Agricultural Science Research Journal Vol. 7(2): 63 – 69, February 2017
Available online at http://resjournals.com/journals/agricultural-science-research-journal.html
ISSN: 2026 –6073 ©2017 International Research Journals

Full Length Research Paper

An indigenous and an exotic AMF strains improve *Dioscorea alata* growth and induce tolerance to *Meloidogyne* spp.

Aka Niangoran Marie-Stéphanie KOUADIO[1], Jacob NANDJUI[1] and *Adolphe ZEZE[1]

[1] Laboratoire de Biotechnologie Microbienne Végétale, Unité Mixte de Recherche et d'Innovation en Sciences Agronomiques et Génie Rural, Institut National Polytechnique Félix Houphouet-Boigny (INP-HB), Yamoussoukro, Côte d'Ivoire

First author's email : akaphany@gmail.com, Tel.: (+225) 57 23 92 06

Second author's email : jacobnandjui@gmail.com, Tel.: (+225) 09 73 37 75.

*Corresponding author's email: youhe.deba@gmail.com[3], (+225) 09 77 43 26

Abstract

Yam (*Dioscorea* spp.) is susceptible to a host of pests including root-knot-nematodes (RKN). Considering that arbuscular mycorrhizal fungi (AMF) improve plant growth and enhance resistance or tolerance to nematodes, there is interest in studying AMF-RKN interactions on yam plants. In this perspective, a study was undertaken to assess the potential of some AMF in growth enhancement and yam protection against *Meloidogyne* spp. For that purpose, two pot experiments performed on *Dioscorea alata* (cultivar *Bètè-bètè*) were carried out for comparing the efficiency of two AMF based inocula, an indigenous strain of *Rhizophagus irregularis* selected in yam rhizosphere in Cote d'Ivoire and a commercial inoculum of *R. intraradices*. Results showed that both AMF inocula were efficient in improving plant growth either in the absence or in the presence of *Meloidogyne* spp. and plant tolerance to nematode infection was achieved through root biomass increase. Indigenous *R. irregularis* was the best inoculum in plant growth enhancement while commercial *R. intraradices* was the most effective inoculum in the RKN control. Comprehensively, indigenous *R. irregularis* was the most promising strain because it showed a better mycorrhizal capacity either in the absence or the presence of nematode and seems to be more compatible to yam plants.

Keywords: indigenous AMF, commercial AMF inoculum, root-knot-nematodes, *Dioscorea alata*, pot experiment

Introduction

Yam (*Dioscorea* spp.) is one of the most important staple food crops widely cultivated in west Africa considered as the yam belt (FAO, 2016). Tubers of *Dioscorea alata* L. are an important source of carbohydrates for millions of people throughout the tropics (Marcos *et al.*, 2011). Globally, yam is the second most important root and tuber crop after cassava, in terms of production and in West and Central Africa production zone (Tchabi *et al.*, 2016b). Due to land pressure, yam crops are increasingly cultivated on low fertile soils (Yasuoka, 2009) which is a major constraint that limits yam productivity and causes progressively yam yield decline. Yam is challenging various attacks from different pathogens. Indeed, yam is susceptible to a host of pests and diseases, including plant-parasitic nematodes, which further affect productivity, tuber quality and storability (Mudiope *et al.*, 2012). Among the nematodes that affect yam productivity in West Africa, *Scutellonema bradys* and *Meloidogyne* spp. are reported as the most important (Bridge *et al.*, 2005; Coyne *et al.*, 2006). Pesticides can be used for nematode control, but they are expensive, unavailable or highly toxic for both the user and the environment. In addition to this, most effective nematicides do not comply with current environmental demands and will have to be replaced by other means of nematode control with less impact on non-target organisms (Hol and Cook, 2005). Plant-parasitic

nematodes, including endoparasitic nematodes and arbuscular mycorrhizal fungi (AMF) occur together in the rhizosphere and colonize the same area of roots of host plants and, therefore, interact with each other. AMF effects are well-documented on the enhancement of plant nutrient uptake (Biricolti *et al.*, 1997; Goussous and Mohammad, 2009; Halder *et al.*, 2015; Nikolaou *et al.*, 2002; Sieverding *et al.*, 1991), plant drought and salinity tolerance (Augé, 2001, 2004; Augé *et al.*, 2015; Porcel *et al.*, 2011) and disease resistance (Pozo and Azcón-Aguilar, 2007; Tchabi *et al.*, 2016a). Considerable attention has also been paid to the potential role of mycorrhiza as biocontrol agents (Diedhiou *et al.*, 2003; Hussey and Roncadori, 1982; Jothi and Sundarababu, 1998). Various plants have been studied (Alban *et al.*, 2013; Banuelos *et al.*, 2014; Campos *et al.*, 2013; Cooper and Gordon, 1987; Elsen *et al.*, 2003) among which yam (Tchabi *et al.*, 2016a, 2016b). (Tchabi *et al.*, 2016b) highlithed the fact in their study AMF products commercially produced in Europe were used due to their availability, may not be the most suitable or compatible for tropical conditions. They also mentioned yam as a suitable candidate for bio-enhancing with AMF and the necessity to performe studies in order to determine more precisely appropriate genotype x AMF strain combinations. We try to address this issue selecting indigenous yam rhizosphere AMF strain and assessing his potential as a biocontrol agent against root-knot-nematodes *Meloidogyne* spp., comparing it to a widely commercial AMF using *Dioscorea alata* in greenhouse conditions.

