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Evaluation of Innovative Cultivation Practices for Optimizing Soil Fertility, Crop Yields and Soil Microorganisms in Western Niger

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Original Research Article

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Abstract

The environmental situation in Niger is alarming. It is characterized by droughts, floods, and irregular rainfall, leading to a decline in agricultural production and food insecurity. These issues are exacerbated by climate change, desertification, and unsuitable farming practices. The poverty of farmers limits the use of

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chemical fertilizers, which are also known to threaten and degrade soil sustainability over time. Moreover, their high cost compared to the purchasing power of Nigerien farmers poses an additional challenge. As a result, Nigerien farmers have no choice but to seek more sustainable alternatives. Mycorrhization could be a viable solution, as it represents a promising strategy for restoring soil fertility and improving agricultural yields. Mycorrhization creates a symbiotic relationship between fungi and plant roots, enabling the absorption of nutrients and water while enhancing plant resistance to stress and diseases. This approach reduces the use of chemical fertilizers and pesticides, thus promoting soil health and fostering more sustainable and economical agriculture. Three experiments were conducted: In Sadoré: Research was conducted to identify legumes that could serve as good precursors to millet cultivation and promote mycorrhization and soil fertility. The legumes used were sesbania, dolichos, and cowpea. In the W National Park region: Methods were explored to enhance mycorrhization, facilitate the proliferation of arbuscular mycorrhizal fungi (AMF) spores, and improve root colonization. The study revealed that bacteria such as Pseudomonas spp. thrive with practices like corralling and manure application, while mulching proved particularly effective in promoting AMF spore proliferation and root colonization. These practices—especially manure application, corralling, and mulching—improved millet yields, with mulching having a long-term positive effect on both grain and straw production. In Saguia: Research focused on the use of organic fertilizers, particularly high-dose poultry manure, which resulted in high tomato yields while improving soil stability through an increase in glomalin levels. These findings highlight the importance of adopting appropriate agricultural practices to restore and enhance soil productivity in Niger through the action of symbiotic microorganisms.

Keywords: Farming practices; symbiotic microorganisms; crop yield; soil fertility.

1. Introduction

The current major social and political concern in Niger is to put the emphasis on improving agricultural productivity, in order to ensure: a quality and quantity of food and the preservation of our ecosystems. Indeed, human activities have had adverse effects on soil productivity and biodiversity (Aune et Bationo, 2008). It is more precisely the work of the soil and the supply of chemical fertilizers Areas that were known as the attic of Niger for example: Tanout, Filingué can no longer manage to be self-sufficient. It is relevant to investigate the source of these problems in order to safeguard our environment. In Niger, few studies have looked at the influence that crop practices put in place by producers can have on the development of soil microbial biodiversity, agricultural yield, soil fertility and mycorrhizogenic parameters. Arbuscular mycorrhizal fungi (AMF) are essential symbiotes of most terrestrial plants, forming a beneficial association with roots. They improve nutrient and water uptake through their hyphae, which extend into the soil and play an interesting ecological role in improving soil fertility, promoting biodiversity, and contributing to plant resilience to stress and disease (Fortin et al., 2008, Ameur et al., 2020 ; Akanmu et al., 2023). This symbiosis is fundamental to plant growth, especially in poor soils, and has been historically important for the colonization of land by plants. Mycorrhization plays a crucial role in ecosystem health and agriculture, including (Fortin et al., 2008, Ameur et al., 2020):

- **Nutrient uptake**: Through the extension of their hyphae network in the soil to capture nutrients such as phosphorus, nitrogen and water, which they provide to the host plant;
- **Internal root structure:** They form branched structures called "arbuscules" within root cells, which serve as a nutrient exchange site;
- **Soil Improvement**: AMCs produce Glinine, a protein that assists in soil aggregation, improving soil structure, water and nutrient retention capacity;
- **Resilience and protection**: They increase plant tolerance to drought, salinity and pathogens. They can also improve plant resistance to disease by strengthening their cell walls;
- **Communication networks**: AMFs form underground networks that connect several plants, allowing the transfer of nutrients and water between them. They can also transmit defense signals to neighbouring plants in the event of pest attacks;
- **Plant** Growth They are vital for plant growth, especially in nutrient-poor soils;
- **Biodiversity**: They contribute to biodiversity by allowing more plants to grow in harsh environments;

- **Sustainable agriculture:** The use of AMF in agriculture can reduce the need for chemical fertilizers, improve crop yields and increase crop resistance to environmental stresses.

