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MAIZE (*Zea mays* l.) RESPONSE TO MYCORRHIZAL FERTILIZATION ON FERRUGINOUS SOIL OF NORTHERN BENIN

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ABSTRACT

The use of Arbuscular Mycorrhizal Fungi (AMF) is considered one of the effective organic ways to increase the crops productivity. The aim of this study was to evaluate the growth promoting effect of three mycorrhizal fungi (*Glomus cubense*, *Rhizophagus intraradices* and *Funneliformis mosseae*) on maize crops in a ferruginous soil of Northern Benin. Maize seeds were inoculated with mycorrhizal fungi in combination with or without minerals fertilizer. Study was conducted in a completely randomized block design with nine treatments and four replicates. The endomycorrhizal infection was evaluated on 68th days of sowing while the crop was harvested after 90 days. Results of study revealed that application of AMF have significant effect ($p< 0.01$) on the growth attributes and performance of maize. Compared to the control, maximum height (increases of 29%) was recorded in the plants treated with a complete dose of NPK, followed by the plant treated by *F. mosseae* combined with 50% NPK

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(increases of 20.28%). Same treatments have better leaf growth, high production of biomass (air and ground) and better seed yield. As far as endomycorrhizal colonization is concerned, plants inoculated with *R. intraradices* had best frequency of mycorrhization (38.50%) and a high number of spores (1.73 spores/g soil), while those inoculated with *F. mosseae* had the best intensity of mycorrhization (11%). Results of present study suggest the use of endomycorrhizal fungi for enhancing the growth and maize seed yield in ferruginous soil in the North of Benin.

1 Introduction

Agriculture occupies an important place in the economy of Sub-Saharan countries such as Benin. Maize cultivation accounts about 70% of total cereal production area and is the basis of food for Beninese populations (MAEP, 2010). Unfortunately, low productivity and unstable yields jeopardize food security and keep farmers in precarious financial conditions (Delphine et al., 2011). This situation became more serious by certain constraints, among these parasite complex (insects, nematodes and striga) and the chronic decline of soil fertility, which marked by deficiency of assailable nitrogen and phosphorus (Igué et al., 2015). Thus, for a production of maize that can cover people's food needs and generating commercial income, producers are increasingly using mineral fertilizers and phyto-sanitary products obtained from chemical industries (Priou, 2013). Further, availability and high prices of these agricultural inputs in Sub-Saharan countries do not allow small producers to acquire them (Micaela, 2015). In addition, prolonged use of these mineral fertilizers leads to acidification of the soil and contamination of ground water. Along with these access used of these chemicals may stimulated the accumulation of heavy metals in harvest products (Dalpé, 2005).

One of the best alternatives of these chemical fertilizers is the use of soil microorganisms that can colonized in plant roots and enhance the soil and crop productivity. Among the currently used soil microorganisms, use of mycorrhizal fungi is most common one (Johnson, 2008). In fact, many researchers from all over the world have been using native or exotic endomycorrhizal symbiosis to improve the productivity of various agricultural crops (Johnson, 2008; Megueni et al., 2011). Further, this association not only improving the plant productivity but also have significant effect on microbial diversity and soil quality (Warda, 2011). Exploitation of these endogenous endo-mycorrhizal potential of soils can optimize growth, hydro mineral nutrition and nitrogen fixation.

In fact, in most of the cases, beneficial effect of mycorrhiza is due to an improvement in the mineral nutrition of the host plant, especially with regard to the low mobility elements in the soil such as phosphorus, zinc and copper (Javot et al., 2007) through extensive exploration of the absorption surface and the volume of soil prospected by fungal hyphae. The aim of our study was to evaluate the effect of three selected mycorrhizae fungi (*Glomus cubense*, *Rhizophagus intraradices* and *Funneliformis mosseae*) strains inoculation on the growth parameters and yield of maize on ferruginous soil in North Benin.

2 Materials and methods

2.1. Variety of maize

Maize variety EVDT 97 STR C1 obtained from the National Institute of Agricultural Research of Benin (INRAB, 1995). This variety has good resistance to lodging, breakage and diseases with a grain yield between 2 and 3 t/ha (Yallou et al., 2010). The vegetative period is 140 to 169 days.

2.2 Microorganisms

Three mycorrhizal fungi strains named *Glomus cubense*, *Rhizophagus intraradices and Funneliformis mosseae*were were used in this study. These strains were provided by the mycorrhiza laboratory of the "Instituto Nacional de Siencias Agricolas (INCA)" of Cuba.

2.3 Characteristics of the experimental site

Present study was conducted at the north experimental station of the Agricultural Research Center of the National Institute of Agricultural Research of Benin, Ina (Borgou) located at 358 meters altitude and between 9°58'N latitude and longitude 2 ° 44'E (Figure 1). The experimental site is characterized by a tropical ferruginous soil with variable characteristics and sensitive to leaching. The soil of Ina has high content of organic matter (1.92%), nitrogen (0.092% at pH 5.7), phosphorus (58 ppm) and potassium (0.49 meq/100g of soil). The sum of the bases and the CEC (Cation Exchange Capacity) are average on surface horizon (Igué et al., 2015). The saturation in bases is average and the pH is moderately acidic. The cumulative rainfall recorded at the experimental site during the trial period is 743.3 mm, distributed over the months of August (493.5 mm), September (144.7 mm) and October (105.1 mm).

