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Impact of native arbuscular mycorrhizal fungi based fertilizers on to increase maize productivity in North Benin

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Mycorrhizae are symbiotic associations between fungi and host plants, which confer several advantages, including good mineral nutrition. Arbuscular mycorrhizal fungi (AMF) then present an effective alternative in order to develop a sustainable agriculture that is less dependent on mineral fertilizers. The objective of this study was to assess the impact of organic fertilizers based on native arbuscular mycorrhizal fungi on increasing maize productivity and improving soil health in North Benin. For this study, three mycorrhizal fungi strains (*Glomeraceae* sp., *Acaulosporaceae sp*. and *Diversisporaceae* sp.) were used with or without mineral fertilizers. The corn variety 2000 SYN EE-W was used. The experimental design is a randomized complete block of nine treatments with three replicates. After 65 days, the endomycorrhizal infection was evaluated. The results showed that mycorhizal fungi had a positive impact on the different plant growth parameters (height, leaf area, and yield). At the height level, Acaulospora + ½ dose of $N_{15}P_{15}K_{15}$ recommended + urea produced good results compared to the control, an increase of 24.9%. The same observations were made for leaf area and yield, an increase of 70.4 and 39.04%, respectively. However, the results show that the rate of endomycorrhizal infection is high with *Diversisporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + urea followed by *Glomeraceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + urea and *Acaulosporeacea* sp.+ 50% of recommended $N_{15}P_{15}K_{15}$ + urea. In terms of spore number, the treatment *Glomeraceae* sp. gave the best result.

Key words: Mycorrhizal fungi, organic fertilizer, corn, Benin.

INTRODUCTION

In West Africa, corn is used for human and animal food and is used as a raw material in industries including brewing, soap and oil (Boone et al., 2008; Naitormmbaide et al., 2015). This cereal represents a significant source of income for producers and traders. However, there is low productivity of maize mainly due to the decline in soil fertility (Balogoun, 2012). The main solution to this problem is the use of mineral manures to increase the yield of maize production. This solution seems not to help an efficient in long term because several studies have shown that long-term fertilizer use leads to acidification of the land (Therond et al., 2017). However, for quality plant production implies high-end finished products and the use of technologies that best protect the environment, any realistic approach aimed at reducing the use of pesticides and chemical fertilizers and protecting crops and the quality of the soil deserves to be exploited (Assogba et al., 2017).

The relationships between soil microorganisms and the functioning of ecosystems have for some years been among the main objects of research in ecology. Those soil microorganisms are considered as a “key” microbial group in the functioning of terrestrial ecosystems, in particular for their ability to promote the development of plants in degraded environments (Abbas, 2014). Previous studies have shown that these mycorrhizae can be beneficial in agricultural ecosystems (Zhang et al., 2016).

It was reported that mycorrhizae are widespread in the main ecosystems and are found in 95% of plants (Diallo et al., 2016; Kouadio et al., 2017). Mycorrhizae are observed on most of the cultivated plants that are used for human and animal foods (Leake et al., 2004). Thus according to Tchabi et al. (2016), it would be possible to promote healthier farming systems using mycorrhizal fungi. This solution can reduce the use of chemical inputs (pesticides and fertilizers) while ensuring the profitability of crops and quality environment and long-term preservation of soil fertility and ecosystem stability. Indeed, mycorrhizae play a key role in the mineral nutrition of many plant species, especially those that thrive in marginal soil fertility conditions (Assogba et al., 2017). The objective of this study was to assess the impact of organic fertilizers based on native arbuscular mycorrhizal fungi to increase the productivity of corn and improve soil health in Benin.

MATERIALS AND METHODS

Variety of corn

For this study, the 2000 SYN EE-W corn variety was used. It is an 80-day extra-early variety developed by the International Institute of Tropical Agriculture (IITA) and the National Institute of Agricultural Research in Benin (INRAB). The grain yield in rural areas is 2.5 $t.ha^{-1}$. A variety has good resistance to breakage, streaking, american rust and helminthosporiasis. In addition, it tolerates pests and drought (MAEP, 2016).

Microorganisms

The inoculum used were native arbuscular mycorrhizal fungi (*Glomeraceae sp., Acaulosporaceae* sp. and *Diversisporaceae* sp.), these strains were isolated and characterized from North Benin rhizospheric soils and then kept at the Laboratory of Biology and Molecular Typing in Microbiology (LBTMM) of the University of Abomey-Calavi (UAC).