Hence the objective of our work: Analysis of the effect of our soil fertility management practices on their productivity, their fertility supported by microorganisms including arbuscular fungi and bacteria PGPR, their structure and the sustainability of agricultural systems.

The cultivation practices used are: The contribution of organic manure, residues of crop precedents, mulching, plating in order to improve the mycorrhizogenic potential, a key indicator of soil fertility and bacteria PGPR.
The aim of this analysis is to be able to highlight best farming practices boosting optimal yield, better soil fertility and sustainability of agricultural systems in the Nigerian context. The latter is often characterized by ferruginous soils that are sablo-silt and clay-sandy and are poor in organic matter and nutrients, making them susceptible to erosion. The aim is to develop and disseminate best practices to promote economic success and sustainable development.

2. Methodology

2.1 Experimental Devices

Experimental devices have been installed in both rain-fed and irrigated crops. The cultivation practices used are diverse, including:

-In Sadoré, the most effective species of legume was sought as a crop precedent and the impact of the return of residues of crop precedents on the yield of millet was evaluated, the effects of the seedling density of legumes used as crop precedents and the restoration of their dry biomass on mycorrhization and millet yield. the species of legumes that have been used in this work are: bean, dolic and sesbania. The experimental scheme was in complete random blocks with 3 factors which are the species with 5 levels including 4 species grown for grains and fodder (niebe, voandzou, dolic and millet) and 1 wild species (sesbania); the density is 2 levels, including traditional density and improved density. Phosphorus treatment with 3 levels, including no supply of PNT, supply of 60 $kgha^{-1}$ of PNT and 120 $kgha^{-1}$ of PNT. Crop yield components, root morphological parameters, and plant root mycorrhization parameters, and soil fungal diversity were evaluated based on restored culture residue doses, natural phosphate doses, and urea.

- At Park W the experiment was conducted in 9 fields of the three selected villages, three fields per village. The study was repeated for three years from 2015 to 2017. The experimental device consists of 16 m^2 plots arranged in blocks dispersed at the rate of one block per field. The farming practices used were amendments of parcelling, mulching, the addition of organic manure and the witness, applied by the peasants. The application concerned only the first year of the study (2015). The plant material used is millet (*Pennisetum glaucum* (L.), a local variety and the main crop produced by peasants in Park W. To carry out the various observations and measurements during these trials, three (3) poets were randomly selected from each plot. The selected poles were then materialized using small pickets. The measurements and samples taken at the level of these poquets concerned the number of talles and the number of spurs per poquet, as well as soil and root samples.
- -In Saguia, the experimental device consisted of 48 plots in pure tomato culture and 20 plots in associated culture including the control treatment with 4 repetitions, treated with three types of organic manure, namely cow dung, goat manure and poultry offspring at three levels of fertilization doses (100%, 125%, 150%) during a three-month campaign. All of these trials were repeated annually for three years. Monitoring of agronomic parameters and sampling of soil and root samples from the tomato growing rhizosphere was carried out.

2.2 Laboratory Analysis

2.2.1 Soil Sampling

Samples were taken using the manual auger with a time horizon of (0-20 cm) from both monoculture and combination tomato plots and millet plots. Two composite samples were formed for each treatment through the sampling method on the four sides and at the centre of the plot. Each sample weighs 500 g of soil and has been carefully labelled, placed in zip plastic bags and dried at an ambient temperature (25 to 30 ° C) before and after planting. These composite samples were prepared and conditioned to ensure the preservation of their quality and were sent to the soil science laboratory for analysis of physico-chemical parameters.