Materials and methods

Plant material

A local cultivar of *Dioscorea alata* commonly called "*Bètè-bètè*" was used for it is the second most important yam species grown in Côte d'Ivoire (Doumbia, 1995; Doumbia *et al.*, 2004). "*Bètè-bètè*" is also the first main yam varieties cultivated in Yamoussoukro region a yam production area in Côte d'Ivoire (Digbeu *et al.*, 2009). Harvest time is characterized by wilting of the aerial parts of the plant. Tubers were submitted to a hot water treatment (50ºC for 20 minutes) (Coyne *et al.*, 2010) to disinfest the tubers of nematodes and other tuber-borne pests and diseases. The disinfested tubers were thereafter cut into mini-setts weighing 30-45g and soaked in a liquide mixture containing mancozeb (80%) and wood ash. Finally, they were air-dried for 24 hours. Mini-setts were placed in sterilized sawdust beds under shade to sprout. Six weeks after, uniformly sprouted and growing setts were transplanted to 10L perforated plastics pots, at one per pot, filled with 8 kg sterilized soil and sand mix (1:1, vol:vol). At transplanting, sprouted setts were separated from the sett to maintain only roots, in order to rapidly allow mycorrhizal symbiosis to establish.

AMF species used for inoculation

Two AMF species including an indigenous strain of *Rhizophagus irregularis* isolated from yam field in Yamoussoukro and a commercial strain of *Rhizophagus intraradices* (formerly named *Glomus intraradices*; Myke® Pro P501) manufactured by Premier Tech Biotechnologies were used.

Preparation of the native AMF inoculum

Yam roots were sampled from yams fields of three villages named Seman, Zambakro and Logbakro located in Yamoussoukro region. Roots were cut into 1cm pieces and used as inocula for root fragments cultures (Walker, 1999). One gram of yam roots fragments was placed in a hole with five to height onion (*Allium cepa*) seeds in the substrate of each 2-l pot filled with a local soil and sand mix (3:1, vol:vol) sterilized twice (121ºC, 1h) with intervals of 24h. They were all covered with sterilized substrate. Two weeks after the emergence of the seeds, some seedlings were removed from each pot in order to acquire a planting density of two seedlings per pot. After six months of culturing in greenhouse conditions one morphotype of AMF sporulated in the pot from Zambakro with a very high density (80 spores.g^{-1}) and spores were isolated by wet-sieving method (Gerdemann and Nicolson, 1963). Soil containing in Zambakro pot were used in pot substrate cultures (Walker, 1999) method in 10L pots as containers for mass-multiplication. Maize (*Zea mays*) was used as host plant for AMF rapid multilplication for three months with the same substrate used before. The maize plants were uprooted and roots were cut into 1 cm pieces and 10L pot soil were mixed thouroughly and used as inoculum. This inoculum was made of soil, colonized root fragments of maize, AMF spores and hyphae. Using molecular tools as (Séry *et al.*, 2016), this morphotype was identified as *Rhizophagus irregularis.*

Meloidogyne spp. inoculum source

The nematode inoculum was made using a population of *Meloidogyne* spp., isolated from naturally galled tomato roots. The inoculum was prepared by finely cutting infected tomato roots that were soaked in a jar containing NaClO (0.25%) and shaken for 2 min (Hussey and Barker, 1973). Nematode eggs and juveniles were collected on a 25 µm sieve, rinsed in sterile water and counted under a 40x binocular magnifier. Yam plants were inoculated one week after transplanting by pipetting 12 ml of an aqueous suspension containing 8000 eggs and juveniles within four holes dug around the plants.

Experimental design

Two experiments were carried out in this work. The first aimed to assess the performance of the indigenous inoculum *Rhizophagus irregularis* produced on yam plant growth in greenhouse as compared to the exotic inoculum *Rhizophagus intraradices*. This experiment involved one factor namely AMF inocula with each AMF inocula and a non-inoculated control (C). The second experiment aimed to assess the efficacy of both inocula in RKN control on yam plant. It involved two factors: AMF inocula (non-inoculated control or C, Rz1 and or

Rz2) and the period of *Meloidogyne* spp. inoculation either simultaneously with AMF inoculation or one week before AMF inoculation and no nematode inoculation. For AMF treatments, each plant received either 3000 spores of commercial *Rhizophagus intraradices* (following the manufacturer's instructions) or 500 spores of native *Rhizophagus irregularis*. Each plant inoculated with *Meloidogyne* spp. received 8000 eggs and juveniles. Both experiments involved three replicates for each treatment. Pots were arranged in a completely randomized. Plants were watered three times weekly until harvest at 4 months after transplanting.

Assessment of AMF root colonization, yam growth parameters and nematode infection

Plants were harvested after heavily watering them the previous day to soften the soil and enable removal of roots and tubers without damage. They were divided into leaves and vine (shoot), and roots. Each part was weighed using an OHAUS balance for collecting fresh weight. Shoot and roots were oven-dried at 70°C until constant weight and weighed. Total dry biomass production was calculated as the sum of the shoot dry and root dry biomass in the first experiment. A subsample of roots in each replicate from each treatment was collected and stained using the method of Phillips and Hayman (1970) in order to assess the percentage of mycorrhizal colonization in yam roots according to the method of (Trouvelot *et al.*, 1986). For each treatment, nematodes density per gram of root was assessed. The roots were chopped into ~2 cm pieces. The roots were thoroughly mixed before removing a 2 g sub-sample to extract nematodes using the maceration technique described above. Nematode eggs and juveniles were collected on a 25 µm sieve, rinsed in sterile water and counted under a 40x binocular magnifier. Data were reported as number of juveniles and eggs per gram of fresh roots.