Characteristics of the experimental site

This study was carried out in Ina, at an altitude of 358 m between a latitude 9˚58'N and a longitude 2˚44'E at the North Benin Agricultural Research Center located in the town of Bembèrèkè (Figure 1). The experimental site is characterized by tropical ferruginous soil with very variable characteristics, very sensitive to leaching and a rainy season between May and September CRA-Nord (2007). The soil content of our experiment site was organic matter (1.92%), nitrogen (0.092%, pH 5.7), phosphorus (58 ppm) and potassium (0.49 meq/100 g of soil). The sum of the bases and the cation exchange capacity are average (Igué et al., 2015).

Experimental design

The experimental design was a randomized complete block of nine treatments with three repetitions. Each treatment covered an elementary plot of 12.8 m² made up of four lines of 4 m. The sowing was done at a spacing of 0.80 m × 0.40 m (a density of 31.250 plants/ha). The aisles between plots and rehearsals were 1.8 and 2 m, respectively. The growth and yield data were collected on the useful plot (6.4 m^2) represented by the two central lines. The different treatments evaluated were T1 (Control), T2 (*Glomeraceae sp.*), T3 (*Acaulospora*), T4 (*Diversisporaceae* sp.), T5 (50% of recommended $N_{15}P_{15}K_{15}$ + Urea), T6 (*Glomeraceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea), T7 (*Acaulosporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea), T8 (*Diversisporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea) and T9 (100% of recommended $N_{15}P_{15}K_{15}$ + Urea). Mineral fertilizer dose recommended in Benin is 200 kg/ha of NPK to sowing and 100 kg/ha of urea 45 days after sowing $N_{15}P_{15}K_{15}$ (INRAB, 1995).

Evaluation of growth parameters

The height, the diameter at the collars and the number of leaves of the selected plants were taken every 15 days after sowing until the 60^{Th} day when the leaf surface was taken. The product of the length and width of the leaves affected by the coefficient 0.75 estimated the leaf area (Ruget et al., 1996).

Evaluation of the yield parameters

Per elementary plot, 12 plants were harvested at 85 DAS on the two central lines of each elementary plot. After the deseeding and ginning of the corncobs, the total weight of the corn kernels in each plot was taken using an electronic scale (Highland HCB 3001 Max 3000 g × 0.1 g). After this operation, the relative humidity (LDS-1F) of the corn kernels was taken for each treatment.

