Influence of agrosystems on the diversity of mycorrhizae under plantain banana cultivation in the forest region of Kisangani (Tshopo Province, DR Congo)

ABSTRACT

The largest genetic diversity of plantain is found in DRCongo hosts (*Musa* AAB subgroup). Arbuscular mycorrhizal fungi (AMF) are synergistic beneficial organisms with a positive effect on plantains' growth vigor. We determined the influence of plantain-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 were 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 lager 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, Vigor.

1. INTRODUCTION

Plantain is 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 local 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 are often grown as monocultures in homegardens. In other cropping systems (fallow and forest), they are often grown in an intercropping system 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 relation 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 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 masl. 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 masl.

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 for both sites: 20 from the cultivar Libanga lifombo and 20 from the cultivar Libanga likale; both cultivars are false horn types.

In home-gardensfields, 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). Plantains 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, up of the soil, 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 dwarf pseudo-trunk, and a diameter taken at 5 cm height, up of the soil, 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 (%) = (number of fragments roots mycorrhized / the total number of fragments roots) x 100 [37].

- the global intensity of mycorrhization:

  M (%) =(95n5+70n4+30n3+5n2+n1) / total number of fragments [38].

  With n5 representing the number of mycorrhized fragments in class 5, n4 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 by [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 identified

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 (Figure 1).

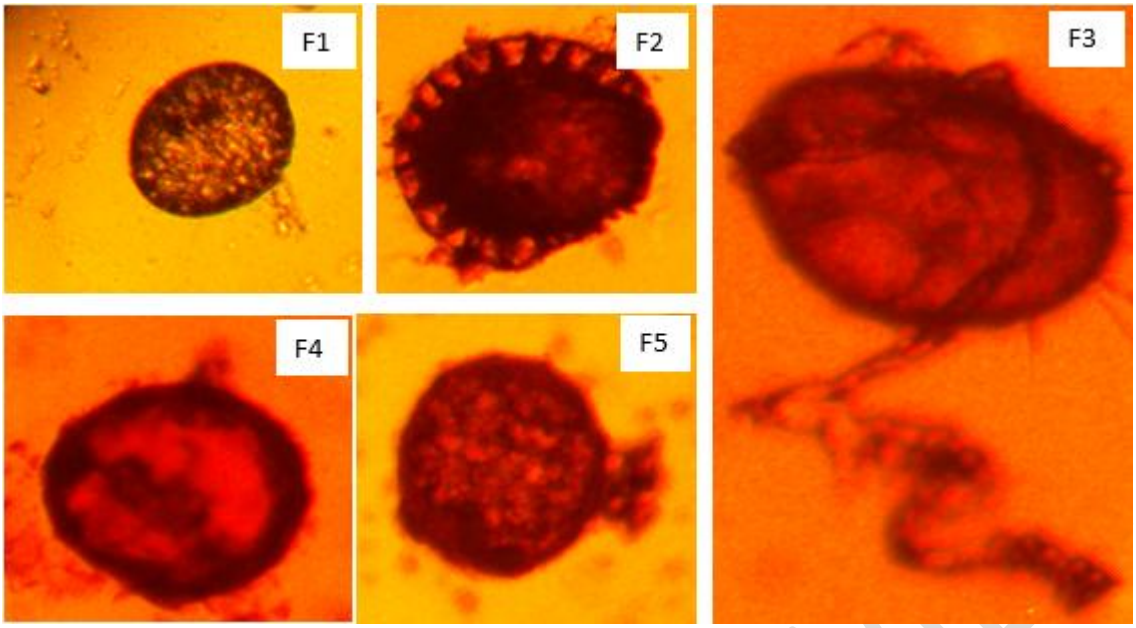

Figure 1. *Mycorrhizal spores of different taxa observed (F1: Gigaspora: size from 200 to 360 µm, shape spherical with hyphae reddish color); (F2: Entrophospora: size from 100 to 250µm characterized by reddish- bright color); (F3: Acaulospora: 100 to 250 µm, shape subglobular with yellow-reddish color) and (F4: Scutellospora: 20 to 100 µm amorphous with reddish form); (F5: Glomus: size 60 to 180 µm. shape spherical ellipsoidal. reddish color).*

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

3.2. AMF spores per genera in the agrosystems studied

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 were non-significant difference between the two agrosystems.