Data analysis

All data were subjected to analysis of variance (ANOVA) using Generalized Linear Model of mean. Values were compared using least significant difference (LSD) test at 0.05 level of probability when the F-ratio was significant. All statistical analyses were carried out using the software Statistica 7.1.

Results

AMF inocula mycorrhizal capacity in the absence of *Meloidogyne* spp.

Four months after inoculating yam plants with *Rhizophagus intraradices* and *Rhizophagus irregularis*, all roots contained mycorrhizal organ (Table 1). Non-inoculated control plants were free of mycorrhizal organ. Both inocula were significantly different for the frequency (p=0.0096) and the intensity (p=0.0000) of mycorrhization. The indigenous *R. irregularis* showed a significant higher mycorrhizal capacity than the commercial *R. intraradices*. Plants inoculated with *R. irregularis* presented 26% of mycorrhizal roots while those inoculated with *R. intraradices* presented 17% of mycorrhizal roots. Furthermore, *R. irregularis* inoculated yam roots showed the highest root colonization degree even though the intensity was low for both inocula (<10%).

AMF inoculation impact on yam growth in the absence of *Meloidogyne* spp.

All growth parameters were significantly improved by AMF inoculation (Table 1) as compared to non-inoculated plants. Root and shoot dry weight and then total dry biomass were significantly (p=0.0001; p=0.0000) affected by AMF inoculation. The highest values of root ans shoot dry weight were obtained with *R. irregularis*. Consequently, *R. irregularis* was the best inoculum for yam plant growth under greenhouse conditions.

Table 1: Impact of Rhizophagus intraradices and R. irregularis on yam plant growth four months after AMF inoculation in the absence of nematodes

AMF inocula	Frequency of mycorrhization (%)	Intensity of mycorrhization (%)	Root dry weight (g)	Shoot dry weight (g)	Total dry biomass (g)
Control (no AMF)	0±0.00	0±0.00	1.38±0.01b	3.05±0.16b	4.43±0.16c
Commercial *R. intraradices*	17.31±1.99b	0.17±0.02b	1.70±0.22b	9.90±0.95a	11.61±1.13b
Indigenous *R. irregularis*	26.77±2.06a	0.64±0.01a	3.54±0.29a	10.78±0.14a	14.31±0.17a
P-value	0.0096	0.0000	0.0001	0.0000	0.0000

(Values sharing the same letter in each column are not significantly different (P < 0.05) according to the LSD test.)

AMF mycorrhizal capacity in the presence of *Meloidogyne* spp.

Yam root frequency (p=0.000) and intensity of colonization (p=0.008) were significantly affected by the interaction between nematodes and AMF inocula. No colonization was observed within non-inoculated plants roots. AMF mycorrhizal capacity showed different trend across the *Meloidogyne* spp. inoculation gradient (Figure 1). When yam plants were simultaneously inoculated with nematode and AMF, indigenous *R. irregularis* showed the best mycorrhizal frequency.

However, when nematode were inoculated before AMF, the better mycorrhizal capacity was obtained with the commercial *R. intraradices*. Nematode inoculation significantly increased *R. intraradices* mycorrhizal capacity. Frequency of mycorrhization noticed within roots inoculated with *R. irregularis* increased when simultaneous AMF and nematode happened and it was depressed when nematodes were inoculated before. Nematode inoculation did not significantly affect colonization intensity induced by both AMF inocula (Figure 1). Only *R. irregularis* showed the highest value when AMF and nematode were inoculated at the same time (Figure 1).

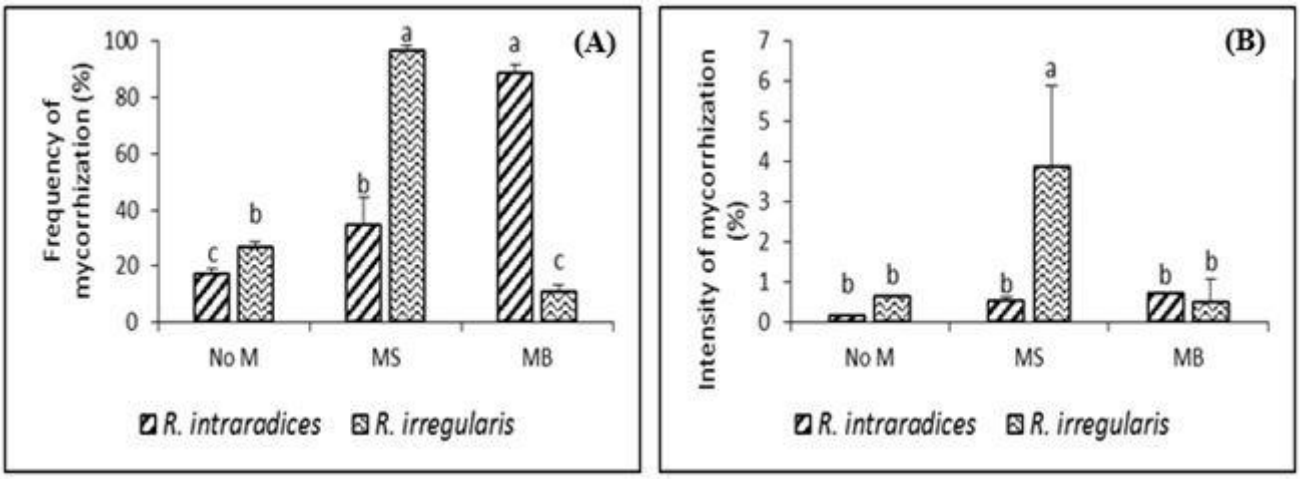

Figure 1: Frequency (A) and intensity of mycorrhization (B).
(Values sharing the same letter in each color are not significantly different (P < 0.05) according to the LSD test. NoM= absence of Meloidogyne spp; MS= Meloidogyne spp inoculated at the same time with AMF; MB=inoculation of Meloidogyne spp. before AMF)