2.2.2 Methods of Analysis of Physico-chemical Properties of Soil

The soil samples taken were treated to obtain the fine particles using a 2 mm mesh sieve. These prepared samples were then subjected to the following physico-chemical parameter analyses:

- **Total carbon (C) and nitrogen (N)** : Measured on ground ground using an elementary analyzer LECO Analysis.
- **PHeau** : Measured in suspensions 1 : 2.5 (soil: water) with a crison electrode.
- **Particle size** : Determined by the Robinson pipette method after destruction of organic matter with carbonates and dispersion with sodium hexametaphosphate.
- **Electrical conductivity (CE)** : Measured with a Hannah conductivity meter on aqueous extracts in ratio 1:2 (Pansu and Gautheryou, 2006).
- **Assimilable phosphorus** : Extract with $NaHCO_3$ 0,5M according to the method of Olsen (1954).
- **Exchangeable cations (Ca, Mg, K, Na)** : Extracts with ammonium acetate 1 N at pH 7; concentrations measured by atomic absorption spectrophotometry for Ca and Mg and by emission spectrometry for K and Na (Varian).
- **Cationic exchange capacity (CEC)** : Determined after leaching the excess ammonium with KCl, followed by the determination of NH_4 by distillation (Pansu and Gautheyrou, 2006).
- **Total heavy metals (Pb, Cu, Zn, Ni, Cr)** : Assays after acid digestion (HF + HNO_3) of microwave ground soils then analysed using a flame Atomic Absorption Spectrometer (SAA).
- **Extractable glomalin** : The extraction of glinine was carried out as described by Bradford (1976). Solutions containing 1 g of soil and 8 ml of sodium citrate (pH = 7 for easy-to-extract gl,), (pH = 8 for hard-to-extract gl,) were sterilized using an autoclave at 121°C. for 20 minutes. The cooled extracts were centrifuged for 30 minutes at a speed of 6000 revolutions per minute. The soil and debris sedimented at the bottom of the centrifuge tubes. The precipitate was extracted twice, and the first extract was used for the extraction of readily extractable glonalin is concentrated in the supernatant. The supernatant was recovered in tubes to assay the GRSP fraction, adding citrate, the dye (blue) and using BSA (Bovine Serum Albumin) as standard. The assay is carried out by the spectrophotometer.
- **Stability of aggregates :** Determined by the method of Kemper and Rosenau (1986).

2.3 Characterization of Arbuscular Mycorrhizal Fungi

2.3.1 Collection of Soil and Root Samples

Soil and root samples from the selected poles were collected during the tallying, ascending, and firing stages. The samples concerned only the fine roots which were easier to observe under the microscope. These roots were stored in numbered boxes containing GEE (Glycerol-Ethanol-Water). The soil samples were taken at the same locations as the radicles and were placed in sterile plastic bags after drying under shelter, in the open air, and then transported to the mycology laboratory of the École Normale Supérieure of Abdou Moumouni University in Niamey.

2.3.2 Spore Extraction and Counting of Native Arbuscular Mycorrhizal Fungi

Spores were extracted using the Walker method (1982). A quantity of 100 g of soil was poured into a seal filled with water at the ¾. Having been agitated during 10-15 seconds, suspension passed through 5 stacked sieves the respective stitches of which are of 63µm, 160µm, 250µm, 315µm, 630µm leaving of the bottom from above. The deposit in the 630 µ m mesh sieve, consisting of debris and rarely containing spores, was discarded. The refusal of the various remaining sieves was collected in petty dishes. The contents of the latter were then mixed and stirred. Each Petri dish containing the spores is placed under a binocular magnifying glass, the estimate of the number of spores in the soil is made by counting the number of live spores contained in 1 ml of supernatant and by extrapolation over the total volume (10 ml). An identification of the genus of spores by soil fertility management practice is carried out based on the criteria proposed by Schenck and Smith (1982).

2.3.3 Estimation of Root Infection by Arbuscular Mycorrhiza Fungi

- **Root staining**

The root staining technique used is that described by modified Philips and Hayman (1970). The roots are washed with water and then stored for 24 hours in a 10% potassium hydroxide solution (KOH). They are then bleached by adding a few drops of H_2O_2 (100V) to the mixture KOH plus roots, for 5 minutes. After rinsing with distilled water, the roots are acidified with 1% HCl for a few minutes. They are rinsed again with distilled water and then stained with trypan blue (for at least 24 hours in ambient air). The roots are finally rinsed with distilled water and stored in a small amount of glycerine.