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

Agrosystems	***Glomus***	***Gigaspora***	**Total**

			Acaulospora	*Scutellospora*	*Entrophospora*	
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

3.3. Distribution of mycorrhizal spores by plantain cultivars

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 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* ($p > 0.05$).

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

Cultivars	***Glomus***	***Gigaspora***	***Acaulospora***	***Scutellospora***	***Entrophospora***	**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

3.4. Repartition of AMF spores in Vigorous and Non-vigorous plantain plants

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

Table 3. AMF presence by genus and plantain vigor

Systems	***Glomus***	***Gigaspora***	***Acaulospora***	***Scutellospora***	***Entrophospora***	**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

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 lager Inv-Simpson and Equitability-J index than home-garden plantains (Table 4).

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

3.6. Influence of soil physico-chemical parameters on mycorrhizal genera

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

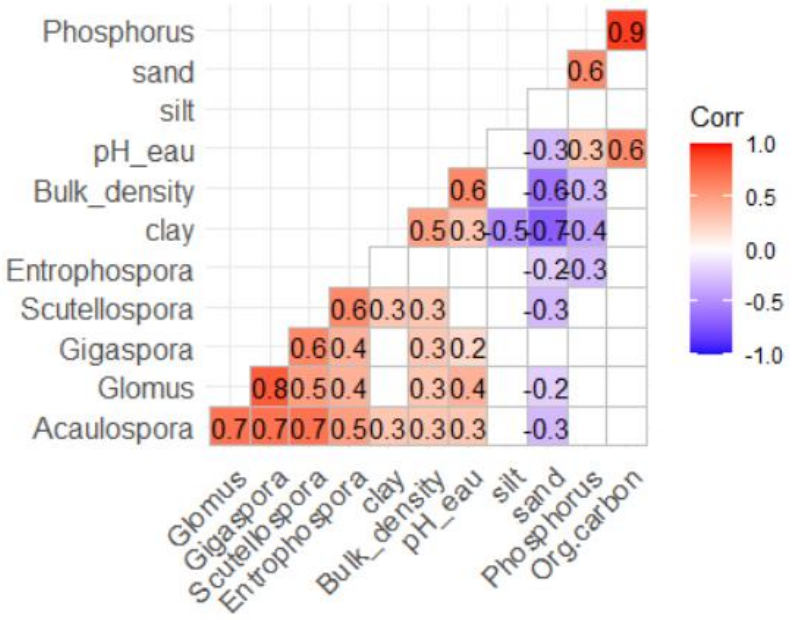

Figure 2. Correlation matrix between soil variables and AMF taxa.

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. geospore* 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 good physico-chemical condition of the soils requires that the home-gardens to be maintained for several years [49], this favourised 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 soil [9]. This research confirms the results found by [32, 49, 9] on the agrosystems effets on AMF spores.

4.3. Mycorrhizal gender and plantains 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 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). Furthermore, in terms of AMF spore diversity, the present research did not reveal evolution over time, as spore

characterization was limited to the genus level. This study confirm the results found by [33] ; that the cultivar effets on AMF spores.

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 level. 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 which found by others on AMF spores. These results confirm which found 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 Agroforestry 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 physico-chemical properties of soil on AMF spores.

5. CONCLUSION

This study aims to determine the taxonomic diversity of AMF under plantains according to two agrosystems, to evaluate the influence of AMF on plantain vigor, to determine the influence of physico-chemical soil parameters on the diversity of AMFs under plantains in the Kisangani region. Thereupon, the roots of vigorous and non-vigorous plantains as well as the soil surrounding these roots were collected for laboratory analysis. 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 would contribute to the increase of the root surface of the plants, especially plantains to increase the production of plantains in the region.