Effect of AMF inocula and *Meloidogyne* spp. on yam plants growth

Four months after transplanting yam plants, differences in yam growth parameters were observed. *Meloidogyne* spp. inoculation did not affect control plants root dry weight while it decreased control plants shoot dry weight even though not significantly (Figure 2).When performing AMF inocula at the same time with nematodes, no difference in root dry weight was observed between AMF inocula while the commercial inoculum allowed an increase in shoot dry weight. Significant impacts of both AMF inoculants were observed on root dry weight when performing nematode inoculant before. The significant impact of AMF inoculant on shoot dry weight was observed only with the indigenous inoculum (Figure 2).

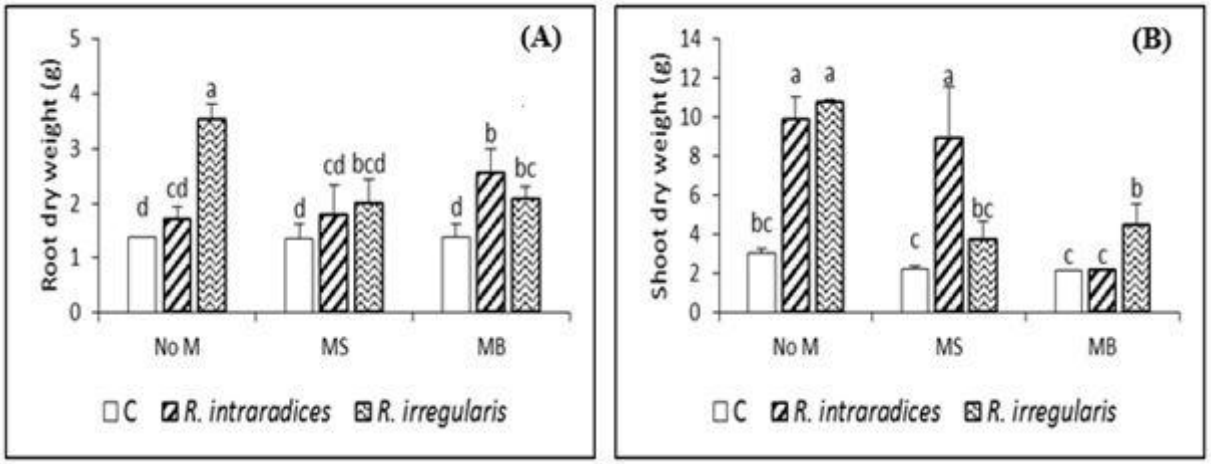

Figure 2: Root dry weight (A) and shoot dry weight (B) four months after yam sett transplanting in pots

(Values sharing the same letter in each color are not significantly different (P < 0.05) according to the LSD test. C= control, no AMF; NoM= absence of Meloidogyne spp; MS= Meloidogyne spp inoculated at the same time with AMF; MB=inoculation of Meloidogyne spp. before AMF)

Effect of AMF inoculation on *Meloidogyne* spp. density and damage

Four months after yam sett transplanting, AMF have affected negatively nematode population. Juveniles and eggs density per gram of root decreased significantly when plants were inoculated by AMF (Figure 3). Nematode inoculation either before or at the same time as AMF inoculation did not affect both AMF inocula efficacy as biocontrol against *Meloidogyne* spp. Indeed,

R. intraradices and *R. irregularis* decreased juveniles and eggs density per gram of root as compared to AMF-free plants. AMF performance as biocontrol against nematode varies between both inocula used and the period of *Meloidogyne* spp. inoculation. *R. intraradices* and *R. irregularis* showed similar performances on juveniles and eggs density per gram of root when AMF and nematode were simultaneously inoculated. *R. intraradices* was better than *R. irregularis* concerning juveniles and eggs density per gram of root under delayed AMF and nematode inoculation (Figure 3).

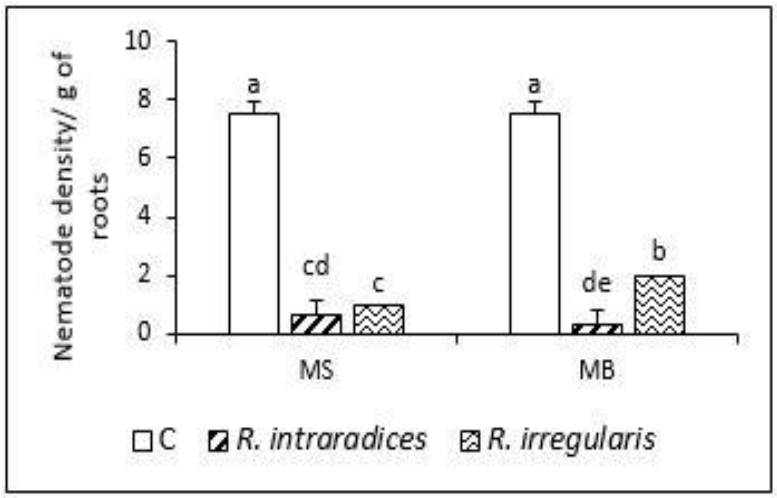

Figure 3: Juveniles and eggs of *Meloidogyne* spp. density per gram of roots

(Values sharing the same letter in each color are not significantly different (P < 0.05) according to the LSD test. C= control, no AMF; MS= Meloidogyne spp. inoculated at the same time with AMF; MB=inoculation of Meloidogyne spp. before AMF)