The average grain yield of corn plants was determined according

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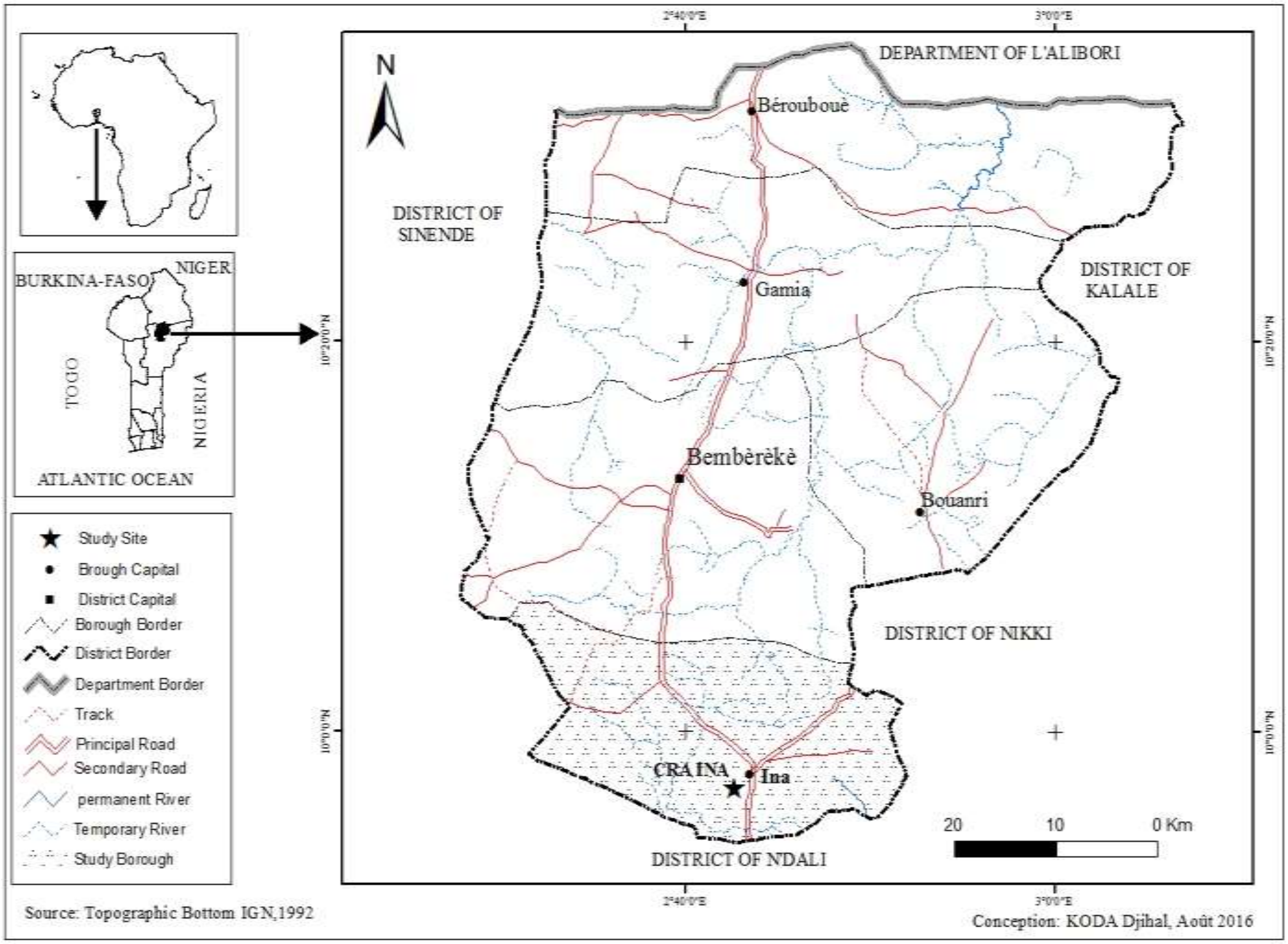

Figure 1. Geographical location of the experimental station.

to the formula developed by Kjeldahl (1883).

$$Y = \frac{P \times 10{,}000}{S \times 1{,}000} \times \frac{14}{\%\,H}$$

With: Y is the average yield of corn kernels expressed in t.ha^{-1}, P is the weight of the corn kernels expressed in kilograms (kg), 10,000 is the conversion from m^2 to ha, S is the harvest area in m², 1000 conversion from kg to ton (t), 14 is the initial humidity value and % H is the percentage of grain moisture, expressed as %.

Sampling and evaluation of endomycorrhizal root infection

The more root soil samples from each plot were taken with an auger at the level of a few feet of corn at a depth of 0-20 cm. Once collected, sample was put in a sterile labeled plastic bag, transported in coolers to the laboratory, and stored at 4°C until treatment.

The technique of Phillips and Haymann (1970) was used for the determination of endomycorrhizal infection. The roots are cut into 1 cm long pieces to 0.2 g; of these, to the roots were added 10% KOH, before incubation at 90°C for 1 h. After the incubation time, samples were rinsed thoroughly with water; the 0.05% trypan blue solution was added to the root and then the whole leaked back into the oven at 70°C for 15 min. After this operation, the roots are washed with cleaned water and then observed with microscope (Motic, S/N S 219031590).

Mycorrhization frequency and intensity were evaluated using the method described by Trouvelot et al. (1986):

$$\mathrm{F}(\%) = \frac{(\mathrm{N} - \mathrm{n0})}{\mathrm{N}} \times 100$$

With: F reflecting the degree of infection of the root system; N corresponds to the number of fragments observed and n0 the number of fragments without trace of mycorrhization.

I (%) = (95n5 + 70 n4 + 30 n3 + 5 n2 + n1) / N-no

With: I is the intensity of mycorrhization; N is number of fragments observed; no is number of fragment without trace of mycorrhization; n5, n4, n3, n2 and n1 are respectively the five classes of infection marking the importance of mycorrhization namely: 5 = more than 95%, 4 = from 50 to 95%, 3 = 30 to 50%, 2 = 1 to 30% and 1 = 1%.