2.4. Experimental design

The experimental design used for this study was completely randomized block design with nine treatments and four replicates. Each treatment covered a plot of 16 m² contained 4 lines of 4 m. Seeding was done by keeping a distance of 0.80 m x 0.40 m, a

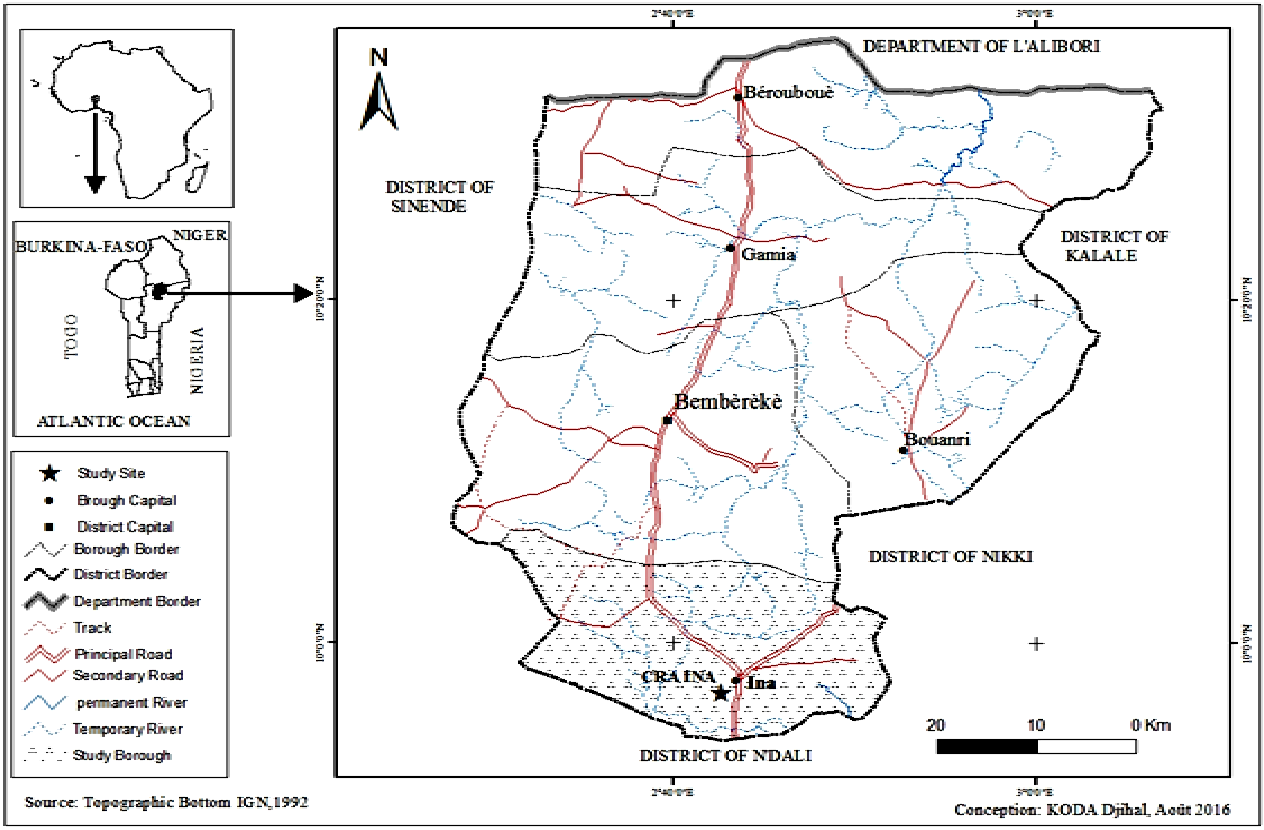

Figure 1: Geographical location of the experimental station

density of 31.25 plants/ha. The paths between plots and between repetitions were 1.8 m and 2 m respectively. The growth and yield data were collected from the representative 2 central lines of each useful plot (6.4 m2). The different treatments formulated were Absolute control (no fungi or mineral fertilizers - CTL), *Glomus cubense* (Gc), *Rhizophagus intraradices* (Ri), *Funneliformis mosseae* (Fm), ½ dose of $N_{15}P_{15}K_{15}$ recommended (½ NPK), *G. cubense* + ½ dose recommended $N_{15}P_{15}K_{15}$ (Gc+½ NPK), *R. intraradices* + ½ dose of $N_{15}P_{15}K_{15}$ recommended (Ri+½ NPK), *F. mosseae* + ½ dose of $N_{15}P_{15}K_{15}$ recommended (Fm+½ NPK) and full recommended dose (150 kg / ha) of $N_{15}P_{15}K_{15}$ (NPK) (Akpinfa et al., 2017).

2.5. Maize seeds inoculation with Arbuscultive Mycorrhiza Fungi

The inoculation of maize seed with selected mycorrhiza fungi (*G. cubense, R. intraradices* and *F. mosseae*) was carried out as per the method given by Fernández et al. (2000). The mycorrhiza fungi applied to the 10% of the maize seed's weight mixed with sterile distilled water (600 $ml.kg^{-1}$). After mixing, seeds have been coated and dried on ambient temperature during 12 hours. The same process was repeated the for all three AMF strains.

2.6. Seedlings and plants maintenance

Two maize seeds was deposited in a hole of about 5 cm depth and immediately closed. Three weeding was carried out; the first weeding was coupled with one planting per plant two weeks after sowing, the least vigorous plant was removed. The second and third weeding were respectively realized six and eight weeks after sowing.