Discussion

This work was undertaken for assessing AMF potential, in the absence or presence of *Meloidogyne* spp. inoculated either before or simultaneously with AMF inocula on yam (*Dioscorea alata*). In this study, one of the most interesting thing was the comparison of two AMF inocula including an indigenous AMF inoculum and a commercial AMF both from the same genus. These inocula showed different behaviour along the experiments. Without nematode, it was shown that both inocula colonized yam plants with similar mycorrhization frequency and *R. irregularis* did it in a greater extent (intensity of mycorrhization). This result was similar to that found by (Rodríguez *et al.*, 2012) working on different AMF genera and species having different infectivity levels where the equal infectivity at strain level was observed. They concluded comparing their results to those from others authors, that the intensity of mycorrhization is more useful to establish the infectivity differences at deeper level when many strains are examined. Thus, the indigenous *R. irregularis* revealed a better mycorrhizal capacity comparing to commercial *R. intraradices* through it highest mycorrhization intensity. When, AMF were challenged by *Meloidogyne* spp. inoculation either simultaneously or prior, *R. intraradices* and *R. irregularis* showed different behaviour. The percentage of mycorrhizal colonization can increase (Tchabi *et al.*, 2016b) or decrease (Séry *et al.*, 2016) or have no effect (Cooper and Gordon, 1987) in the presence of plant parasitic nematodes, depending on the arbuscular mycorrhizal species involved (Waceke *et al.*, 2001) or plant cultivars (Tchabi *et al.*, 2016b). *R. irregularis* better infectivity (higher mycorrhization intensity) could be due to the fact that although there is no specificity between AMF and their hosts, greater compatibility can occur between some species of AMF and plants (Campos *et al.*, 2013; Cesaro *et al.*, 2008). Indeed, *R. irregularis* as an indigenous strain isolated from yam rhizosphere may be more compatible to yam plant than the commercial *R. intraradices.*

An enhancement in yam plants growth after AMF inoculation has been clearly demonstrated as it is well-known in the litterature with various plants. AMF have been shown particularly important for improving various plant growth and yield (Cozzolino *et al.*, 2013; Ortas, 2010; Seema and Garampalli, 2015; Shuab *et al.*, 2014) . Studies on yam plant interaction with AMF were scarce but recenlty, some authors have focused their work on this matter. Our results were similar to those found by (Dare *et al.*, 2010; Lu *et al.*, 2015; Tchabi *et al.*, 2008, 2009, 2010). Indeed, they noticed AMF potential to improve yam plant growth either in greenhouse and field conditions. AMF beneficial effect on plant growth is generally a consequence of an improvement of plant nutrient uptake (Aka-Kacar *et al.*, 2010; Al-Karaki *et al.*, 2004; Dare *et al.*, 2010). In the presence of *Meloidogyne* spp. inoculated at the same time as AMF inocula, no significant difference was observed between AMF-free and AMF inoculated plants. The presence of the nematode may interfere with nutrient flow between the root and the fungus, reducing AMF efficiency (Cofcewicz *et al.*, 2001).Yam plants pre-inoculated with nematode before AMF, enhanced the root dry weight as compared to AMF-free plants. This ability of mycorrhizal plant to grow well despite the infection by nematode, was also

observed by (Cooper and Gordon, 1987) . It is one of the mains effect of AMF on the interaction of host plant and plant parasitic nematode. Inside the roots, the root-knot nematodes (*Meloidogyne* spp.) create a feeding site deriving continuous nourishment from adjacent cells and producing galls that affect the plant's metabolism and resource allocation. This impairs the absorption and transport of water and nutrients which results in decreased plant development (Borowicz, 2001; Carneiro *et al.*, 2002). The presence of AMF, which compete for space and nutrients with the nematode, may reduce this effect, inducing plant development even in the presence of the pathogen, as observed in guava plants (Campos *et al.*, 2013). Both AMF inocula showed similar efficacy in root dry weight enhancement. The increment induced by *Rhizophagus intraradices* for shoot development when AMF and *Meloidogyne* spp. were simultaneously inoculated meaned that nematode inoculation did not alter *R. intraradices* performance to improve plant growth. According to (Alban *et al.*, 2013) working on coffee plants, if AMF and the nematode were simultaneously present in the soil, AMF colonized the roots before nematode infestation. Thus, coffee plants can regain the energy lost by the parasitic interaction, preventing the reduction in plant growth. The same phenomenon surely happened with *R. irregularis* and *R. intraradices* inoculated yam plants. *R. intraradices* and *R. irregularis* showed themselves faster and more competitive than *Meloidogyne* spp. *R. intraradices* could therefore express its efficacy and improve shoot growth while *R. irregularis* prevented reduction in plant growth. (Alban *et al.*, 2013) proposed also for coffee plant that if coffee seedlings are attacked by *Meloidogyne exigua* it is possible to use AM fungi in order to prevent productivity loss. This occurs because the symbiosis interaction speeds up. It aims to maintain plant growth similar to non-infected plants. This is what happen exactly with *R. intraradices* inoculated plants. In this case, *R. irregularis* was more efficient than *R. intraradices* probably because of it compatibility with yam plant as a strain isolated from yam rhizosphere.