The determination of the number of spores was made using an adaptation of the protocol described by Rivera et al. (2003) and the formula used is as follows:

$S = n_0 \times 1g / N$

With: S is number of spores, n_0 is number of spores observed and N is amount of soil

Statistical analysis

By fitting a linear model with mixed effects on longitudinal data, the impact of mycorrhizal fungi on plant growth parameters (height and diameter at the collar) was evaluated. Treatments were considered to be fixed factors and time was considered a random factor. The adjusted means were also calculated in order to represent the evolutionary trends of each growth parameter at the level of each treatment. These analyzes were done with R 3.6.0 software (R Core Team, 2019) using the packages nlme (for fitting the model), lsmeans (for calculating adjusted means), and ggplot2 (for representing curves). The performance of the plants (leaf area and grain yield) was assessed using an analysis of variance. The tests of Ryan-Joiner and Levene (Glèlè Kakaï et al., 2006) were carried out in order to verify the conditions of normality and homoscedasticity of the data essential for the realization of ANOVA. The Dunnett test (post-hoc or multiple comparisons) was carried out in order to assess the statistical differences in the means when the results of the ANOVA are significant. The adjusted means were also calculated in order to represent the means of each growth parameter according to each treatment. The packages car, lsmeans and ggplot2 were respectively used to perform the ANOVA, the calculation of adjusted averages and the editing of graphs.

RESULTS

Plant height

The results of the linear mixed effects model have shown that time has a significant effect on the plant height ($p < 0.0001$). Also, the processing ($p = 0.031$) and then the interaction between time and processing ($p = 0.034$) are not significant. We deduce that the variations observed over time depend on the treatment. In this study, the *Acaulosporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ and 100% of recommended $N_{15}P_{15}K_{15}$ treatments have a significant effect on plant growth regardless of the duration of the treatment (Table 1). The recommended full dose of P and *Acaulosporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea better affects plant growth.

Collar diameter

The variations observed in plant growth in terms of collar diameter over time depend on the treatments ($p = 0.0002$). Treatments supplying 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, *Glomeraceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, *Acaulosporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, *Diversisporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea and full dose of recommended $N_{15}P_{15}K_{15}$ + Urea have a significant effect over time on the collar diameter of the plants (Table 2). Those treatments have a significant impact on corn plants.

Impact of mycorrhizal fungi on leaf area and grain yield

The results of the analysis of variance (Table 3) show a significant difference in the effects of the treatments on the leaf surfaces of the plants ($p = 0.003$).

The leaf area of plants subjected to the *Acaulosporaceae sp.*+ 50% of recommended $N_{15}P_{15}K_{15}$ and full dose of recommended $N_{15}P_{15}K_{15}$ + urea treatments had a different statistical effect on the leaf area of the plants subjected to the control (Figure 2).

It should be noted that the other treatments do not have statistically different effects from that of the control treatment. However, treatments did not have statistically different effects on plant yields (Figure 3).

Field infestation settings

The analysis of variance shows a significant difference with the treatment of *Diversisporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea compared to the control. However, the plants that received the *Glomeraceae* sp. inoculum induced the best frequency of mycorrhization (Table 4).

Number of spores

The analysis of variance results showed (Table 5) a significant difference in the treatment that receives *Glomeraceae sp.*, *Diversisporaceae sp.*, *Diversisporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea. The number of spores is high with these same strains.

DISCUSSION

Mycorrhizal fungi are generally described as essential components of soil-plant systems. Representing a key interface between host plants and soil (macro- and micro-) nutrients, the benefits of mycorrhizal symbiosis also include increased plant resistance to pathogens and other environmental stresses (that is, organic and metallic pollution, salinity and acidity) and an improvement in the water nutrition of host plants in exchange for photosynthetes (Lambers et al., 2008). Statistical analyzes have shown that of the three strains only treatment with Acaulospora + ½ dose of recommended $N_{15}P_{15}K_{15}$ + Urea induced good results

Table 1. Effects of treatments on corn plant height.