- **Evaluation of mycorrhizal parameters**

For each sample, 30 fragments one (1) cm long of the colored roots are cut and mounted between the blade and the lamella because of 10 fragments per blade. The slides are observed under a microscope; each fragment is carefully examined over its entire length for mycorrhizal parameters. The scoring system used to assess the importance of mycorrhizal colonization is that proposed by (Trouvelot et al., 1986). It is based on the overall assessment of 10 root fragments. A class score of between 0 and 5 corresponding to the estimation of the proportion of cortex colonized by the mycorrhizal symbiote is attributed to each of the root fragments observed. The presence of arbuscules and vesicles is noted simultaneously.

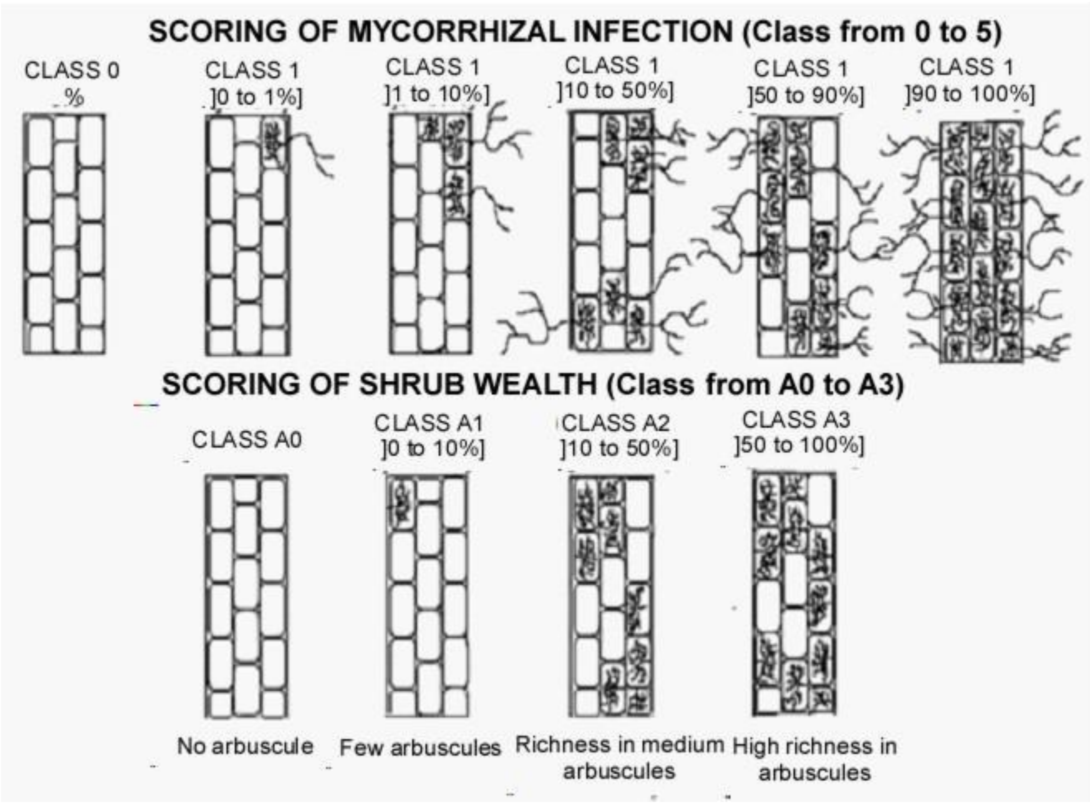

Fig. 1. Scoring scale for the degree of mycorrhizal of root fragments (Trouvelot et al 1986)

The parameters observed are: Frequency of mycorrhization (F%); Mycorrhizal intensity (M%); Arbuscule content (A%)

2.4 Characterization of Microorganisms from Soil Fertility Management Practices

The technique used for the counting of soil germs comprises several steps ranging from the preparation of the suspension dilutions to the interpretation of the results. The measurement of microbial densities by the soil suspension-dilutions technique used in this study is a good indicator of the presence of soil microorganisms. This measurement is easy to carry out, economical, and gives reliable and reproducible results (DAVET, 1996).

2.5 Data Processing and Analysis

The data collected from the various parameters were subjected to a variance analysis (ANOVA) using the Minitab version 16 software and the means of the variables were compared using the Tukey test at the probability threshold p = 5%. The software Mycocalc, was used for the evaluation of the parameters of mycorrhization (F%, M% and A%). And the software SPSS 16 allows to analyze the data of the surveys.