The interaction between AMF and nematodes has been studied by several workers and it has resulted in nematode reduction (Alban *et al.*, 2013; Campos *et al.*, 2013; Castillo *et al.*, 2006; Habte *et al.*, 1999; Tchabi *et al.*, 2016a), no effect (Manandhar, 2011) or even an increase in numbers of nematodes (Atilano *et al.*, 1981). In this work, juveniles and eggs density per gram of roots was decreased when plants were inoculated with AMF. The outcome of AMF and nematodes interactions depend on several factors including host plant, AMF and nematode species and the cultivation conditions (Diedhiou *et al.*, 2003; Elsen *et al.*, 2003). The nature of interaction varied to neutral, positive or negative. Several mechanisms may operate simultaneously in the enhanced resistance or tolerance of mycorrhizal plants to RKN. AMF and RKN occur together in the rhizosphere and colonize the same area of roots of host plants. Therefore, a competition between both organisms for feeding sites and carbon substrates from host photosynthesis (Hol and Cook, 2005) can occured. In addition to this, the presence of mycorrhiza in the host can reduce attraction to roots and juvenile penetration and retard nematode development after penetration (Pozo *et al.*, 2010) by inducing changes in root exudation into the mycorrhizosphere. This may result in a decrease of nematodes density per gram of roots. Nevertheless, in this study, nematode density per gram of root decrement was due to the increase of root biomass by AMF inoculation. *R. intraradices* showed a better potential in reducing nematode damage than *R. irregularis*.

Conclusion

The current study has shown that both AMF inocula used were efficient in improving plant growth in the absence even in the presence of *Meloidogyne* spp. and induced yam plants tolerance to nematode infection. Tolerance to nematode infection was achieved through root biomass increase. Commercial *R. intraradices* was more effective in root-knot-nematodes control while indigenous *R. irregularis* was the best in improving yam growth. Thus inocula were both good for plant growth enhancement and tolerance to *Meloidogyne* spp. Among the AMF inocula, that with *R. irregularis* was the most promising because it not only allowed tolerance to root-knot-nematodes and was efficient in increasing plant growth, but also presented a better mycorrhizal capacity either in the absence or the presence of nematode and seems to be more compatible to yam plants. This compatibility could have been of high interest if these experiments were carried out under more real conditions with various environmental factors such as field conditions.

Funding

This research was funded by the West Africa Agricultural Productivity Program (WAAPP/PPAAO) coordonated by the Interprofessional Fund for Agricultural Research and Advice (which stands for FIRCA in french).

References

Aka-Kacar Y, Akpinar C, Agar A, Yalcin-Mendi Y, Serce S, Ortas I (2010). The effect of mycorrhiza in nutrient uptake and biomass of cherry rootstocks during acclimatization. Romanian Biotechnol Lett 15: 5246–5252.

Alban R, Guerrero R, Toro M (2013). Interactions between a Root Knot Nematode (Meloidogyne exigua) and Arbuscular Mycorrhizae in Coffee Plant Development (Coffea arabica). Am J Plant Sci 04: 19–23.

Al-Karaki G, McMichael B, Zak J (2004). Field response of wheat to arbuscular mycorrhizal fungi and drought stress. Mycorrhiza 14: 263–269.

Atilano RA, Menge JA, Gundy SDV (1981). Interaction Between Meloidogyne arenaria and Glomus fasciculatus in Grape. J Nematol 13: 52–57.

Augé RM (2001). Water relations, drought and vesicular-arbuscular mycorrhizal symbiosis. Mycorrhiza 11: 3–42.

Augé RM (2004). Arbuscular mycorrhizae and soil/plant water relations. Can J Soil Sci 84: 373–381.

Augé RM, Toler HD, Saxton AM (2015). Arbuscular mycorrhizal symbiosis alters stomatal conductance of host plants more under drought than under amply watered conditions: a meta-analysis. Mycorrhiza 25: 13–24.

Banuelos J, Alarcón A, Larsen J, Cruz-Sánchez S, Trejo D (2014). Interactions between arbuscular mycorrhizal fungi and Meloidogyne incognita in the ornamental plant Impatiens balsamina. J Soil Sci Plant Nutr 14: 63–74.

Biricolti S (Universita di F, Ferrini F, Rinaldelli E, Tamantini I, Vignozzi N (1997). VAM fungi and soil lime content influence rootstock growth and nutrient content. Am J Enol Vitic USA.

Borowicz VA (2001). Do Arbuscular Mycorrhizal Fungi Alter Plant-Pathogen Relations? Ecology 82: 3057–3068.

Bridge J, Coyne DL, Kwoseh CK (2005). Nematode parasites of tropical root and tuber crops (excluding potatoes). In: Luc M, Sikora RA, Bridge J, eds. Plant Parasitic Nematodes in Subtropical and Tropical Agriculture, Second Edition. CABI, Wallingford, pp 221–258.

Campos MADS, Silva FSBD, Yano-Melo AM, Melo NFD, Pedrosa EMR, Maia LC (2013). Responses of Guava Plants to Inoculation with Arbuscular Mycorrhizal Fungi in Soil Infested with Meloidogyne enterolobii. Plant Pathol J 29: 242–248.