Parameter	t-Value	p-Value
(Intercept)	-2.884910	0.0049
Time	8.775380	0.0000
Glomeraceae sp. (T2)	0.227477	0.8206
Acaulosporaceae sp (T3)	0.832007	0.4077
Diversisporaceae sp (T4)	1.186087	0.2388
50% of $N_{15}P_{15}K_{15}$ + Urea (T5)	0.506738	0.6136
Glomeraceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T6)	0.930430	0.3547
Acaulosporaceae sp+ 50% $N_{15}P_{15}K_{15}$ + Urea **(T7)**	**2.135818**	**0.0355 ***
Diversisporaceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T8)	1.947296	0.0547
100% $N_{15}P_{15}K_{15}$ + Urea (**T9)**	**3.152591**	**0.0022 ***
Time: T2	0.830792	0.4083
Time: T3	-0.454600	0.6505
Time: T4	-0.651631	0.5163
Time: T5	0.149723	0.8813
Time: T6	-0262951	0.7932
Time**: T7**	**-2.113554**	**0.0374 ***
Time: T8	-1.161590	0.2485
Time**: T9**	**-2.219381**	**0.0290 ***

T1 = Absolute control, T2 = *Glomeraceae sp.*, T3 = *Acaulosporaceae* sp. T4 = *Diversisporaceae sp.*, T5 = 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T6 = *Glomeraceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T7 = *Acaulosporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T8 = *Diversisporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T9 = full dose of recommended $N_{15}P_{15}K_{15}$ + Urea, * significant values, Time: T = interaction time and treatment

Table 2. Effects of the treatments on the growth in diameter at the collar of the plants.

Parameter	t-Value	p-Value
(Intercept)	2.702686	0.0083
Time	1.894991	0.0614
Glomeraceae sp. (T2)	0.203106	0.8395
Acaulosporaceae sp (T3)	-0.524080	0.6015
Diversisporaceae sp (T4)	-0.476715	0.6347
50% of $N_{15}P_{15}K_{15}$ + Urea (T5)	**-2.146334**	**0.0346 *****
Glomeraceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T6)	-1.790805	0.0768
Acaulosporaceae sp+ 50% $N_{15}P_{15}K_{15}$ + Urea **(T7)**	**-3.166270**	**0.0021 *****
Diversisporaceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T8)	**-2.757414**	**0.0071 *****
100% $N_{15}P_{15}K_{15}$ + Urea (**T9)**	**-2.698718**	**0.0083 *****
Time: T2	0.253567	0.8004
Time: T3	0.856038	0.3943
Time: T4	1.298533	0.1975
Time: T5	**3.527295**	**0.0007 *****
Time: T6	**2.880950**	**0.0050 *****
Time: T7	**4.133472**	**0.0001 *****
Time: T8	**4.425512**	**0.0000 *****
Time: T9	**4.479283**	**0.0000 *****

T1 = *Glomeraceae* sp. Absolute control, T2 = *Glomeraceae sp.*, T3 = *Acaulosporaceae sp.*, T4 = *Diversisporaceae sp.*, T5 = 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T6 = + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T7 = *Acaulosporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T8 = *Diversisporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T9 = full dose of recommended $N_{15}P_{15}K_{15}$ + Urea, * significant values, ** highly significant, *** very highly significant, Time: T = Interaction time and treatment.

with regard to the height growth of the plants (Table 2) compared to the control. Other authors observed similar

Table 3. Effects of treatments on yield parameters.

Parameter	Leaf area (cm^2)	Yield (kg/ha)
	Moy ± sd	**Moy ± sd**
Absolute control (T1)	119.25 ± 25.62	1.46 ± 0.18
Glomeraceae sp. (T2)	123.29 ± 57.75	1.13 ± 0.41
Acaulosporaceae sp (T3)	95.59 ± 19.03	1.37 ± 0.35
Diversisporaceae sp. (T4)	108.04 ± 31.34	1.22 ± 0.39
50% $N_{15}P_{15}K_{15}$ + Urea (T5)	179.50 ± 3.11	1.71 ± 0.17
Glomeraceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T6)	172.77 ± 19.57	1.87 ± 0.56
Acaulosporaceae sp+ 50% $N_{15}P_{15}K_{15}$ + Urea (T7)	203.21 ± 13.81	2.03 ± 0.57
Diversisporaceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T8)	199.09 ± 60.00	1.95 ± 0.54
100% $N_{15}P_{15}K_{15}$ + Urea (T9)	213.32 ± 23.37	1.73 ± 0.28
F value	4.936	1.76
Pr (>F)	0.003 ***	0.161

T1 = Absolute control, T2 = *Glomeraceae sp.*, T3 = *Acaulosporaceae* sp. T4 = *Diversisporaceae sp.*, T5 = 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T6 = Glomeraceae sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T7 = Acaulospora + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T8 = Diversisporaceae sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T9 = full dose of recommended $N_{15}P_{15}K_{15}$ + Urea, *** significant values.

