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Effect of maize and peanut crops on Ivory Coast northern soil biological activities and their response to arbuscular mycorrhizal fungi inoculation

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The overuse of chemical fertilizers in agriculture remains an environmental concern, especially in sub-Saharan areas of Africa where soil degradation lead to low crop yield. Crop inoculation with beneficial microorganisms appears a good alternative to reduce chemical substances and improve yield. In this regard, studies on soil biological activities and inoculation experiments on maize (*Zea mays* L.) and peanut (*Arachis hypogaea* L.) crops were conducted. The aim of this work was to evaluate the effect of these crops on soil microbial activities and to assess their response to inoculation with two fungi (*Glomus aggregatum* and *Glomus etunicatum*) alone or in combination. Rhizospheric and non rhizospheric soils were collected in peanut and maize fields at Takali in northern Côte d'Ivoire. Soil enzymes activities, total microbial biomass, AMF spore and rhizobia densities were determined in these soils. Then, mycorrhizal inoculation experiment of these plant species was conducted in a greenhouse located at Nangui Abrogoua University, Abidjan, Côte d'Ivoire. After three months, plant growth and yield, mycorrhizal and nodulation parameters were measured. Results showed that maize has significantly improved enzymes activities, spore density and total microbial biomass of soil. Effect of peanut was only significant on chitinase. Moreover, soil rhizobia density was reduced under this crop effect. Maize significantly improved these parameters more than peanut. Inoculation results showed a significant enhancement of the height and shoot dry weight of maize with single inoculation with *G. aggregatum* or *G. etunicatum* even if a low mycorrhization rate was observed. However, in peanut, the mixed inoculants (*G. aggregatum* + *G. etunicatum*) significantly increased the pod weight and nodulation parameters. Results showed the importance of plant cover in the improvement of soil biological quality including enzymes activities and microbial community and suggested that the effect of mycorrhizal inoculation is influenced by many factors as plant species, AMF and soil environment characteristics.

Key words: *A. hypogaea*, *Z. mays*, soil enzyme activities, microbial biomass, soil microorganisms' density, mycorrhizal inoculation.

INTRODUCTION

For developing countries, the economy of Côte d'Ivoire is based primarily on agriculture and more than 50% of population lives mainly from this activity, which confirms its importance for food security (Kouakou et al., 2010). Maize and peanut are two foods crops that are sources of income for local population, which the main growing area is Korhogo in northern country. Maize *(Zea mays* L.) is a cereal, belonging to grass family (Kellogg, 2001), cultivated for its carbohydrate-rich seeds. It is the third most cultivated cereal in the world after rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.).

Indeed, world food security depends on ample supply of these three major cereals (Ferrar, 1995). It's used in both human and animal feed. Peanut (*Arachis hypogaea* L.) is a legume grown for its high protein and oil content. Its fatty and amino acid composition and its taste and flavor are important features attributed (Asibuo et al., 2008). It is considered to be one of the most important oilseed crops worldwide. This plant is also cultivated in rotation to improve the nitrogen content of the soil and thus contributes to its fertility.

However, in northern Côte d'Ivoire, crop yields remain low and environmental concerns caused by, the expensive chemical fertilizers (Dobermann and Cassman, 2004) support researchers for new sustainable strategies to promote soil fertility and thereby, improve crop production. In this context, exploitation of soil microbial communities such as arbuscular mycorrhizal fungi (AMF), to improve food quantity and quality (Barea, 2015), has been considered as safe, inexpensive and environmentally friendly.

AMF establish a mutual relationship with plant roots which benefit from water and nutrients that fungus collects in soil; in turn it feeds on carbon allocated by plant (Parniske, 2008). They contribute to the mineral nutrition of plants even during drought and other environmental stress (Martínez-García and Pugnaire, 2009; Martínez-García, 2010). Several studies have demonstrated the stimulatory effect of these symbiontes on growth parameters in grasses and legumes (Smith et al., 1998) and in decomposition of organic matters. Positive effects of AMF and phosphorus application were observed on the growth and phosphatase activities of peanut (Doley and Jite, 2012).