Carneiro RG, MAZZAFERA P, FERRAZ LCC, MURAOKA T, TRIVELIN PCO (2002). Uptake and translocation of nitrogen, phosphorus and calcium in soybean infected with Meloidogyne incognita and M. javanica. Fitopatol Bras 27: 141–150.

Castillo P, Nico AI, Azcón-Aguilar C, Del Río Rincón C, Calvet C, Jiménez-Díaz RM (2006). Protection of olive planting stocks against parasitism of root-knot nematodes by arbuscular mycorrhizal fungi. Plant Pathol 55: 705–713.

Cesaro P, van Tuinen D, Copetta A, Chatagnier O, Berta G, Gianinazzi S, Lingua G (2008). Preferential Colonization of Solanum tuberosum L. Roots by the Fungus Glomus intraradices in Arable Soil of a Potato Farming Area. Appl Environ Microbiol 74: 5776–5783.

Cofcewicz ET, Medeiros CAB, Carneiro RMDG, Pierobom CR (2001). Interação dos fungos micorrízicos arbusculares Glomus etunicatum e Gigaspora margarita e o nematóide das galhas Meloidogyne javanica em tomateiro. Fitopatol Bras 26. doi:10.1590/S0100-41582001000100011

Cooper KM, Gordon SG (1987). Effects of Vesicular-Arbuscular Mycorrhizal Fungi on Infection of Tamarillo (Cyphomandra betacea) by Meloidogyne incognita in Fumigated Soil. Plant Dis 71: 1101–1106.

Coyne DL, Claudius-Cole AO, Kenyon L, Baimey H (2010). Differential effect of hot water treatment on whole tubers versus cut setts of yam (Dioscorea spp.). Pest Manag Sci 66: 385–389.

Coyne DL, Tchabi A, Baimey H, Labuschagne N, Rotifa I (2006). Distribution and prevalence of nematodes (Scutellonema bradys and Meloidogyne spp.) on marketed yam (Dioscorea spp.) in West Africa. Field Crops Res 96: 142–150.

Cozzolino V, Di Meo V, Piccolo A (2013). Impact of arbuscular mycorrhizal fungi applications on maize production and soil phosphorus availability. J Geochem Explor 129: 40–44.

Dare MO, Abaidoo RC, Fagbola O, Asiedu R (2010). Effects of Arbuscular Mycorrhizal Inoculation and Phosphorus Application on Yield and Nutrient Uptake of Yam. Commun Soil Sci Plant Anal 41: 2729–2743.

Diedhiou PM, Hallmann J, Oerke E-C, Dehne H-W (2003). Effects of arbuscular mycorrhizal fungi and a non-pathogenic Fusarium oxysporum on Meloidogyne incognita infestation of tomato. Mycorrhiza 13: 199–204.

Digbeu DY, Due AE, Brou K, Kouakou AM, Nemlin GJ, Dago G (2009). Characterization of yam land races in Côte d'Ivoire with respect to food quality and end uses. J Appl Biosci 20: 1203–1214.

Doumbia S (1995). Les déterminants agro-écologiques et socio-économiques de la production et de l'offre en igname en Côte d'Ivoire. Inst Savanes 1.

Doumbia S, Tshiunza M, Tollens E, Stessens J (2004). Rapid spread of the florido yam variety in Ivory Coast.pdf. AGRICULTURE 33: 49–54.

Elsen A, Baimey H, Swennen R, De Waele D (2003). Relative mycorrhizal dependency and mycorrhiza-nematode interaction in banana cultivars (Musa spp.) differing in nematode susceptibility. Plant Soil 256: 303–313.

FAO (2016). FAOSTAT. http://faostat3.fao.org/download/Q/QC/F (last accessed 22 April 2016).

Gerdemann JW, Nicolson TH (1963) Spores of mycorrhizal Endogone species extracted from soil by wet sieving and decanting. Trans Br Mycol Soc 46: 235–244.

Goussous SJ, Mohammad MJ (2009). Comparative Effect of Two Arbuscular Mycorrhizae and N and P Fertilizers on Growth and Nutrient Uptake of Onions. Int J Agric Biol 11.

Habte M, Zhang YC, Schmitt DP (1999). Effectiveness of Glomus species in protecting white clover against nematode damage. Can J Bot 77: 135–139.

Halder M, Dhar P., Mujib AS., Khan MS, Joardar J, Akhter S (2015). Effect of Arbuscular Mycorrhiza Fungi Inoculation on Growth and Uptake of Mineral Nutrition in Ipomoea aquatica. Curr World Environ 10: 67–75.

Hol WHG, Cook R (2005). An overview of arbuscular mycorrhizal fungi–nematode interactions. Basic Appl Ecol 6: 489–503.

Hussey RS, Barker KR (1973). A comparison of methods of collecting inocula of Meloidogyne spp., including a new technique. Plant Dis Report 57: 1025–1028.

Hussey RS, Roncadori RW (1982). Vesicular-Arbuscular Mycorrhizae may limit nematode activity and improve plant growth. Plant Dis 66: 9–14.

Jothi G, Sundarababu R (1998). Interaction of vesicular-arbuscular mycorrhizae with reniform nematode, rotylenchulus reniformis on Ragi. Indian J Nematol 28: 145–149.

Lu F-C, Lee C-Y, Wang C-L (2015). The influence of arbuscular mycorrhizal fungi inoculation on yam (Dioscorea spp.) tuber weights and secondary metabolite content. PeerJ 3: e1266.

Manandhar S (2011). Study on the Bioprotective Effect of Endomycorrhizae against M. Graminicola in Rice. Dissertation. Catholic University of Leuven, Belgium.