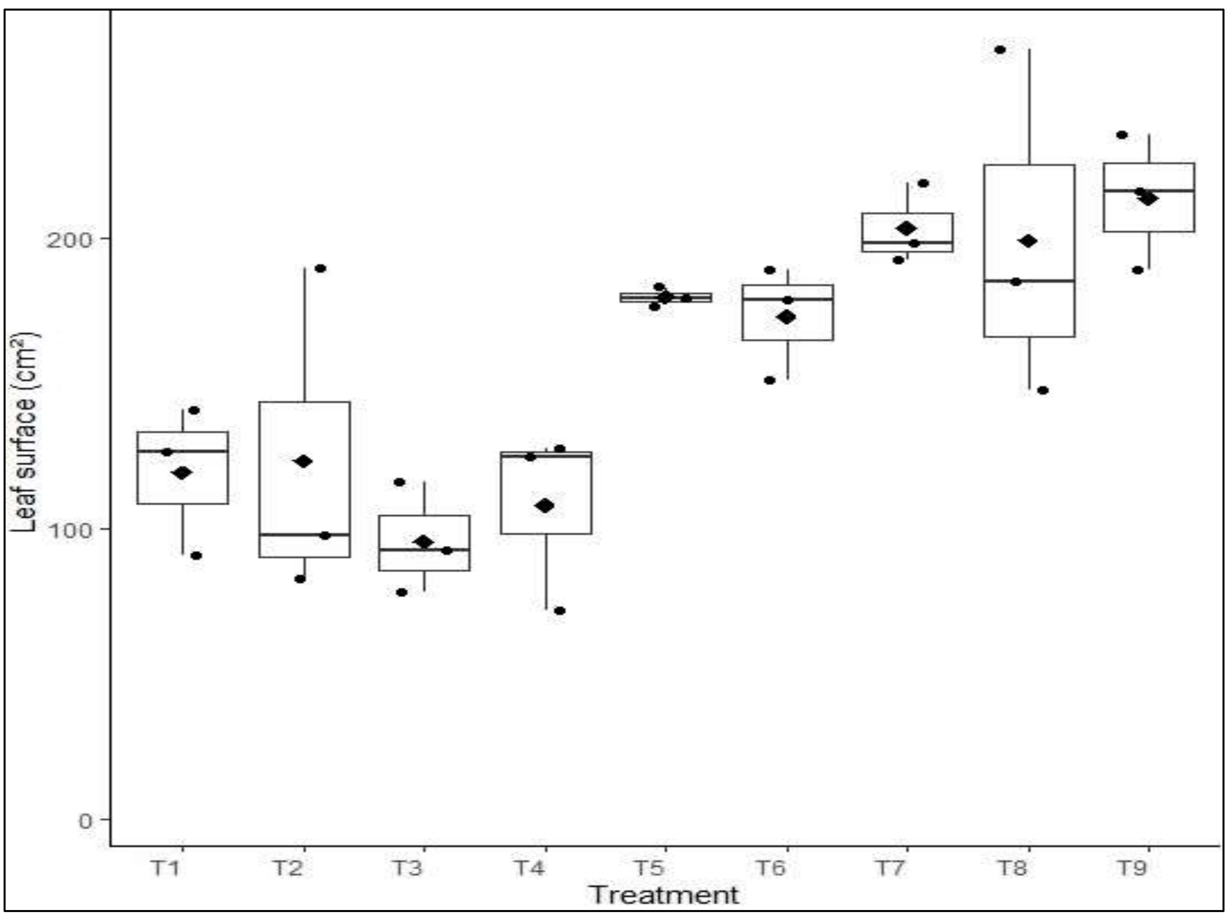

Figure 2. Average values of leaf areas per treatment. T1 = Absolute control, T2 = *Glomeraceae sp.*, T3 = *Acaulosporaceae* sp. T4 = *Diversisporaceae sp.*, T5 = 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T6 = Glomeraceae sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T7 = Acaulospora + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T8 = Diversisporaceae sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T9 = full dose of recommended $N_{15}P_{15}K_{15}$ + Urea; *** significant values.