2.7. Growth and yield data collection

The data related to leaf area of the plants was taken sixty days after sowing. The product of leaf length and width affected by the coefficient 0.75 estimated the leaf area (Ruget et al., 1996). In each elementary parcel, the plant height was measured by using the ruler and stem diameter with the help of caliper. The measurements were taken at each 15 days of intervals and carried out upto 60^{th} days after Seedling (DAS). To avoid all contamination, the two lateral lines on each side were eliminated,

Table 1 Difference between average value of the growth parameters and the treatments performance compared to the references T1 (CTL) (the Dunnett test results)

Treatments	Height	Diameter at the collar	Leaf area	Above-ground biomass	Underground biomass	Performance
Gc	10.53*	0.06	53.8***	0.10	-0.70	0.23*
Ri	11.36*	-0.02	63.14***	-0.02	-0.26	0.27*
Fm	13.67**	0.04	56.53***	0.06	0.14	0.32**
½ NPK	11.49*	0.12	58.03***	0.19	1.00*	0.28**
Gc+½ NPK	12.85**	0.06	61.1***	0.20	0.42	0.35***
Ri+½ NPK	14.67***	0.13	63.87***	0.21	0.90	0.41***
Fm+½ NPK	20.28***	0.19	68.49***	0.24*	0.88	0.68***
NPK	28.99***	0.40**	87.11***	0.24*	1.17**	0.77***
R^2 (%)	73.52	41.69	93.73	35.53	37.82	82.20

**p < 0.05 (significant); **p < 0.01 (highly significant); ***P < 0.001 (very highly significant); CTL - witness absolute (not mushrooms or fertilizer minerals); Gc - Glomus cubense; Ri - Rhizophagus intraradices; Fm - Funneliformis mosseae; ½ NPK - ½ dose of $N_{15}P_{15}K_{15}$ recommended; Gc+½ NPK - Glomus cubense + ½ dose of $N_{15}P_{15}K_{15}$ recommended; Ri+½ NPK - Rhizophagus intraradices + ½ dose of $N_{15}P_{15}K_{15}$ recommended; Fm+½ NPK - Funneliformis mosseae + ½ dose of $N_{15}P_{15}K_{15}$ recommended; NPK - full dose of $N_{15}P_{15}K_{15}$ recommended*

Table 2 Average value of the growth parameters based on the treatments: results of the analysis of variance followed by Student Newman and Keuls test

Treatments	Height (cm)		Diameter (cm)		Leaf area (cm^2)	
	m	CV (%)	m	CV (%)	m	CV (%)
CTL	118.33^c	3.89	1.33^c	6.60	464.46^c	1.23
Gc	128.86^b	3.58	1.39^b	11.60	518.27^b	1.38
Ri	129.70^b	4.16	1.31^c	11.38	527.60^b	1.04
Fm	132.01^b	5.83	1.37^b	8.30	521.00^b	3.04
½ NPK	129.83^b	1.58	1.45^b	14.19	522.50^b	0.77
Gc+½ NPK	131.18^b	3.63	1.39^b	8.96	525.57^b	2.13
Ri+½ NPK	133.01^b	4.70	1.47^b	9.64	528.34^b	0.65
Fm+½ NPK	138.61^b	1.74	1.52^b	2.74	532.95^b	1.34
NPK	147.33^a	3.56	1.73^a	6.81	551.58^a	2.53
Probability	0.000	-	0.005	-	0.000	-
Meaning	***		**		***	

*** p < 0.001 (very highly significant.); **p < 0.01 (highly significant); medium having the same letters are not significantly different; M - average; cv - coefficient of variation; *CTL - witness absolute (not mushrooms or fertilizer minerals); Gc - Glomus cubense; Ri - Rhizophagus intraradices; Fm - Funneliformis mosseae; ½ NPK - ½ dose of $N_{15}P_{15}K_{15}$ recommended; Gc+½ NPK - Glomus cubense + ½ dose of $N_{15}P_{15}K_{15}$ recommended; Ri+½ NPK - Rhizophagus intraradices + ½ dose of $N_{15}P_{15}K_{15}$ recommended; Fm+½ NPK - Funneliformis mosseae + ½ dose of $N_{15}P_{15}K_{15}$ recommended; NPK - full dose of $N_{15}P_{15}K_{15}$ recommended*

the first two feet on each side were removed, and other two central lines have been eliminated. Twelve plants were selected from the two central lines at the rate of six plants per line. In addition, the leaf area of the plants was taken 60 DAS. The leaf area of the plants has been taken sixty (60) days after seedling.

2.8 Evaluation of the yield parameters

At 103^{th} days after seeding, 12 plants from the two central lines of each elementary plot were harvested. After destalking corncobs, the total weight of the corncobs in each plot was taken using an electronic scale (Highland HCB 3001. Max 3000g × 0.1g). After this operation, the ears of each plot were ginned. The total weight of maize kernels was also taken as well as the relative humidity of the kernels at each treatment. The average grain yield of maize plants was determined according to the formula:

$\boldsymbol{R} = \frac{\boldsymbol{P}\times\mathbf{10.000}}{\boldsymbol{S}\times\mathbf{1.000}} \times \frac{\mathbf{14}}{\%\,\boldsymbol{H}}$ Where:

Whereas R yield of maize kernels expressed in t. ha^{-1}; P represents the grain weight (kg); 10000 represents the conversion of ha in m^2; S represents the harvest area (m²); 1000 represents the conversion of tone (t) in kg; H is the percentage of grain moisture, expressed %

2.9. Assessment of roots endomycorrhizal infection

On each basic plot, the maize rhizospheric soil and roots were sampled. Root sampling was done 68 DAS, and rhizopheric soils 95 DAS. Each sample was put in a labeled sterile plastic bag and taken to the laboratory where they were conserved at 4°C until treatment. The method described by Phillips &Hayman (1970) has been used to determine the frequency of mycorrhization.

$$\mathbf{F}(\%) = \frac{(\mathbf{N-no})}{\mathbf{N}} \times \mathbf{100.}$$

Whereas F= infection level of root system, N= number of investigated fragments, n_0= number of fragments without mycorrhization.