In the same way, Mustafa et al. (2010) found beneficial effect of inoculation with *Glomus mossae* on growth parameters of maize. Others stimulatory effects of these fungi in ecosystems by, governing a large number of crucial soil processes including soil nutrient biochemical cycling, decomposition of litter and the establishment of soil living components were also demonstrated (Chen et al., 2015). These beneficial effects are due mainly to enzymatic complex such as phosphatase, which participates to organic phosphorus decomposition and improves soil phosphorus concentration that is, an important index to assess soil phosphorus bioavailability (Panettieri et al., 2014).

Bacteria and fungi are the main source of enzymes in the soil which constitute the largest fraction of soil organisms in terms of biomass and number and the main factor influencing litter decomposition in soil (Berg and McClaugherty, 2014). Their activities are particularly relevant at the root–soil interface microhabitats known as the rhizosphere, where microorganisms are stimulated by carbon substrates provided by plant rhizodeposits (Hirsch et al., 2013). Compared to bulk soil, the rhizosphere soil is characterized by higher concentrations of nutrients and labile organic C (Duineveld et al., 2001). Therefore, controlling the components in agricultural soils is a crucial feature of the biological components of these soils, as a vital aspect of sustainable crop farming system (Malherbe and Marais, 2015).

However, these beneficial actions of AMF are difficult to generalize because plant response to mycorrhization depends on several parameters such as AMF species, plant and the environmental conditions (Rodríguez-Echeverria et al., 2016). Moreover, studies on soil enzymes activities are concentrated on temperate areas; and very few data are available in tropical environment in the literature (Acosta-Martinez et al., 2007). So far, no studies have been carried out on the inoculation of maize and peanut with AMF strains and on enzymes activities under crop influence, in Côte d'Ivoire, are more accurately in Korhogo area. The aim of this study is not only to assess the impact of peanut and maize crops on soil enzymes activities and total microbial biomass, but also to evaluate the effect of two arbuscular mycorrhizal fungi (*Glomus aggregatum* and *G. etunicatum)* on growth parameters and yield of these crops.

MATERIALS AND METHODS

Soil sampling

Soils used for the biological activities were collected in October 2016, in peanut and maize monoculture fields in Takali (9°25 N; 5°35 W) located in Korhogo in northern Côte d'Ivoire. For each crop, a composite sample of rhizospheric soil under maize or peanut was collected by removing five plants and shaking the soil surrounding of the roots. Composite soil used as control was also

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collected on bulk without any vegetation.

These soils were used to study biological activities beneathmaize and peanut. For a greenhouse experiment, another soil collection was done at ten points of the plot, to obtain a representative composite soil sample of the targeted plot. Physical and chemical parameters of this composite soil were determined at the Centre de Recherche en Océanographie (CRO) of Abidjan, Côte d'Ivoire. The pH (water) was measured in the supernatant of a soil / distilled water mixture in a ratio of 1:2.5.

Organic and mineral matters content were determined according to Moreno et al. (2001). Contents of total nitrogen (N) and phosphorus (P) were quantified according to Bremner (1960) and Sherrell and Saunders (1966), respectively by atomic absorption spectrometer after digestion with concentrated sulfuric acid. Potassium (K) was analyzed by means of argon plasma ionization source mass spectrometer (ICP-MS) according to Rao and Talluri (2007) method.

Soil biological activities

AMF spore density in rhizospheric and non rhizospheric soils was determined by, counting after extraction through moistening sieving method as described by Gerdeman and Nicholson (1963). The number of rhizobia was evaluated by the most probable number plant infection (MPN) method of Brockwell (1980) and siratro (*Macroptilium atropurpureum*) was used as trap plant. It consists of dilute soils used to inoculate siratro seedlings with soil suspension.

Four enzymes activities: acid phosphatase, β-glucosidase, fluorescein diacetate (FDA) and chitinase were assayed in rhizospheric and non rhizospheric soils collected in fields of peanut and maize. For each enzyme activity, three replicates were carried out. Acid phosphatase activity was measured according to Tabatabai and Bremner (1969) method. Soils were incubated with modified universal buffer (pH 6.5) and *p*-nitro-phenyl-phosphate substrate at 37°C under stirring during 1 h. Reaction was stopped with $CaCl_2$ (0.5 M) and NaOH (0.5 M) and the supernatant was taken and assayed in spectrophotometer at 400 nm.