Marcos J, Cornet D, Bussière F, Sierra J (2011). Water yam (Dioscorea alata L.) growth and yield as affected by the planting date: Experiment and modelling. Eur J Agron 34: 247–256.

Mudiope J, Coyne DL, Adipala E, Talwana HAL (2012). Damage to yam (Dioscorea spp.) by root-knot nematode (Meloidogyne spp.) under field and storage conditions in Uganda. Nematropica 42: 137–145.

Nikolaou N ((Aristotle U of T (Grèce))), Karagiannidis N, Koundouras S, Fysarakis I (2002) Effects of different P sources in soil on increasing growth and mineral uptake of mycorrhizal Vitis vinifera l. (cv Victoria) vines. J Int Sci Vigne Vin Fr.

Ortas İ (2010). Effect of mycorrhiza application on plant growth and nutrient uptake in cucumber production under field conditions. Span J Agric Res 8: 116–122.

Phillips JM, Hayman DS (1970). Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. Trans Br Mycol Soc 55. doi:10.1016/S0007-1536(70)80110-3

Porcel R, Aroca R, Ruiz-Lozano JM (2011). Salinity stress alleviation using arbuscular mycorrhizal fungi. A review. Agron Sustain Dev 32: 182–200.

Pozo MJ, Azcón-Aguilar C (2007). Unraveling mycorrhiza-induced resistance. Curr Opin Plant Biol 10: 393–398.

Pozo MJ, Jung SC, López-Ráez JA, Azcón-Aguilar C (2010). Impact of Arbuscular Mycorrhizal Symbiosis on Plant Response to Biotic Stress: The Role of Plant Defence Mechanisms. In: Koltai H, Kapulnik Y, eds. Arbuscular Mycorrhizas: Physiology and Function. Springer Netherlands, Dordrecht, pp 193–207.

Rodríguez Y, Vierheilig H, Mazorra LM (2012). Alterations of the antioxidant enzyme activities are not general characteristics of the colonization process by arbuscular mycorrhizal fungi. Chil J Agric Res 72: 411–418.

Seema HS, Garampalli RH (2015). Effect of Arbuscular Mycorrhizal fungi on growth and biomass enhancement in Piper longum L.(Piperaceae). Int J Curr Microbiol App Sci 4: 11–18.

Séry D, Kouadjo Z, Voko DRR, Zézé A (2016). Selecting native arbuscular mycorrhizal fungi to promote cassava growth and increase yield under field conditions. Front Microbiol. doi:10.3389/fmicb.2016.02063

Shuab R, Lone R, Naidu J, Sharma V, Imtiyaz S, Koul KK (2014) Benefits of inoculation of arbuscular mycorrhizal fungi on growth and development of onion (Allium cepa) plant. Am-Eurasian J Agric Environ Sci 14: 527–535.

Sieverding E, Friedrichsen J, Suden W (1991). Vesicular-arbuscular mycorrhiza management in tropical agrosystems. Schriftenreihe GTZ 371.

Tchabi A, Burger S, Coyne D, Hountondji F, Lawouin L, Wiemken A, Oehl F (2009). Promiscuous arbuscular mycorrhizal symbiosis of yam (Dioscorea spp.), a key staple crop in West Africa. Mycorrhiza 19: 375–392.

Tchabi A, Coyne D, Hountondji F, Lawouin L, Wiemken A, Oehl F (2008). Arbuscular mycorrhizal fungal communities in sub-Saharan Savannas of Benin, West Africa, as affected by agricultural land use intensity and ecological zone. Mycorrhiza 18: 181–195.

Tchabi A, Coyne D, Hountondji F, Lawouin L, Wiemken A, Oehl F (2010). Efficacy of indigenous arbuscular mycorrhizal fungi for promoting white yam (Dioscorea rotundata) growth in West Africa. Appl Soil Ecol 45: 92–100.

Tchabi A, Hountondji F, Ogunsola B, Lawouin L, Coyne D, Wiemken A, Oehl F (2016a). Effect of two species of arbuscular mycorrhizal fungi inoculation on development of micro-propagated yam plantlets and suppression of Scutellonema bradys (Tylenchideae). J Entomol Nematol 8: 1–10.

Tchabi A, Hountondji FCC, Ogunsola B, Lawouin L, Coyne D, Wiemken A, Oehl F (2016b). The Influence of Arbuscular Mycorrhizal Fungi Inoculation on Micro-Propagated Hybrid Yam (Dioscorea spp.) Growth and Root Knot Nematode (Meloidogyne spp.) Suppression. Int J Curr Microbiol Appl Sci 5: 267–281.

Trouvelot A, Kough JL, Gianinazzi-Pearson V (1986). Mesure du taux de mycorhization VA d'un systeme radiculaire. Recherche de methodes d'estimation ayant une signification fonctionnelle. In: Aspects Physiologiques et Genetiques Des Mycorhizes, INRA. Edition. Paris, pp 217–221.

Waceke J, Waudo S, Sikora R (2001). Response of meloidogyne hapla to mycorrhiza fungi inoculation on pyrethrum. Afr J Sci Technol 2: 63–70.

Walker C (1999). Methods for culturing and isolating arbuscular mycorrhizal fungi. Mycorrhiza News 11: 2–4.

Yasuoka H (2009). Concentrated Distribution of Wild Yam Patches: Historical Ecology and the Subsistence of African Rainforest Hunter-Gatherers. Hum Ecol 37: 577–587.