6. REFERENCES

1. Temple, L., Chataigner, J., Kamajou, F. 1996. Le marché plantain au Cameroun, des dynamiques de l'offre au fonctionnement du système de commercialisation, Fruits 51(2): pp.83-98.
2. Dhed'a, D.B., Moango, M.A., Swennen, R. 2011. La culture des bananiers et bananier plantains en République Démocratique du Congo, Support didactique, Media Congo, Saint-Paul, Kinshasa, 88 p.
3. Tutu, T.S., Kasaka, D.L., Ahed'a, G.J., Dhed'a, D.B., Swennen, R. 2020. Growth and yield increases induced by soil cover during the first plantain crop cycle in DR Congo, International Journal of Agricultural Science, 5: pp.25-33.
4. FAOSTAT. 2016. FAO Online statistical database, Food and Agriculture Organization of the United Nations, Rome, Available at: http://faostat,fao,org/(accessed 22 June 2012.
5. INS : Institut National de la Statistique. 2020. Annuaire statistique 2020, Ministère de Plan, INS/commission des études statistiques et des comptes nationaux, 433p.

6. De Langhe, E. 1961. Multiplication végétative accélérée en plantation de plantain «Bosua», Bull, d'info de l'INEAC, pp. 70-87.

7. Adheka, G., Dhed'a, D., Karamura, D., Blomme, G., Swennen, R., De Langhe, E. 2018. The morphological diversity of banana plantain in the Democratic Republic of Congo, Scientia Horticulturae 234:126-133.

8. Lassoudière, A. 2007. Le bananier et sa culture, Edition Quae, pp. 384.

9. Onautshu, O.D. 2013. Caractérisation des populations de *Mycosphaerella fijiensis* et épidémiologie de la cercosporiose noire du bananier (Musa spp.) dans la région de Kisangani (RDC), thèse de doctorat, Louvain-la-neuve en Belgique, 281p.

le Sud de la Côte d'Ivoire. code INRA 1432A : Rapport final de projet de sous-traitance. INRA/IDEFOR-DFAdu 3 février 1992.

10.Kwa, M., and Temple, L. 2019. Le bananier plantain, Enjeux socio-économiques et techniques, expériences en Afrique intertropicale, édition Quae CTA, presse agronomique de Gembloux, 199 p.

11. Swennen, R., Adheka, J., Tutu, T., Tchatchambe, N.B.J., Dhed'a, D. 2019. La culture des bananiers et bananier plantains dans les zones agroécologiques de la République Démocratique du Congo, Chapitre 4, Techniques culturales, Presse universitaire, Unikis, pp. 2-4.

12. Mate, M. 2001. Croissance phytomasse et mineralomasse des haies des légumineuses améliorantes en cultures en allées à Kisangani (RDC), Thèse de doctorat, Université Libre de Bruxelles : pp. 235.

13. Swennen, R., Vuylsteke, D. 2001. Bananier, In : Raekemaekers R.H., eds, Agriculture en Afrique tropicale, DGCI, Bruxelles, Belgique, pp. 611-637.

14. Mérien, E.D. 2013. Quand la ville mange la forêt : les défis du bois-énergie en Afrique centrale, Versailles : Quae, pp. 12.

15. PFBC. 2005. Les forêts du bassin du Congo, une évaluation préliminaire, Partenariat pour les forêts du Bassin du Congo, 39 p.

16. CHN. 2008. Rapport National d'investissement en République Démocratique du Congo, Agriculture et Energie en Afrique, Syrte, Lybie, 11 p.

17. Jaizme-Vega, M.C., and Azcón, R. 1995. Responses of some tropical and subtropical cultures to endomycorrhizal fungi, Mycorrhiza 5: pp.213-217.

18. Gagné-Serge. 2010. Les mycorhizes : Une solution naturelle pour améliorer les rendements des cultures, capter le phosphore et réduire l'érosion, Montréal: Environnement et développement durable, Montérégie, 6 p.

19. D'haene, E. 2015. Increasing soil fertility and agricultural productivity in the north-east of the Democratic Republic of Congo (DRC) through organic fertilization, microdosing and arbuscular mycorrhizae, Thesis, Gent, University Gent, Faculty of Bioscience Engineering, 117 p.

20. Jefwa, J., Vanlauwe, B., Coyne, D., Van Asten, P., Gaidashova, S., Rurangwa, E., Mwashasha, M., Elsen, A. 2010. Benefits and potential use of arbuscular mycorrhizal fungi (AMF) in banana and plantain (Musa spp,) systems in Africa, Acta Horticulturae, 142: pp.479-486.

21.Thienpondt, B. 2016. Increasing soil fertility and crop yield in the Democratic Republic of Congo through implementation of an integrated soil fertility management approach, Faculteit Bio-ingenieurswetenschappen, MSc thesis, Universiteit GENT, 102p.