Further, Trouvelot et al. (1986) method was used to determine the intensity of mycorrhization

$$\mathbf{I\ (\%)=(95n_5+70\ n_4+30\ n_3+5\ n_2+n_1)\ /\ N-n_0}$$

Whereas I= intensity of mycorrhization; N= number of investigated fragment; n_o = number of fragment without mycorrhization; n_5, n_4, n_3, n_2 and n_1 = five classes of infection that mark the importance of the mycorrhization which are: n5 = more than 95%, n4 = between 50 and 95%, n3 = between 30 and 50%, n2 = between 1 and 30%, n1 = 1%.

While Ramon et al. (2003) adjusted protocol was used to determine the Spores number.

$$\mathbf{S = n_0 \times 1g/N}$$

Whereas S = spore number; n_0=number of observed spore; N= soil quantity.

2.10. Statistical analysis

The influence of various treatments on growth, yield, mycorrhizal parameters and nutritional status of plants compared with control and examined using analysis of variance model based to two factors (Block and treatment). After that, the Dunnett test was used to assess the relative performance of each treatment compared to controls. The influence of the AMF on the mycorrhizal parameters has been analyzed with a stationary model of analysis of the variance followed of the t test of Student Newman Keuls for the treatments structuring. The regression of Fisher has been used to model build the production of spore number and the intensity of mycorhization. Categorization and discrimination of treatment was made with hierarchical digital classification followed by Principal Component Analysis (ACP) with using the R software 3.3.2 with FactoMineR, car, MASS, nnet, heplots et candisc package. Presentation of the segregation of treatment groups in the axis plan (can1, can2).

3 Results

3.1. Effects of various treatments on plant growth and maize grain yield

Effect of different mycorrhizal treatments on maize plant growth and grain yield was found highly significant compared to the control (p <0.01). Thus, the results of Dunnett's test showed that all treatments induced a significant difference in maize height, maize leaf area, and maize grain yield compared to the control (Table 1). The induced effects of mycorrhizal fungi are very high (R2>50%). Among the various texted combinations, full-dose of NPK resulted a significant difference in collar diameter of plants. For the aerial part, higher value was reported for the treatment Fm+½ NPK (*F. mosseae* + ½ dose of NPK) and NPK (full dose of NPK). While in case of underground biomass, highest value was reported for the treatment NPK (full dose of NPK) and ½ NPK (½dose of NPK) compared to controls. The effects induced for the latter are relatively low (R2 <50%).

3.2. Determination of treatments with better performance on maize growth and yield parameters

3.2.1 Growth parameters

The results obtained after analysis of variance showed highly significant difference (p <0.001) between all treatments for plant height and leaf area. Highly significant difference (p <0.01) was reported in case of plants diameter between all tested treatments (Table 2). Plants treated with the full dose of NPK showed superiority over the all other treatments. However, plants treated

with *F. mosseae* + ½ dose of NPK (Fm+½ NPK) also showed good growth in length (24.78%), thickness (14.28%) and leaves width (14.75%) compared to control plants (Table 2).

3.2.2 Yield parameters

The Analysis of variance indicated a significant difference (p <0.05) between treatments for plant biomass and maize grain yield (p <0.001) (Table 3). The highest values of aboveground and

Table 3 Production parameters average value based on the treatments: results of the variance analysis followed by Student Newman and Keuls test

	Biomass Aerial		Underground biomass		Performance	
	m	CV (%)	m	CV (%)	M	CV (%)
CTL	0.36[b]	25.59	0.15[c]	35.61	1.46[c]	4.95
Gc	0.46[b]	45.68	0.11[c]	110.22	1.70[b]	7.87
Ri	0.34[b]	5.42	0.11[c]	64.38	1.73[b]	3.62
Fm	0.42[b]	22.21	0.16[c]	42.96	1.78[b]	4.05
½ NPK	0.55[a]	28.42	0.39[b]	49.23	1.74[b]	1.47
Gc+½ NPK	0.56[a]	18.98	0.21[b]	40.00	1.81[b]	5.68
Ri+½ NPK	0.57[a]	20.88	0.32[b]	19.56	1.87[b]	4.65
Fm+½ NPK	0.60[a]	12.47	0.72[a]	150.45	2.14[a]	3.64
NPK	0.60[a]	12.47	0.42[b]	22.11	2.24[a]	7.25
Probability	0.012		0.020		0.000	
Meaning	*		*		***	

*** p < 0.001 (very highly significant.); *** = p < 0.001 (very highly significant; medium having the same letters are not significantly different; M - average; cv - coefficient of variation; *CTL - witness absolute (not mushrooms or fertilizer minerals); Gc - Glomus cubense; Ri - Rhizophagus intraradices; Fm - Funneliformis mosseae; ½ NPK - ½ dose of $N_{15}P_{15}K_{15}$ recommended; Gc+½ NPK - Glomus cubense + ½ dose of $N_{15}P_{15}K_{15}$ recommended; Ri+½ NPK - Rhizophagus intraradices + ½ dose of $N_{15}P_{15}K_{15}$ recommended; Fm+½ NPK - Funneliformis mosseae + ½ dose of $N_{15}P_{15}K_{15}$ recommended; NPK - full dose of $N_{15}P_{15}K_{15}$ recommended*