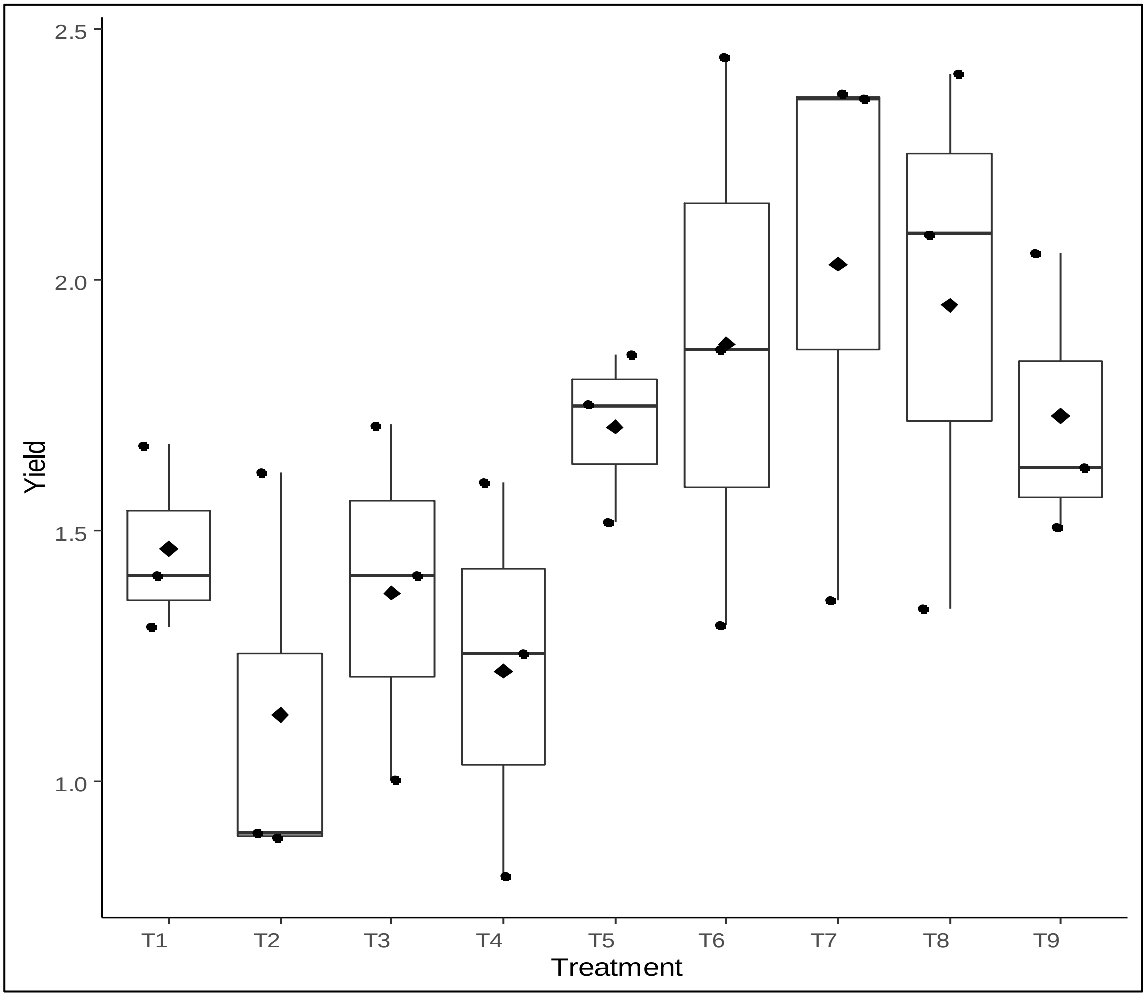

Figure 3. Average values of yields per treatment. T1 = Absolute control, T2 = *Glomeraceae sp.*, T3 = *Acaulosporaceae* sp. T4 = *Diversisporaceae sp.*, T5 = 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T6 = Glomeraceae sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T7 = Acaulospora + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T8 = Diversisporaceae sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T9 = full dose of recommended $N_{15}P_{15}K_{15}$ + Urea, *** significant values.

Table 4. Frequency of mycorrhization of corn plants.