22. Adamou, S., Ngonkeu, M.E., Nwaga, D., Fokom, R., Tchameni, N.S., Onguene, N.A., Nana, W.L., Chaintreuil, C., The, C., Amougou, A., Moulin, L., Prin, Y., Lebrun, M., Dreyfus, B. 2013. Diversité des champignons mycorhiziens arbusculaires du Cameroun, Université de Yaoundé, Institut de recherche agricole pour le développement, Yaoundé/Cameroun et IRD, UMR 113 CIRAD/INRA/IRD/AGRO-

M/UM2, Laboratoire des symbioses tropicales et méditerranéennes (LSTM), Campus international de Baillarguet, Montpellier, France, pp. 141-154.

23. Makana, M. 1986. Contribution à l'étude floristique et écologique de la forêt à *Gilbertiondendron dewevrei* (De Wild) J, Léonard de Masako (Kisangani), Mémoire, Fac, Des Sciences, Unikis, RRCongo, 62 p.
24. Dudu, A. 1991. Etude du peuplement d'insectivores et rongeurs de la forêt ombrophile de basse altitude du Zaïre (Kisangani, Masako), Thèse de doctorat, UIA, Anvers, 171p,
25. FAO. 1977. Organic materials and soil productivity, Soil bulletin 35, FAO, Rome, 417 p.
26. Girard, M.C., Schvartz, C., Jabiol, B. 2011. Etude des sols, éd : Z,I des Hauts-Sarts-Zone3, Dunod, Paris, 404 p.
27. Bray, R.H., and Kurtz, L.T. 1945. Determination of soil total organic and available phosphorus in soils, Soil Science 59: pp.39-45.
28. Anderson, J.M., and Ingram, J.S.I. 1993. Tropical Soil biology and Fertility: A handbook of methods, CAB International, Wallingford, UK, pp. 95-99.
29. Van Ranst, E., Verloo, M., Demeyer, A., Panverls, J.M. 1988. Manual for the Soil Chemistry and Fertility Laboratory, Analytical methods for soils and plants equipment, and management of consumables, International Training Centre for Post-Graduate Soil Scientists Krijgslaan, University of Ghent, Belgium, 246 p.
30. Mambani, B. 1986. Effect of land clearing by slash burning on soil properties of an Oxisol in the Zairean Bassin, In: Land clearing in the tropics, Lal R, Sanchez PA, Cummings RW Jr (Ed) Balkema, Rotterdam: III: pp. 227-239.
31. UNICEF. 2014. Présentation des méthodes de collecte et d'analyse des données dans l'évaluation d'impact, Centre Innocenti de l'UNICEF, RMIT University, 24 p.
32. Muliwambene, K., Kasaka, D., Onautshu, O., Haesaert, G., Swennen, R., Dhed'a, D. 2020. Agrosystems and mycorrhizae of plantain (Musa AAB subgroup) in the Forest

Region of Kisangani in DR Congo: Abundance and Diversity, Agricultural and Food Science Journal of Ghana 13: pp.1209-1224.

33. Kasaka, D., Onautshu, O., Muliwambene, K., Lebisabo, B., Baert, G., Swennen, R., Haesaert, G., Dhed'a, D. 2021. Importance and diversity of mycorrhizae under plantain cultivation in the slash-and-burn and non-burn cropping systems in the forest region of Kisangani, Tshopo Province, D.R.Congo, African Journal of Agricultural Research 17(6): pp.809-821.

34. Guizon, A.H, and Selosse, M.A. 2010. Coloration des mycorhizes, Pédagogie lycée et post bac, Biologie géologie n°4, Université de Montpellier II, France, 6 p.

35. Hamid, A., and Collion, A. 2004. Etude microbiologique de quelques sols des forêts sclérophylles de Nouvelle-Calédonie, Laboratoire de biologie et physiologie végétales appliquées, rapport de recherche de l'Université de la Nouvelle–Calédonie, Nomea, Convention PCFS-UNC, N°41/2004/CP, 23 p.

36. Trouvelot, A., Kough, J.L., Gianinazzi-Pearson, V. 1986. Mesure du taux de mycorhization d'un système radiculaire, Recherche de méthodes d'estimation ayant une signification fonctionnelle, In : Physiological and genetical aspects of mycorrhizae, INRA édition, Paris, pp. 217-221.