β-glucosidase was evaluated according to Hayano (1973), the substrate used was *p*-nitro-phenyl-β-glucopyranoside. Soils were also incubated with substrate and citrate phosphate buffer (pH 5.8) during 2 h at 37°C under stirring. After incubation, the reaction was stopped with Na_2CO_3 (0.2 %), mixed and the optic density was read also at 400 nm. FDA activity was determined as described by Adam and Duncan (2001) in presence of potassium phosphate buffer (pH 7.6) and fluorescein diacetate substrate. After 1 h of incubation at 30°C under stirring, reaction was stopped by addition with 1 mL of pure acetone, mixed and centrifuged. Then, 1 mL of supernatant was taken and assayed at 490 nm.

For chitinase activity, soils were incubated with acetate buffer (pH 5.5) and substrate *p*-nitro-phenyl-β-glucosaminide during 1 h under stirring and stopped by addition of $CaCl_2$ (0.5 M) and NaOH (0.5 M) (Parham and Deng, 2002). Results were reported in µg of product released per hour and gram of dry soil following µg /h/g.

Soil total microbial biomass was also determined according to the fumigation-extraction method as described by Amato and Ladd (1988). Two extractions to KCl were done at T0 (extraction before fumigation) and T10 (extraction after fumigation). For T0 extraction, soils were incubated in the presence of KCl under stirring and after decantation; the supernatant was taken and stored at -20°C for colorimetric analysis. Before T10 extraction, fumigation is previously done. It is intended to kill all living microorganisms in the soil and targeted to incubate soils in presence of chloroform vapors at obscurity. After 10 days of incubation, the extraction to KCl was done as in the case of samples T0. Total biomasses in carbon (C), ammonium (NH_4^+) and nitrate (NO_3^-) were measured in these samples.

Fungal inoculum preparation

Fungal inoculum *G. aggregatum* and *G. etunicatum* were supplied by the Laboratoire Commun de Microbiologie IRD/ISRA/UCAD of Dakar, Senegal. *G. aggregatum*(Schenck and Smith emend. Koske; DAOM 227 128) was isolated from Djignaki (Senegal) and *G. etunicatum* from Dijon (France). These strains were chosen for their performance in an efficiency test on many plants (Kruger et al., 2012). They were isolated and multiplied on sterile soil, poor in phosphorus with maize as trap plant under greenhouse conditions.

Three months after cultivation, roots were harvested and mycorrhizal inoculums were prepared as described by Plenchette et al. (1989). Each inoculum of fungi consists of sand, spores, hyphae and mycorrhizal root fragments. It contained an average of 40 spores per gram of soil and roots fragments with 80% of colonization (Guissou et al., 1998). The mixed inoculum was obtained by a mixture of equivalent quantities of the two fungi and contained approximately the same spore's number and infective propagules of each fungal species.

Greenhouse inoculation test

The inoculation experiment was conducted in a greenhouse (5°23 N to 4°0 W) located at the University of Nangui Abrogoua (UNA) in Abidjan, Côte d'Ivoire during three months (from October to December 2016). The average temperature and humidity were 31.2°C and 38.80%, respectively during the day and 26°C and 62.5% at night.

Seeds of maize CNRA-GMPR-18 and peanut CNRA-ara 8-20 varieties were provided by the *Centre National de Recherche Agronomique* of Abidjan. These two varieties have a short cycle of 90 days. Peanut seeds were surface-scarified in 70% calcium hypochlorite solution ($CaCl_2O_2$) for 8 min and then rinsed several times with sterile water (Gottardi and Nagl, 1998). The maize seeds were surface-sterilized in 20% bleach for 10 min and rinsed several times with sterile water, allowed to soak for 30 min (Hite et al., 1999). They were then pre-germinated in Petri dishes containing 0.9% agar and incubated for 72 h at 28°C in the dark (covered with aluminum foil) in an oven.

The pre-germinated seedlings were transferred into plastic bags containing about 1 kg of non-sterile soil moistened slightly with tap water. For each plant species (maize or peanut), four inoculation treatments were applied: inoculation with *G. aggregatum* (Ga), *G. etunicatum* (Ge), mixed inoculum (Ga+Ge) and control without inoculum. Also, for each treatment, 9 replicates were performed in a completely randomized block. The inoculation was done at sowing with 20 g of fungal inoculum. Mixed treatment consists in inoculating seedlings with 10 g of Ga and 10 g of Ge. Plants were watered every day to maintain soil water content close to field capacity during 3 months.