The data obtained were recorded in the Microsoft Excel spreadsheet version 2013. All analyses of the physicochemical parameters of the soil, the glinine content and the stability of the aggregates were carried out using the R software (version 4.0.2). The confidence interval used to assess the degree of accuracy is 95%.

The descriptive and advanced statistical analyses were carried out for these data on the physico-chemical properties of soils, namely:

- **Shapiro-Wilk test**: Was applied to each dependent variable for the normality law.
- **Test ANOVA at one factor** was used to test the differences between the means of several groups or samples.
- **Kruskal-Wallis test**: Was applied as a non-parametric alternative to ANOVA to compare medians between several groups when the dependent variable is not normally distributed.
- **Statistical correlation** method (Pearson's test): Was used to evaluate the strength and direction of the linear relationship between two quantitative variables. It measures the extent to which variations in one variable are associated with variations in another variable, but does not provide evidence of causality.
- **Principal Component Analysis (CPA)**: Was used to identify important variables to determine which original variables contribute more to data variance, to select the most relevant variables for further analysis or modelling.

3. Results and Discussion

3.1 In Sadoré

3.1.1 Impact of Cropping Practices on the Physico-chemical Properties of Soils

Intensive tillage, pesticide use and fertilization can degrade soil structure and reduce organic matter, while more sustainable practices such as reduced tillage, crop rotation and the use of plant cover can improve fertility and water and nutrient retention capacity. Regarding the proposed approaches to a sustainable production system: input of Tahoua crop and phosphate residues and urea. The results show that cultural precedents have positively influenced the content of organic carbon (Corg), total nitrogen (Ntot) and assimilable phosphorus (PBray1).

It has been shown that the contribution of PNT alone cannot improve either the PBray1 status in the soil or the yield of millet and that the contribution of urea, even in microdosage, is essential to enhance the effect of PNT and crop residues on the mineral content of the soil and the yield of millet. It is necessary to intercalate the cycle of monoculture with a legume and, if not, a natural set-aside to reinforce microbial activity in the soil in order to ensure the production and mineralization of organic matter. This study concludes that the exploitation of arbuscular mycorrhizal fungi (AMFs) in the soil is a system for managing the fertility of sandy soils to mitigate the adverse effects of climate change at a lower cost, and is an intelligent management of fertility because it does not generate greenhouse effects and does not pollute the environment.

3.1.2 Impact of Cultural Practices on Mycorrhization

The aim of this study is to investigate the effects of legume seedling density (as in previous crops) and the restoration of their dry biomass on mycorrhization. On the basis of the results obtained, it can be concluded that mulching is a peasant soil fertility management practice that allows good maintenance of AMF propagules. In addition, the results obtained showed that all practices (parking, manure, mulching) allowed the proliferation of soil microorganisms, but the parking and contribution of manure did not make it possible to maintain the dynamics of the microorganisms as a function of time, unlike mulching which allowed mycorrhizal development until the end of the trials.

The study determined that spore proliferation is a function of the species of pulses used as a crop precedent. In this study, rotation with pulses was shown to increase frequency, mycorrhizal intensity, and arbuscular content. The lessons learned from this study are that the contribution of organic manure, such as animal parking and manure, would improve yields of millet crops and that the use of these same fertility management practices, at high doses, would reduce the mycorrhizal potential of the soil. The correlation with environmental stresses (drought, soil mineral deficiency) and millet yield were investigated to assess the contribution of mycorrhization to increasing millet productivity.

The highest spore density was obtained in the root zone of the dolichos bean, followed by that of the cowpea and the bambara groundnut. These results corroborate those obtained by Plenchette et al. (2000). However, the highest spore density was obtained in 2014. This suggests that spore proliferation increased to adapt to a harsh environmental condition (such as high soil moisture). These results are similar to those of Füzy et al. (2014), who observed that increased soil moisture increases AMF spore proliferation but reduces AMF root colonization. Glomus spores were the most abundant (90%) compared to Gigaspora spores (9%) in the soil of Sadoré in the root zone of legumes and millet crops.