37. Marx, D.H., Hatch, A.B., Mendicino, J.F. 1977. High soil fertility decreases sucrose content and susceptibility of loblolly pine roots to ectomycorrhizal infection by *Pisolithus tinctorius,* Canadian journal of Botany, 55: pp.77-185.

38. Zézé, A., Ouattare, B., Brou, C.Y., Van Tuinen, D., Diallo-Ottah, H., Sangare, A. 2007. Distribution et abondance de spores de champignons endomycorhizogenes à arbuscules dans différents types des forêts de la tene à Côte d'Ivoire, Laboratoire d'Agronomie, Ecole Supérieure d'Agronomie, Institut National Polytechnique, Yamoussoukro ; Université Abobo-Adjamé, UFR Sciences Naturelles, Côte

d'Ivoire ; Unité Mixte de Recherche INRA/Université de Bourgogne, Biochimie, Biologie Cellulaire et Ecologie des Interactions Plantes/Microorganismes, CMSE-INRA, Dijon, France ; Laboratoire de biotechnologies, Centre National de la Recherche Agronomique, 9p.

39. Phillips, J.M., Hayman, D.S. 1970. Improved procedures for clearing and staining parasitic and vesicular arbuscular mycorrhizal fungi for rapid assessment of infection, Trans, Br, Mycol, Soc 55: pp.158-161.

40. Gerdemann JW and Trappe (1975). Vesicular-arbuscular mycorrhizae, In: The development and function of roots, Eds, J G Torrey and DT Clarkson, Academic Press, London, UK, pp. 575-591.

41. Omar, M.B., Bolland, L., Heather, W.A. 1979. A permanent mounting medium for fungi, Bull, Br, Mycol, Soc 13: pp.31-32.

42. Schenck, N.C., and Pérez, Y. 1987. Manual for the identification of Vesicular Arbuscular mycorrhizal fungi, 1st ed: INVAM, University of Florida, Gainesville, 245p.

43. Lakshmipathy, R., Balakrishna, A.N., Bagyaraj, D.J. 2012. Abundance and Diversity of Arbuscular mycorrhizae fungi across a gradient of land use intensity and their seasonal variations in Niligiri Biosphere of the Western Ghats, India, J, Agr, Sci, Tech, 14: pp.903-918.

44. Miransari, M., Khavazi, K., Rejali, Segiun, P. 2007. Effects of carrier, sterilisation method, and incubation on survival of *Bradyrhizobium japonicum* in soybean (*Glycine max* L,) inoculants, Enzyme and Microbial Technology 41(6-7): pp.780-784.

45. Gamalero, E., Trotta, A., Massa, N., Copetta, A., Martinotti, M.G., Berta, G. 2004. Impact of two fluorescent Pseudomonads and an arbuscular mycorrhizal fungus on tomato plant growth, root architecture and P acquisition, Mycorrhiza 14 (3): pp.185-192.

46. Das, K., Dang, R., Shivananda, T.N., Sekeroglu, N. 2007. Influence of bio-fertilizers on the biomass yield and nutrient content in *Stevia rebaudiana* Bert, grown in Indian subtropics, Journal of Medicinal Plants Research 1(1): pp.5-8.

47. Sunisa, J., Kanokkorn, S., Pornpairin, R., Suphachai, A. 2020. Arbuscular mycorrhiza fungi applications and rock phosphate fertilizers enhance available phosphorus in soil and promote plant immunity in robusta coffee, Soil Science and Plant Nutrition, 67(1-5): pp. 97-101.

48. Tshibangu, K.A., Lwalaba wa Lwalaba, J., Kirika, K.B., Mavungu, M.J., Manda, K.G., Iband, K.M., Baert, G., Haesaert, G., Mukobo, R-P, Mukobo, M.P.R. 2021. Effect of phoshorus and Arbuscuar mycorrhizae fungi (AMF) Inoculation on Growth and Productivity of Maize (Zea maysL) in a tropical Ferralsol, Genunde pflanzen, https://doi.org/10.1007/s10343-021-00598, 8 p.