The height of plants was measured every two weeks during experimentation and after three months of cultivation, they were harvested. Shoot, root and total weights of peanut and maize plants were obtained after drying at 70°C for 48 h. Before drying the peanut roots, the fresh nodules and pods of each plant were detached, counted and weighed separately. Frequency and intensity of mycorrhization of peanut and maize roots were determined according to Phillips and Hayman (1970) method. For that, roots were previously rinsed with tap water and placed in tubes containing 10% KOH. The tubes were then boiled in a water bath at 90°C for 60 min.

This step makes it possible to empty the cytoplasm content of

Table 1. Soil enzymes activities beneath maize and peanut crops.

Plants species	β-Glucosidase (µg p-Np/h/g)		Chitinase (µg p-Np/h/g)		Phosphatase (µg p-Np/h/g)		FDA (µg fda/h/g)	
	RS	NRS	RS	NRS	RS	NRS	RS	NRS
Maize	51.09±7.43^{aB}	40.65±0.78^{a}	3.90±0.76^{bB}	1.60±0.21^{a}	214.35±19.13^{bB}	134.76±18.38^{a}	99.47±17.33^{aA}	73.57±12.93^{a}
Peanut	32.27±7.47^{aA}	31.17±5.90^{a}	1.37±0.21^{bA}	0.82±0.21^{a}	129.53±34.38^{aA}	117.23±13.35^{a}	94.86±17.04^{aA}	67.86±9.52^{a}

RS: rhizospheric soil; NRS: non rhizospheric soil. For each enzyme activity and plant species, in column, values following with the same minuscule letter for RS and NRS or with the same majuscule letter for RS are not significantly different according to student test t ($p<0.05$).

Table 2. Soil physical and chemical characteristics.

Parameter	Values
pH	5.25
Organic matters (%)	4.23
Mineral matters (%)	2.53
Total nitrogen (mg/kg)	1.01
Total phosphorus (mg/kg)	4.57
Potassium (mg/kg)	244.27

the cells and to facilitate the coloration. The roots were rinsed abundantly with tap water to remove KOH, and then stained with 0.05% trypan blue which is brought to water bath at 80°C for 30 min. For each sample, root fragments of about 1 cm were mounted between slide and cover slide crushed in 20% glycerol and observed under a microscope. Estimation of root colonization by AMF was carried out using the method of Trouvelot et al. (1986) according to a rating system based on 6 classes. Mycorrhizal frequency (F %) and intensity (I %) were measured as follows:

F % = (number of mycorrhizal fragments / total number of fragments observed) × 100

Where (F %) is the frequency of mycorrhization reflecting the importance and the percentage of fragments of infected roots, with n as the total number of root fragments observed.

I% = (95n5 + 70n4 + 30n3 + 5n2 + n1) / total number of fragments observed

Where (I%) is the intensity of the cortex colonization expressing the portion of the cortex colonized with respect to the entire root system, with n5, n4,…, n1 as the number of fragments, respectively, denoted as 5, 4,…, 1.

Data analysis

The data obtained were analyzed using the XLSTAT 2010 software. The means values of different parameters were compared by the ANOVA according to the Student Newman Keuls test ($p<0.05$) for the inoculation test. Percentage data of root mycorrhizal colonization were arcsine transformed prior to analysis. Analyses were performed separately for each plant species.

For soil biological activities, data were performed with test t of Student for two independent samples. The comparison was done between rhizospheric and non rhizospheric soils for each parameter and plant species.

The aim of this test was to evaluate the impact of crop of maize or peanut on the parameters studied. Another comparison was assayed between the two crops in order to know the crop which has improved most of these parameters.

RESULTS

Crop effect on soil enzymes activities

Soil enzymes activities are more important in rhizospheric (RS) than in non rhizospheric soils (NRS) for all activities measured (Table 1). Indeed, chitinase activities were significantly improved both in beneath peanut and maize crops, respectively by 67.07 and 143.75% compared to non rhizospheric soils.

Acid phosphatase was significantly increased in RS with maize by 59.06% but not with peanut. However, there was no significant difference between RS and NRS regarding FDA and β-glucosidase. Compared to peanut, maize crop significantly improved β-glucosidase, chitinase and phosphatase activities, respectively by 58.32, 184.67 and 65.89% except FDA. Results on soil physical and chemical characteristics are given in Table 2.