Parameter	Estimate	Std. error	t value	Pr(>|t|)	
(Intercept)	2.73003	0.18429	14.814	4.48e-09	***
Acaulospora (T3)	0.10318	0.25416	0.406	0.69190	
Diversisporaceae sp. (T4)	-0.06744	0.26513	-0.254	0.80352	
Glomeraceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T6)	0.29849	0.24323	1.227	0.24328	
Acaulospora + 50% $N_{15}P_{15}K_{15}$ + Urea (T7)	0.23180	0.24678	0.939	0.36609	
Diversisporaceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T8)	0.72524	0.22452	3.230	0.00722	**

results (Jesús et al., 2004). This growth increase would be the result of an improvement in the nutritional and especially phosphate status of plants by mycorrhizae (Benjelloun et al., 2004) as well as an improvement in the photosynthesis of plants (Jesús et al., 2004). Babana (2003) showed that the use of mycorrhizal fungi on wheat had a positive effect on the height growth of the plants. Contrary results have been observed by Plenchette et al. (2000) who observed that mycorrhization of millet with *Glomus aggregatum* did not stimulate its growth.

Table 5. Number of spores / 50g of soil.

Parameter	Estimate	Std. error	z value	Pr(>|z|)	
(Intercept)	4.13250	0.07313	56.511	< 2e-16	***
Acaulospora (T3)	-0.19416	0.10882	-1.784	0.074384	.
Diversisporaceae sp. (T4)	-0.46042	0.11757	-3.916	8.99e-05	***
Glomeraceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T6)	-0.34076	0.11343	-3.004	0.002663	**
Acaulospora + 50% $N_{15}P_{15}K_{15}$ + Urea (T7)	-0.14970	0.10751	-1.392	0.163787	
Diversisporaceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T8)	-0.44362	0.11697	-3.793	0.000149	***

However, at the level of the collar diameter, five treatments (*Glomeraceae sp.*+50% of recommended $N_{15}P_{15}K_{15}$ + urea, *Acaulospora*+50% of recommended $N_{15}P_{15}K_{15}$ + urea, *Diversisporaceae sp.*+50% of recommended $N_{15}P_{15}K_{15}$ + Urea and 100% of recommended $N_{15}P_{15}K_{15}$ + urea) produced a significant effect. These results agree with those observed by Bulakali et al. (2000), who showed in their study that mycorrhizal fungi had a beneficial effect on the growth in diameter at the collar of corn plants. The same observations were made by Aguegue et al. (2017), who showed that the inoculation of corn seeds by mycorhizal fungi had a beneficial effect on the diameter at the collar of the treated plants compared to the control.

Previous studies have shown that the presence of mycorrhizal fungi stimulate the growth of the leaf surface of corn plants (Kothari et al., 1990). These observations are in agreement with the study data, which showed that, of the three strains used, only the treatment with *Acaulosporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea gave the best yield in leaf area compared to the control (70.4%). This increase in leaf area in mycorrhizal plants is thought to be due to an improvement in nitrogen acquisition from the soil due to the hyphae of mycorrhizal fungi (Tobar et al., 1994).

Considering the yield grain, the treatment *Acaulosporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea gave the best result compared to the control with an increase of 39.04%. These results corroborate those of Diatta et al. (2013), who showed in their work that the *G. fasciculatum* strain induced a good grain yield (1324 kg/ha) compared to the control (1019 kg/ha).

Focusing in the endomycorrhizal infection, the highest infection frequency was obtained with *Diversisporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea. Similar results have been reported by several authors, who have shown in their work that in general, the frequency of mycorrhization of inoculated plants is high, while the intensity of mycorrhization remains low (Haro, 2016; Koda et al., 2018). Indeed, according to Diagne and Ingleby (2003), the level of infection does not have to be very high to be beneficial to the plant. In addition, Hart et al. (2003) suggest that a heavily infected plant will transfer more of its carbon resources to mycorrhizal fungi, thereby reducing their beneficial effect.

Analyzes of variances have shown that the greatest number of spores is observed at the treatment with only *Glomeraceae* sp., but the number of spores decreases in the presence of mineral fertilizer. These results evolve in the same direction as those obtained by some authors who showed that the infection rate decreases when the amount of phosphorus is high. Indeed, several studies have shown that optimal or high phosphorus levels inhibit arbuscular colonization of plant roots (Koide and Li, 1990).

Conclusion

Agriculture is the biggest interface between humans and the environment; humanity will have to meet the ever-increasing food demands while facing a decrease in dependence on mineral fertilizers. In view of the results obtained, it can be retained that the native mycorrhizal fungi have given good results on growth and yield of corn. Of the three tested strains, the *Acaulospora* treatment + 50% of recommended of $N_{15}P_{15}K_{15}$ + Urea displays the best result. This result opens the gate of the possible use of those fungi not only to improve the productivity but also to restore sols.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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