49. Osseni, B. 1993. Etude des systèmes agroforestiers comportant le bananier plantain dans

50. Declerck, S., Plenchette, C., Strullu, D.G. 1995. Mycorrhizal dependency of banana (*Musa acuminata* AAA group) cultivar, Plant and Soil 176: pp.183-187.

51. Adriano-Anaya, M., Solis-Dominguez, F., Gavito-Pardo, M.E., Salvador-Figueroa, M. 2006. Agronomical and environmental factors influence root colonization, Sporulation and diversity of arbuscular mycorrhizal fungi at a specific phenological stage of banana trees, Journal of Agronomy 5: pp.11-15.

52. Sidibe, K., Yossi, H. 1997. Effet de l'âge de la jachère sur le nombre de spores de champignons endomycorhiziens en zone soudanienne du Mali, In : Floret C, ed. Jachère et Maintien de La Fertilité, CORAF, Bamako : pp. 69-76.

53. Duponnois, R., Bâ, M.A., Plenchette, C., Thioulouse, J., Cadet, P. 2000. Effets de la jachère sur des populations de champignons mycorhiziens à arbuscules au Sénégal,

In: Floret C., Pontanier R, eds. La Jachère en Afrique Tropicale, Session 3, John Libbey Eurotext, Paris, pp. 325-332.

54. Dandan, Z., Zhiwei, Z. 2007. Biodiversity of arbuscular mycorrhizal fungi in the hot-dry valley of the Jinsha River, southwest China, Appl, Soil Ecol, 37 (1-2): pp.118-128.

55. Lachance. 2012. Les mycorhizes en étroite relation avec les racines des plantes, Cultures en santé supérieure, https://www,google,com/search;http://www.maraibio,fr.

57. Tshibangu, K., Ngoy, S., Baert G., Haesaert G., Mundende, M. 2020. Effet of soil properties on Arbuscular Mycorrhizae Fungi (AMF) Activity and Assessment of some Methods of Common bean (Phaseolus vulgaris L.) Inoculation in Lubumbashi region (DRCongo), Crops Sciences, 6(8): pp.198-207.

58. Karaarslan, E., Uyanöz, R., Doğu, S. 2015. Morphological identification of vesicular-arbuscular mycorrhiza on bulbous plants (Taurus Mountain in Turkey), Archives of Biological Sciences 67(2): pp.411-426.

59. Sheikh, N.A., Saif, S.E., and Khan, A.G. 1975. Ecology of Endogone II. Relationship of endogone spore population with chemical soil factors, Islamabad J. Sci. 2: pp.6-9.

60. Garo, G., Van Geel, M., Fassil, E., Swennen, R., Honnay, O., Vancampenhout, K. 2021. Arbuscular mycorrhizal fungus communities and their response to soil phosphorous differ between wild and domesticated enset (*Ensete ventricosum*) in Southern Ethiopia, Rhizosphere, Vol. 20; pp. DOI: 10.1016/j.rhisph.2021.100444

61. Lovelock, C.E., Andersen, K., Morton, J.B. 2003. Arbuscular mycorrhizal communities in tropical forests are affected by host tree species and environment, Oecologia 135(2): pp.268-279.

Annex

	Agroforestry					**Homegarden**				
	Masako		**Simi-Simi**			**Masako**		**Simi-Simi**		
Soil analyses	**VPP**	**NVPP**	**VPP**	**NVPP**	**Mean**	**VPP**	**NVPP**	**VPP**	**NVPP**	**Mean**
B.D (g/cm3)	1,53	1,6	1,23	1,46	**1,455**	1,6	1,7	1,29	1,29	**1,475**
pH-H_2O	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	5,51	4,41	1,51	7,97	**5,94**	9,53	10,0	5,59	7,72	**8,23**

(méq/100g)							9			**25**
Al^{3+} (méq/100g)	0,47	0,88	0,53	0,25	**0,53 25**	0,96	1,03	1,36	1,41	**1,19**
H^{+} (méq/100g)	1,81	1,68	3,02	1,12	**1,90 75**	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	**2,99 5**	1,86	1,49	1,36	1,84	**1,63 75**

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, Al^{3+} (méq/100g) : Aluminium, H^{+} (méq/100g) : Proton +, E.B (méq/100g) : Exchanges bases, $H^{+}+Al^{3+}$(méq/100g) : Exchanges acidity.