Impact of plant crops on total microbial biomasses, and AMF spores and rhizobial densities

Results presented in Table 3 showed that similarly to enzyme activities, maize crop (RS) significantly improved total microbial biomasses C, NH_4^+ and NO_3^-

Table 3. Soil total microbial biomass beneath maize and peanut crops.

Parameter	Biomass C(µg C/g)		NH_4^+ (µgN-NH_4^+/g)		NO_3^- (µgN-NO_3^-/g)	
	RS	NRS	RS	NRS	RS	NRS
Maize	23.50±0.50^{bB}	11.50±0.50^{a}	1.40±0.20^{bB}	0.77±0.12^{a}	7.77±1.15^{bB}	3.10±0.46^{a}
Peanut	14.00±2.00^{aA}	17.33±1.61^{a}	0.90±0.01^{aA}	0.93±0.15^{a}	3.93±0.64^{aA}	4.50±0.26^{a}

RS: rhizospheric soil; NRS: non rhizospheric soil. For each parameter and plant species, in column, values following with the same minuscule letter for RS and NRS or with the same majuscule letter for RS are not significantly different according to student t test ($p<0.05$).

Table 4. Densities of AMF spores and rhizobia in soil beneath maize and peanut crops.

Number	Spores/50g of soil		Rhizobia/g of soil	
	RS	NRS	RS	NRS
Maize	1180±67.02^{bB}	917.67±143.49^{a}	ND	ND
Peanut	1036±47.03^{aA}	871.33±69.24^{a}	8.1 10^{3a}	1.08 10^{4a}

RS: rhizospheric soil; NRS: non rhizospheric soil. For each density and plant species, in column, values following with the same minuscule letter for RS and NRS or with the same majuscule letter for RS are not significantly different according to student test t ($p<0.05$).

Table 5. Plant growth parameters of maize and peanut inoculated with arbuscular mycorrhizal fungi.

Plant species	Treatment	Plant growth				Pods yield	
		Height (cm)	SDW (g)	RDW (g)	TDW (g)	Number	Weight (g)
Peanut	Ga	34.06±6.24^{a}	3.16±0.63^{a}	0.46±0.12^{a}	3.62±0.73^{a}	1.44±0.53^{a}	2.1±0.52^{a}
	Ge	37.26± 5.04^{ab}	3.91±1.11^{a}	0.67±0.22^{b}	4.58±1.26^{a}	2.11±0.67^{a}	3.78±1.06^{b}
	Ge+Ga	42.80±5.95^{b}	4.29±0.97^{a}	0.70±0.12^{b}	4.99±1.03^{a}	2.22±0.88^{a}	4.0±1.28^{b}
	Control	38.33±2.86^{ab}	4.00±0.94^{a}	0.71±0.14^{b}	4.72±1.05^{a}	1.44±0.52^{a}	2.15±0.61^{a}
Maize	Ga	66.7±8.14^{b}	2.45±0.70^{ab}	1.05±0.35^{a}	3.50±1.03^{a}	-	-
	Ge	65.61±6.7^{b}	2.59±0.48^{b}	1.44±0.30^{a}	4.03±0.75^{a}	-	-
	Ge+Ga	61.26±3.45^{ab}	2.24±0.22^{ab}	0.92±0.19^{a}	3.16±0.35^{a}	-	-
	Control	59.56±5.03^{a}	1.91±0.48^{a}	0.86±0.32^{a}	2.77±0.74^{a}	-	-

For each plant in column, Values following by same letters are not significantly different according to student Newman-keuls test ($p<0.05$). Ga: Glomus aggregatum; Ge: Glomus etunicatum.

two times, compared to non rhizospheric soils (NRS). In contrary, peanut negatively affect these parameters, but any significant difference was observed.

Same trends were also observed with AMF spore density which was significantly improved under maize crop influence by 28.68%, compared to non rhizospheric soil and by 13.90% compared to peanut soils (Table 4). Peanut crop also increased AMF spore density by 18.94% compared to NRS.

However, surprisingly rhizobial density was decreased from 1.08 10^4 to 8.1 10^3 Rhizobia/g (25% discount) by peanut crop even if there was no significant difference.