Table -4: Effects of CMA on the mycorrhization parameters (Variance test result)

Treatments	Frequency (%)		Intensity (%)		Number of spore	
	m	CV (%)	m	CV (%)	m	CV (%)
Gc	29.75 [a]	16.32	09.50 [a]	40.77	1.00[a]	-
Ri	38.50[a]	43.28	07.25 [b]	42.70	1.73[a]	49.95
Fm	31.75[a]	53.60	11.00 [a]	61.66	1.52[a]	41.16
Gc+½ NPK	38.50[a]	23.76	9.50 [a]	36.97	1.15[a]	26.09
Ri+½ NPK	37.00[a]	35.92	5.25 [c]	32.53	1.00[a]	-
Fm+½ NPK	32.00[a]	20.25	4.00 [c]	45.64	1.00[a]	-
Probability	0.842	-	0.127	-	0.139	-
Significance	NS		NS		NS	

ns: not significant, the medium having the same letters are not significantly different. m: average; cv: coefficient of variation; Glomus cubense (Gc); Rhizophagus intraradices (Ri); Funneliformis mosseae (Fm); Glomus cubense + ½ dose of $N_{15}P_{15}K_{15}$ recommended (Gc+½ NPK); Rhizophagus intraradices + ½ dose of $N_{15}P_{15}K_{15}$ recommended (Ri+½ NPK); Funneliformis mosseae + ½ dose of $N_{15}P_{15}K_{15}$ recommended (Fm+½ NPK)

belowground biomass were obtained with plants treated with *F. mosseae* + ½ NPK dose (Fm+½ NPK) followed by those treated with the full NPK dose. In terms of grain yield, the treatment having Fm+½ NPK (*F. mosseae* + ½ NPK dose) and NPK (full-dose NPK) yielded highest yields, with respective increases of 46.57% and 53.42% yield compared to control plants (CTL).

3.3. Effects of endomycorrhizal infection on mychorhization parameters

In case of mycorrhizal frequency, mycorrhizal intensity and spore number, the analysis of variance revealed non significant difference between the different AMFs (Table 4). However, the plants receiving only *R. intraradices* induced the best roots frequency of mycorrhization (38.50%) and a high number of spores (1.73 spores/g of soil). While those receiving only *F. mosseae* induced the best roots intensity of mycorrhization (11%). Globally, plants that received AMFs in combination with mineral fertilizers had the lowest values for all mycorrhizal parameters.

3.4. Categorization and discrimination of treatments according to their potential for action on maize plant growth and grain yield

The results of the hierarchical classification based on the performances of mycorrhizal fungi on maize plant growth and grain yield showed four groups of treatments (Figure 2). The cluster 1 is composed only of treatment Fm+½ NPK and the cluster 2 is consists of treatment NPK. The cluster 3 is composed of the ½ NPK, Gc+½ NPK and Ri+½ NPK treatments whereas the cluster 4 is composed of the Gc, Ri and Fm treatments. The canonical discriminative analysis carried out on the clusters in order to differentiate them with respect to the growth and yield parameters showed that the Cluster 1 treatment induced a high production of the aboveground and underground biomass and a good yield (Figure 3). Cluster 2 treatments, as it concern, caused mainly high growth in neck height and diameter and large leaf area of plants with high maize grain yields. Cluster 3 treatments induced mean aboveground and belowground biomass and opposed Cluster 4 treatment, which yielded seedlings of height, leaf area and average neck diameter (Figure 3).

4 Discussion

This increase in growth may be due to the fineness of the mycorrhizal hyphae (diameter <3 µm) which allows them to penetrate all the interstices of soil particles to facilitate the transport of non-mobile mineral elements particularly phosphorus in favor of the plant (Lambers et al., 2008). Laminou (2010) reported that mycorrhizal inoculation stimulates the growth of sorghum (*Sorghum bicolor* L.), these results are in agreement with the findings of present study. Similarly, Ouahmane et al. (2007) also reported the beneficial effects of mycorrhizal symbiosis on the growth of Gaussen (*Cupressus atlantica*). Moreover, Diouf et al. (2009) and Bourou (2012) observed that *F. mosseae* induced an improvement in the foliar growth of Sesame

