pH 5.8, than soils with high pH, 47% at pH 6.2 and 25% at pH 6.5. The same authors mention that a soil pH of 5.8 leads to a higher frequency of AMF colonization, a higher common beans plant height, a higher number of leaves per plant and a higher leaves chlorophyll than for a soil pH 6.2 or 6.5. This suggests that soil acidity increases mycorrhizal activity. These results are not in agreement with this research which showed the high presence of mycorrhizal spores in home gardens with a soil pH 6.8 where soils are fertile compared to whose a soil pH was 5.2. [58] found under Turkish conditions that the number of AMF spores varied significantly with soil texture: clay soils had more AMF spores than sandy soils. The same authors mention a negative effect of pH, CaCO_3 and K_2O on the AMF spores' number in bulbous crops, a significant and positive effect of organic matter, total nitrogen, phosphorus, zinc and soil texture on mycorrhizal root colonization of all studied species. [59] reported low AMF spore abundance in soils rich in organic matter but [58] mention a variable effect of the organic matter content on the AMF spores number depending on the plant species studied. [60] confirmed that available soil phosphorus is the important factor driver of AMF in abundance and diversity of plant species. [61] showed a positive influence of crop age on the number of AMF spores per unit of soil. Generally, soil organic matter declines during the cropping phase due to high mineralization and limited replacement. The results found in this research confirm the effect of physico-chemical properties of soil on AMF spores.

5. CONCLUSION

This study aimed to determine the influence of agrosystems on the diversity of the Arbuscular Mycorrhizal Fungi (AMF) under plantain to

contribute to the development of efficient biofertilizers in the Kisangani region. The results revealed that mycorrhization promotes the growth of plantains, thus helping to combat food insecurity in the region. In the agrosystems, mycorrhizal activities in the soils showed a high mycorrhizal frequency, with an overall mycorrhizal rate as high as under local conditions. Vigorous plantain plants showed a higher average spore count than non-vigorous plants. Compared to the cultivars, the results were significantly different. The genera of mycorrhizal spores were dominantly *Glomus*, followed by *Gigaspora*, *Acaulospora*, *Scutellospora* and *Entrophospora*. Furthermore, the correlation between physico-chemical elements and mycorrhizal spore genera showed positive and negative effects on all the taxa inventoried. However, the results found on vigorous plantain plants on AMF spores showed the possibility to isolate the performing mycorrhizal strains, the production of plantains in the Kisangani Region of DR Congo.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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ANNEX

Soil analyses	Agroforestry					Homegarden				
	Masako		Simi-Simi			Masako		Simi-Simi		
	VPP	NVPP	VPP	NVPP	Mean	VPP	NVPP	VPP	NVPP	Mean
B.D (g/cm ³)	1,53	1,6	1,23	1,46	1,455	1,6	1,7	1,29	1,29	1,47
pH-H ₂ O	5,4	5,7	5	4,5	5,15	8	7,4	5,8	5,8	6,75
OC(%)	1,4	1	3,1	2,8	2,075	3,8	4,5	2,4	2,4	3,275
P (ppm)	16,6	16,5	17,4	17,2	16,925	17,3	17,7	17,4	17,4	17,45
Sand (%)	77,6	79,7	81,9	81,9	80,275	78,1	85,1	84,5	84,5	83,05
Silt (%)	11,2	16,5	14,9	14,9	14,375	14,9	10,7	12,8	14,9	13,325
Clay (%)	11,2	3,7	3,2	3,2	5,325	6,9	4,3	2,7	4,8	4,675
N (%)	0,21	0,07	0,07	0,14	0,1225	0,42	0,28	0,14	0,07	0,2275
CEC (méq/100g)	5,51	4,41	1,51	7,97	5,94	9,53	10,09	5,59	7,72	8,2325
Al ³⁺ (méq/100g)	0,47	0,88	0,53	0,25	0,5325	0,96	1,03	1,36	1,41	1,19
H ⁺ (méq/100g)	1,81	1,68	3,02	1,12	1,9075	1,7	1,45	1,57	1,36	1,52
E.B (méq/100g)	3,11	2,79	3,35	1,23	2,62	4,21	5,13	1,32	2,18	3,21
H ⁺ +Al ³⁺ (méq/100g)	2,42	2,61	3,58	3,37	2,995	1,86	1,49	1,36	1,84	1,6375

Legend : VPP (Vigorous plantain plant), NVPP (non-vigorous plantain plant), B.D (Bulk density : g/cm³), OC (%) : Organic matter in pourcentage, P(ppm) (Phosphore en parti par million), N (%) : Nitrogen in pourcentage, CEC (méq/100g) : Cations exchanges capacity, Al³⁺ (méq/100g) : Aluminium, H⁺ (méq/100g) : Proton +, E.B (méq/100g) : Exchanges bases, H⁺+Al³⁺ (méq/100g) : Exchanges acidity.

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