Effect of mycorrhizal inoculation on crop growth and yield

Results showed that pods weight of peanut was significantly increased by 86.05% in mixed inoculums (Ga + Ge) compared to the non-inoculated control (Table 5). The pods weight was nearly two times higher in plants inoculated by Ge alone and the mixed (Ga + Ge). However, plant height, shoot, root and total dry weight and pods number were not significantly improved in comparison with control. The peanut root dry matter of plants inoculated with Ga was lower than non-inoculated control.

With maize plants, significant increase was obtained when plants were inoculated alone with Ge (10.16%) or Ga (12%) (Table 5). The cocktail of the two inocula had no significant effect on maize plants. Maize shoot dry weight (SDW) was improved by fungal inoculation with a significant effect in plants inoculated with Ge (35.60%) in comparison to the control. In contrast, root dry weight (RDW) and total dry weight (TDW) were not significantly improved by AMF inoculation.

Table 6. Nodulation and mycorrhization parameters.

Species	Treatment	Nodulation		Mycorrhization	
		Nod. Number	Nod. Weight (mg)	Frequency (%)	Intensity (%)
Peanut	Ga	60.00±8.41[a]	143.00±8.92[a]	7.22±2.54[a]	0.13±0.06[a]
	Ge	70.11±12.1[b]	166.50±9.97[b]	8.89±2.55[a]	0.16±0.02[ab]
	Ge+Ga	78.78±6.94[b]	186±12.54[b]	10±2.89[a]	0.24±0.03[b]
	control	72.33±7.47[b]	171.00±11.84[b]	9.44±2.54[a]	0.19±0.06[ab]
Maize	Ga	-	-	11.84±2.38[a]	0.19±0.05[a]
	Ge	-	-	15.41±2.22[a]	0.27±0.08[a]
	Ge+Ga	-	-	10.49±3.08[a]	0.16±0.03[a]
	Control	-	-	10.49±3.08[a]	0.16±0.03[a]

For each plant species, values followed by the same letter in the columns are not statistically different according to student Newmann-Keuls test ($p<0.05$). Mycorhizal values were prior transformed in arcsine before data analysis.

Effect of inoculation on microbial symbiosis

Results of nodulation and mycorrhization parameters are presented in Table 6. Peanut nodulation parameters (nodules number and weight) were not significantly improved by AMF inoculation. Surprisingly, inoculation with Ga significantly decreased the number and fresh weight of nodules compared to the non-inoculated control.

No positive effect of AMF inoculation on mycorrhizal parameters of maize and peanut roots was observed in comparison to non-inoculated control. Moreover, treatment Ga significantly decreased the mycorrhizal intensity of peanut roots compared to that of roots inoculated with the mixed treatment (Ge+Ga).

DISCUSSION

Plants improve soil biological activities

Enzyme activities were higher in rhizospheric soil beneath maize and peanut compared to non rhizospheric soils. That suggests the importance of plant cover in the soil microbial activities. The rhizosphere is a narrow region of the soil that is directly influenced by root secretions and associated microbial activity, and sustains dense populations of root-associated and free-living microorganisms (Cheng et al., 2014). Thus, biological activity in topsoil and litter layer is not only governed by abiotic factors such as pH, humidity, temperature but also by biotic factors including interaction with microbial biomass (Zhou et al., 2016).

In fact, soil enzymes activities are provided mainly from microorganisms such as soil bacteria and fungi, widely distributed which involved in degradation of organic matter in field soils (Tedersoo et al., 2014; Wardle and Lindahl, 2014). However, maize crop has significantly improved these activities compared to peanut crop, except FDA. These results indicated the importance of incorporating plants of the grass family in a crop system and its influence on soil density microorganisms and their biological activity. Indeed according to Natywa and Selwet (2011), maize produces significant quantities of root exudates secretions that may include amino acids, hydrocarbons, vitamins, organic acids, and enzymes. These substances stimulate the growth and development of microorganisms in the rhizosphere of this plant.