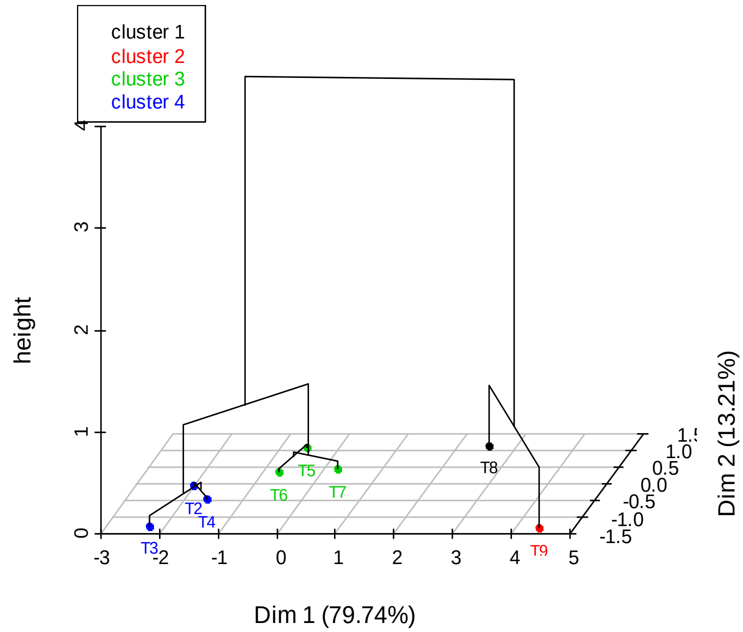

Figure 2 Representation of the cluster treatment obtained after the digital classification (*Whereas T2 – Gc; T3 – Ri; T3 – Fm; T5 - ½ NPK; T6 - Gc+½ NPK; T7 - Ri+½ NPK; T8 - Fm+½ NPK; T9 - NPK*)

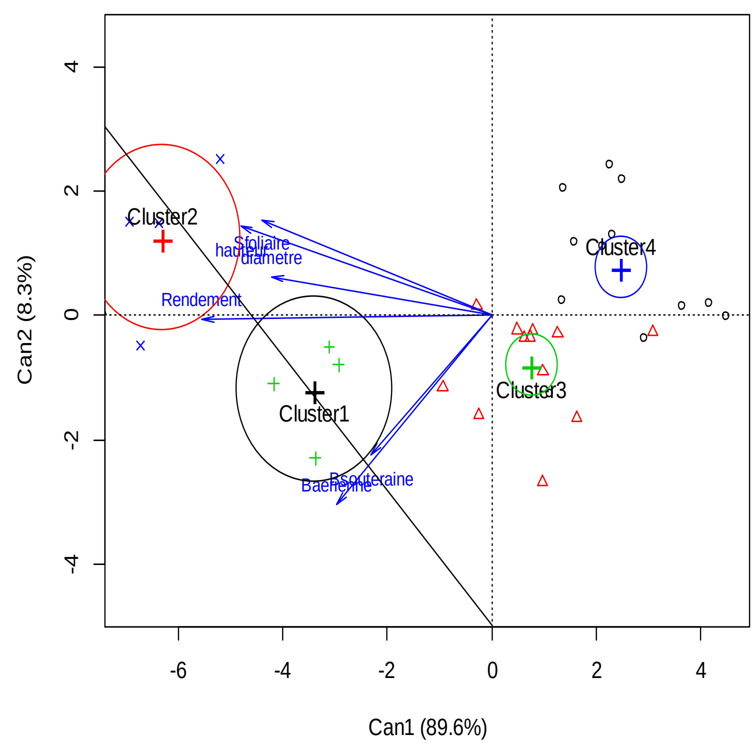

Figure 3 Representation of the segregation of treatment groups in the axis plan (can1, can2).

(*Sesamum indicum* L.) plants and the neck diameter of tamarind (*Tamarindus indica* L.) plants. Balzergue (2012) suggested that mycorrhizae establish symbiotic associations with the roots of plants, which allows them to provide plants water and minerals which help in establishing good yield.

The highest yields of aerial and underground biomass production were obtained with plants treated with *F. mosseae* combined with half-dose of NPK. These results confirm by the work of Diouf et al. (2009), who observed an increase in aerial and underground biomass of *Sesamum indicum* plants inoculated with *F. mosseae*. This stimulation is the result of an improvement in the nutritional and especially phosphate status of plants (Benjelloun et al., 2004) as well as an improvement in plants photosynthesis (Jesús et al., 2004).

In case of maize grain yield, plants treated with the full-dose of NPK followed by those treated with *F. mosseae* and half-dose of NPK significantly improved maize grain yield with increases of 53.42% and 46.57%, respectively compared to control plants. These results confirmed with the findings of Haro (2016) in Burkina Faso that showed that *Scutellospora* ssp. and *Gigaspora* ssp. have great potential to increase cowpea yield from 28.78% to 60.16% respectively. Similarly, Labidi et al. (2014) reported the beneficial role of mycorrhizal inoculation in Tunisia on the yield of durum wheat (*Triticum durum* Desf.). On the other hand, although CMAs positively influenced grain yield, these results would be even better if plants had received the normal amount of rain. Indeed, during the years 1990 to 2012, the rainfall ranged from 873 to 1700 mm in North Benin. In the period of our study, the rainfall recorded during the three test months was 743.3 mm, with a decrease in rainfall especially in the months of September (144.7 mm) and October (105.1 mm). Similar results were observed by Diouf & Lambin (2001) who have shown through their work that maize plants that have undergone water stress (465 mm and 430 mm) have a low yield (2.28 t / ha and 1.44 t / ha) compared to those which have been irrigated normally.

The results obtained on endomycorrhizal infection revealed that there is no significant difference between treatments. However, plants treated with *R. intraradices* had a better frequency of mycorrhization (38.50%). Results of present study are in agreement with the findings of Meddad et al. (2011), who observed that *R. intraradices* have high rate of mycorhization (69.96%). Some differences were observed between these two studies which can be explained by the use of different soil. However, in some studies level of infection is very high and it is more beneficial to the plant (Diagne & Ingleby, 2003) than the result of present study but it might be due to difference in climatic conditions. Hetrick et al. (1992) also observe that plant growth is not necessarily related to the degree of colonization of their roots by AMFs.