In this study, phosphatase activities were the highest (214.35±19.13 µg p-Np/h/g of dry soil), that can be due to their ability to persist in soils for long periods by binding to soil organic matter and clays (Matus, 2014). The high content of phosphatase in soils may also be due to the poor availability of this element in soils therefore to a high P demand of plants and microorganisms living in soil. In fact, soil physical and chemical analysis revealed that our soils were poor in P with an average value of 4.57 mg/kg of dry soil. These results demonstrate preferentially the development of a mechanism in response to a mineral deficit such as P to produce phosphatase when soil P resources are limited. Our investigations showed also that phosphatase content was significantly higher in maize soil than soil beneath peanut, which may be due to high density of AMF spores in maize soil and a greater secretion of this enzyme by maize roots. In contrary, Maseko and Dakora (2013) have reported that legumes secrete more phosphatase enzymes than cereal which might be explained by a higher requirement of P by legumes in the symbiotic nitrogen fixation process. The amount of acid phosphatase exuded by plant roots has been shown to differ between crop species and varieties (Kidd et al., 2016).

β-glucosidase plays an important role in the degradation of glucose polymer and regulates the supply in glucose; an important carbon energy source for growth and activity of soil microorganisms (Merino et al., 2016). It was significantly higher in rhizospheric soil

under maize compared to that of peanut. These results can be explained also by the high number of AMF spores beneath maize crop compared to that of peanut. In fact, β-glucosidase is derived predominantly from heterotroph fungi (Turner et al., 2002) which require a lot of amount of carbon providing from glucose for the establishment of mycorrhiza (Böhme and Böhme**,** 2006). N-acetyl-β-glucosaminidase or chitinase catalyzes the hydrolysis of chitin, a linear polymer of β-1,4-N-acetylglucosamine units which is abundance next to cellulose.

Chitinase was significantly higher in rhizospheric soils of peanut and maize compared to non rhizospheric soils. This may be attributed to the fact that, the oxidative functional activity of microbial communities in the rhizosphere is higher than that of non rhizospheric soil (Yang et al., 2013). This heightened chitinase activity may be due to the higher carbon resources in the rhizosphere soil, which is considered as the driving force for microbial activity and density as reported by Yang et al. (2013).

Fluorescein diacetate is hydrolyzed by a number of different enzymes, such as proteases, lipases and esterase. This activity was higher in rhizospheric soils of peanut and maize than in non rhizospheric soils but no significant effect was observed. That may be due to the fact that, FDA is hydrolyzed by a non-specific group of enzymes which are widely present in soils (Adam and Duncan, 2001).

In our study, microbial biomasses in carbon, ammonium, nitrate and AMF spores density were significantly higher in soil beneath maize compared to peanut rhizospheric soils. These observations suggest that maize rhizosphere herbages many microorganisms than that of peanut. Indeed, soil microbial biomass is the weight in term of C and N of all living microorganisms in soil and it's recognized as a sensitive indicator of environmental change (Li and Chen, 2004). The occurrence of microorganisms depends on the presence of allopathic compounds secreted by roots as well as mutual interactions between different groups of microorganisms in the soil (Bowles, 2014). Plant-induced differences in microbial communities due to the rhizosphere effect are well established (Hamdan and Kavazanjian, 2016). Thus, plant cover and consequently soil moisture can be an important driver of a soil microbial community (Lange et al., 2014). However, a decrease of these biomasses (C, NH_4^+, NO_3^-) and rhizobia density was found in rhizospheric soil of peanut compared to non rhizospheric soil. This may be due to the fact that rhizobia infect root legume and develop into the roots of their host. These observations may be due to the rhizobia sensitivity to cropping system and to soil acidity (Hungria and Vargas, 2000), whose pH was 5.25 and root exudates secrete acid also. According to Landon (1991), the optimum soil pH for legume plants is between 6.5 to 7.0. Moreover, Moir and Moot (2010) have shown a low persistence of legume species in soils of low pH (pH <5.8).

Plant response to mycorrhizal inoculation

Height and shoot dry weight (SDW) of maize plants were significantly improved by the single inoculation (Ga or Ge). These results are in agreement with other studies which showed that inoculation with AMF improved the growth parameters of plants (Ndoye et al., 2013; Diatta et al., 2014; Sánchez-Roque et al., 2016). This increase of SDW and height of maize plants results in a good mineral nutrition, which can be due to the introduced AM fungi. The lowest values recorded following inoculation with the mixed treatment (Ge+Ga) compared to single treatments with Ga and Ge were found in maize in all parameters. These results corroborated with those of Baxter and Dighton (2001) who suggest that co-inoculation with endomycorrhizal fungal strains does not necessarily improve plant development parameters. The low rate of mycorrhization of AMF species observed can be attributed to antagonism between fungal strains, competition for nutrients such as carbohydrates and environmental conditions of the trial such as reduced growing substrate (nursery condition), temperature, soil pH, moisture content or phosphorus availability of the soil (Dalpé, 1997).