Among the three treatments with half-dose of NPK, only treatment with *F. mosseae* gave the lowest frequency of mycorrhization (32%). Our results evolved in the same direction as those obtained by Meddad et al. (2011). Indeed, these authors have shown in their work that the inoculation of the olive tree (*Olea europea* L.) with *F. mosseae* induces a mycorhization frequency of 51.06% and it was lower than that of *R. intraradices* (69.96%). This difference in value might be difference in the soils and nature of the plant used for experimentation. In addition, Diatta et al. (2013) worked on sesame (*Sesamum indicum*) and reported that *F. mosseae* have no significant difference on the intensity of mycorrhization between treatments. These results are in agreement with the findings of present study. Similarly, Haro (2016) have shown that the mycorrhization frequency of inoculated plants is high (82%) whereas the intensity of mycorrhization remains low (27.89%).

In addition, the results obtained in present study showed that plants received only *R. intraradices* induced a high number of spores (1.73 spores / g of soil) compared to the other two strains. However, after adding the NPK, the number of spores is one per g of soil. Other studies have shown that the addition of inorganic phosphorus decreases the colonization rate of *R. intraradices* (Nouaim & Chaussod, 1996). Similarly, Mäder et al. (2000) and Goalbaye et al. (2013) have reported that the increase in mineral phosphate fertilizer in conventional agriculture decrease the AMFs colonization in root.

Conclusion

The results of the present study showed the beneficial role of mycorrhizae inoculation on the growth and seeds yield of maize plant. The assessment in station showed that the combination of these three arbuscular mycorrhizal fungi with 50% of recommended NPK had a meaningful effect on the growth and the yield of the maize on ferruginous soil in the Northern Benin. The most important result was the one with *F. mosseae* combined to half dose of recommended NPK. This bio product can be recommended in the future to improve the productivity and the durability of agricultural system. This study is a complementary contribution of the fertilizing organic on ferruginous soil to the Northern Benin. It will be interesting to identify and to characterize the native species of arbuscular mycorrhizal fungi in Northern Benin, and evaluate their effects on the growth and seeds yield of maize.

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Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

Akpinfa ED, Kissira A, Akpo MA, Houssou CS (2017) Evaluation du cout économique de la dégradation des terres dans la zone agro-écologique du centre Benin. European Scientific Journal 13 : 354-366

Balzergue C (2012) Regulation of the symbiosis endomycorhizienne by lephosphate, PhD thesis submitted to the department of Biology, University Paul Sabatier - Toulouse III.

Benjelloun C, Ghachtouli NE, Benbrahim K, Amrani JK, Yamani JE (2004) Influence of the mycorhization by the mushroom glomus mosseae on the growth and the metabolism of the corn (*Zea mays*. L) under conditions of stress hydrique. Journal of Catalysis, Material and Environment III: 31-36.

Bourou S (2012) Survey physiological éco of the Tamarind (*Tamarindus indica* L.) in arid tropical environment. PhD Thesis submitted to the Faculty of Bioscience Engineering, University of Ghent, Pp. 193.

Dalpé Y (2005) Les mycorhizes : un outil de protection des plantes mais non une panacée Phytoprotection 86 : 1-82.

Delphine M, Thé C, Tsoata E, Zonkeng C, Yvette C, Mfopou M (2011) Inhibition of the growth and the output of the corn (*Zea mays*) in very acidic soils in Cameroon, and identification of precocious criterias of tolerance to the toxicity, Tropicultura, Pp. 94-100.

Diagne O, Ingleby K. (2003) Ecology of the AMF mycorhiziens arbusculaires infecting *Acacia raddiana*. *In* : Grouzis M, Floc'h L (Eds.) Un arbre au desert. IRD Editions: Paris; Pp : 205-228.

Diatta MB, Laminou O, Macoumba PR, Diop T (2013) Effects of the inoculation mycorhizienne on the sesame (*Sesamumindicum L.*) in natural conditions. International Journal of Biological and Chemical Science 7: 2050-2057.

Diouf A, Lambin E (2001) Monitoring land-cover changes in semi-arid regions: Remote sensing data and field observations in the Ferlo, Senegal. Journal of Arid Environments 48: 129–148.

Diouf M, Boureima S, Diop TA (2009) Answers of two varieties of sesame have inoculation with Arbuscular mycorrhizal fungi candidates. Agronomy African 21: 37 – 47

Fernández F, Gómez R, Vanegas LF, Noval BM, Martínez MA (2000) Producto inoculante micorrizógeno. Oficina Nacional de Propiedad Industrial. Cuba, Patente No. 22641.

Goalbaye T, Guisse A, Ndiaye MR, Tissou M (2013) The populations of corn improven and adapted to the drought for the zones to weak pluviométrie in the Tchad. International Journal of Biological and Chemical Science, 7: 2275-2282.

Haro H (2016) Optimization of the symbioses rhizobienne and mycorhizienne to improve the productivity of the cowpea [*Vigna unguiculata* (L.) Walp.] to Burkina. PhD thesis submitted to the University Ouaga, Pp. 241.

Hetrick B, Wilson G, Cox T (1992) Mycorrhizal dependency of modern wheat varieties, landraces ancestors. Canadian and Newspaper of Botany 70: 2032-2040.

Igué A, Adjanohoun A, Aîhou C, Mensah G (2015) Technique of information: Assessment of the state of the fertility of the soils fields of the producers elites of corn of Benin. Deposit legal N° 8116 of the 09/09/2015, 3rd Quarter, National Library (BN) of Benin - ISBN: 978-99919-0-707-9.

INRAB (1995) Fiches Techniques Des Cultures Vivrières.