Although contradictory in peanut, the best values were observed by the co-inoculation treatment (Ga+Ge) in comparison to treatment alone Ga or Ge. Moreover, a significant effect was observed in pods weight with the mixed inoculum (Ga+Ge) and treatment Ge, which may be due to the introduced AMF (Gill and Singh, 2002). That can be explained by the synergy between the two strains of fungi and bacteria such as rhizobia. In fact, peanut is a legume which associates with rhizobia and co-inoculation with fungi can promote the synergy between the three symbiontes (native rhizobia, *G. etunicatum* and *G. aggregatum*). Some rhizosphere bacteria function in synergy with mycorrhizae, thus promoting their growth and protection while others might interfere negatively (Barea et al., 2002). This assertion might justify the fact that the mixed inoculum was more effective in peanut and not in maize. However no significant effect was observed on height, SDW, mycorrhization (frequency and intensity) and nodulation parameters (number and weight of nodules) of peanut. These results are consistent with those of Morte and Honrubia (2002) who found that the height and dry weight of *Phoenix canariens* inoculated with *Glomus deserticola* and *G. intraradices* were not different from those of uninoculated control. Sgrott et al. (2012) also found in their study that AMF had no significant effect on plant height but increased total biomass. In addition, inoculation with Ga decreased nodulation parameters

and root dry weight of peanut in comparison to control plants. This result on peanut inoculation with Ga is in disagreement with those obtained by Leye et al. (2015) on the inoculation with AMF on sesame where they found satisfactory results. These contradictory results confirm once again the variability of plant's response to inoculation as a function of the fungal species. It has been shown that plant response to microbial inoculation depends not only on the inoculum strain, host plant and environmental conditions, but also on the compatibility between these factors (Azcon et al., 1991). The significant decrease observed in root dry weight (RDW) and nodulation parameters of peanut plant inoculated mainly with Ga could be due to a diversion of carbohydrates substances by the introduced AMF (Waceke et al., 2001). Also, these results might be explained by non-efficiency of this AMF or to competitiveness with native soil microorganisms (Graham, 2008). Indeed, inoculation is beneficial only if the strains used are more competitive than the existing strains in the soil (Bâ et al., 1996). In fact, in a study of the symbiosis Glycine-Glomus-rhizobium, it was showed the antagonist effects between endomycorrhizal colonization and the nodulation which may be due to competition for carbohydrates. Thus, they act as parasites which exploit soil resources and reduce host growth (Lau et al., 2012). The failure of inoculation with AMF on non-sterile soil was also observed by Plenchette et al. (2000) and it's due in partly to high energetic costs of this symbiosis. In fact, in mycorrhizal symbiosis AMF can consume up to 20% of C produced by their host plant to supply substrate indispensable to their growth (Bago et al., 2000). This negative response to endomycorrhizal inoculation of peanut with Ga would also be related to the origin (Senegal) of this strain. Some authors have reported that the introduction of non-indigenous strains may be a barrier to successful inoculation (Chi et al., 2013). The use of indigenous strains of AMF can improve these parameters in this case.

Conclusion

Results suggest that maize significantly improved soil enzymes activities, total microbial biomass and AMF spores density. However, no significant effect was observed with peanut crop on these parameters apart from chitinase activity. Moreover, this crop has decreased soil rhizobia density and total microbial biomass.

Single treatment with Ge or Ga significantly increased the growth parameters of maize. However in peanut, yield parameters were significantly improved by AMF cocktail. These results highlight not only the importance of plant cover in the rehabilitation of soil bio-functioning but also the variability of plant response to microbial inoculation and the potential beneficial effects of these fungi on few growth parameters of plants.

The inoculums can be used to improve the yields of these two crops. However, it is important to select indigenous AM fungi from crop substratum in order to reduce competitiveness effect for a better response of the plant to mycorrhizal inoculation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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