Javot H, Penmetsa RV, Terzaghi N, Cook DR, Harrison J (2007) To Medicagotruncatula phosphate to transport indispensable heart the arbuscular mycorrhizal symbiosis. Proceedings of the National Academy of Sciences of the United States of America 104: 1720-1725.

Jesús SB, Trinitario F, Angeles M, Asunción M, José A (2004) Variations in water status, gas exchange, and growth in *Rosmarinus officinalis* plantations infected Glomus with deserticola under drought conditions. Plantation Physiology 161: 675-682.

Johnson Y (2008) Biodiversity of the mushrooms indigenous endomycorhiziens associated to the niébé (*Vigna unguiculata (L.) Walpers*) in different agroécosystèmes of the Bénin. PhD Thèsis submitted to the University of Calavi Abomey.

Labidi S, Lounès-Hadj SA, Tisserant B, Laruelle F, Rjaibia W, Hamdi K, Ben Jeddi F (2014) Interest of a fertilizing local mycorhizien in the growth of the plants in big cultures. National day on the valorization of the Research results in the Big Culture domain. Tunisia, Available on www.iresa.agrinet.tn access on 25th September, 2018.

Lambers H, Raven JA, Shaver GR, Smith SE (2008) Plant nutrient-acquisition strategies change with soil age. Trends in Ecology and Evolution 23 : 95-103.

Laminou MO (2010) Fixing of the dunes in the southeast of Niger: assessment of the efficiency of the mechanical gate, adapted woody species and potentialities of inoculation mycorhizienne. PhD thesis submitted to the University of Cork, Cork, Belgium, Pp. 158.

Mader P, Edenhofer S, Boller T, Wiemken A, Niggli U (2000) Arbuscular mycorrhizae in a long-term fiel trial comparing low-input (organic, biological) and high-input (conventional) farming systems in a crop rotation. Journal of Biology and Fertility of Soil 31: 150-156.

MAEP (Ministry agriculture, raising and the Fishing) (2010) Strategic plan of Raise of Agricultural Sector (PSRSA). MAEP, Cotonou, Benin, Pp. 69

Meddad-Hamza, Beddiar1 A, Gollotte A, Gianinazzi S (2011) Management des mycorhizes chez l'olivier. Available on https://www.researchgate.net/publication/313837067 access on 25th September, 2018.

Megueni C, Awono ET, Ndjouenkeu R (2011) Simultaneous effect of dilution and the combination of the Rhizobium and mycorhizes on the leaveproduction and the physico - chemical properties of the young leaves of *Vigna unguiculata* (L.) Walp. Journal of Applied Biosciences 40 : 2668 – 2676.

Micaela N (2015) Impact of a mushroom mycorhizien to arbuscules (*Rhizophagus irregularis* MUCL 41833) on the withdrawal of the phosphor at the corn (*Zea mays*) in condition of saline stress, Pp. 14.

Nouaim R, Chaussod R (1996) Role of the mycorhizes in the food hydrique and mineral of the plants, notably of the woody of arid zones. Notebooks Mediterranean Options, Vol. 20 seminary.

Ouahmane L, Hafidi M, Thioulouse J, Ducousso M, Kisa M, Prin Y, Galiana A, Boumezzough A, Duponnois R (2007) Improvement of *Cupressusatlantica*Gaussen growth by inoculation with native arbuscularmycorrhizal fungi. Journal of Applied Microbiology, 103: 683-690. Doi: 10.1111/j.1365-2672.2007.03296.x

Phillips JM, Hayman DS (1970) Improved procedures heart clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi heart rapid assessment of infection. Transactions of the British Mycological Society 55: 158-161.

Priou L (2013) Multiplication des mycorhizes arbusculaires en milieu liquide et solide afin d'améliorer la formulation de biofertilisants. Sciences agricoles. Available on https://dumas.ccsd.cnrs.fr/file/index/docid/975007/filename/Priou_Laure_Mycorhizes_arbusculaires_milieu_liquide_solide.fr.pdf access on 25th septembre, 2018.

Ramon ARE, Felix F, Alberto HJ, José RT (2003) The simbiosismicorrizicaarbuscular. In: El manejoefectivo of the simbiosismicorrizica, unaviahacialaagriculturasostenible. Estudio of caso: El Caribe. The Habana INCA, 2003 :1-42.

Ruget FB, Bonhomme R, Chartier M (1996) Estimation simple de la surface foliaire de plantes de maïs en croissance. Agronomie 16: 553-562. DOI : https://doi.org/10.1051/agro:19960903

Trouvelot A, Kough JL, Gianinazzi-Pearson V (1986) Mesure du taux de mycorhization VA d'un système radiculaire. Recherches et méthodes d'estimation ayant une signification fonctionnelle. In: Aspects physiologiques et génétiques des mycorhizes, Dijon, 1985: INRA.

Warda S (2011) Diversité des mycorhizes arbusculaire chez la variété « Sigoise » d'olivier (*Oleaeuropea* L.) : étude de leurs efficacités sur la croissance des plants. M.Sc. Thesis submitted to the University of Oran ES-SENIA, Pp. 180 available on https://theses.univ-oran1.dz/document/TH3392.pdf

Yallou CG, Aïhou K, Adjanohoun A, Toukourou M, Sanni OA, Ali D (2010) Itinéraires techniques de production de maïs au Bénin. Fiche technique. Dépôt légal N° 4922 du 3 Décembre, Bibliothèque Nationale du Bénin.