3.1.3 Impact of Cropping Practices on Crop Yield and Biomass

The study found that sesbania, dolique and niebé are good cultural precedents for improving millet yield. The niebe is known for its use in rotation but sesbania and dolique would be new sources for the restoration of degraded soils in the Sahel. This study would have estimated the comparative advantage (as a percentage) of these crop precedents over the yield of fallow and monoculture millet. One of the specific objectives is to identify the best cultural precedent that allows the highest rate of mycorrhization on millet in monoculture. The combination of several techniques, including the use of crop residues, Tahoua natural phosphate and urea as a new approach to a sustainable production system.

The techniques that the author proposes to improve and sustainably maintain the fertility of the sandy soil and increase the yield of millet, even if additional studies are necessary to prove their effectiveness, are within the reach of Sahelian peasants. The applications of this study are diverse and respond well to the strategy of sustainable management of crop systems to increase agricultural production, mitigate the adverse effects of climate change and maintain a clean environment. The study also highlights the importance of rainfall in soil fertility and the need to use drought-resistant species. Finally, future research should explore other species to expand rotation opportunities and improve agricultural practices, including raising farmers' awareness of the importance of mycorrhizal fungi for soil fertility. The importance of this work lies in its contribution to the search for the best cultural practices to solve these different problems.

The response of millet yield to the effects of previous crops varied depending on the species, with the effects of legumes being predominant over millet monoculture. Several factors could explain the good performance of millet following sesbania, dolichos, and cowpea in terms of yield, as demonstrated in the results of the present study. These positive and varied effects of legumes as previous crops on millet yield in the rotation are explained by their ability to improve the physicochemical and biological fertility of the soil, benefiting the millet. The legume/cereal rotation with residue return provided an additional gain in cereal yields, and this corroborates the results of previous work (Bationo et al., 2008). These authors have shown that these gains are linked to the advantages of the residual effects of mycorrhizal symbiosis (available phosphorus) and rhizobium symbiosis (mineral nitrogen). Indeed, legume cultivation allows for nitrogen enrichment of the soil through atmospheric nitrogen-fixing bacteria, the quantities of which depend on their relationship with the symbionts (Lamb et al., 2014; Droppelmann et al., 2017). Similarly, the mineral and organic matter content left in the root zone of previous crops varies according to their root systems, their capacity to solubilize insoluble elements, and their ability to promote microbial activity in the rhizosphere.

3.2 W Park Area

Soil fertility management practices have a significant and direct impact on populations of arbuscular mycorrhiza (AMF) fungi, rhizobacteria that promote plant growth (PGRN), and therefore on crop yield. The cultivation practices used were among the 3: amendments of parcelling, mulching, supply of organic manure and the witness, applied by the peasants.

3.2.1 Impact of Cropping Practices on the Physico-chemical Properties of Soils

The highest clay content was found in the third horizon for the manure treatment and in the first for the other treatments. Silt was most abundant in the first horizon, except for the mulch treatment. Sand predominated in the first two horizons for the mulch treatment and in the last two for the other treatments. Analysis revealed that pH decreased with depth for all treatments. Carbon increased with depth for the control, decreased for the manure treatment, and remained stable for the mulch and enclosure treatments. Total phosphorus and organic matter generally decreased with depth, with some variations depending on the treatment. Calcium was highest in the second horizon and lowest in the last. Magnesium, cation exchange capacity (CEC), and base saturation decreased with depth for the manure, control, and enclosure treatments, but varied for the mulch treatment. Potassium and sodium remained stable at all depths. These results for the manure treatment corroborate those observed by Naitormbaide et al. (2010) in the savannas of Chad. Organic carbon levels ranging from 0.21 to 0.61 are higher than those obtained by Dutordoir (less than 0.2) in 2007 in the Fakara area.

3.2.2 Impact of Cultural Practices on Mycorrhizobacteria

In the W Park area, two genera of AMF spores are Gigasporaceae *spp* and *Glomaceae spp*. have been identified in soils and the genus *Glomus* appears to be the most ubiquitous. The study revealed that the density of the two genera of AMF spores identified varied according to the treatments applied by the producers, with a predominance in mulching. Tallage and ascent are the two phenological stages that have a significant effect on mycorrhizal parameters. The presence of *Bacillus sp of Serratia sp and Pseudomonas sp* as bacteria in this area, with a predominance of *Pseudomonas sp* (61%), was noted among the cultivational practices used, including plots, manure use and mulching. The study also showed that soil bacteria have a preference for parking and manure. This study also revealed that bacteria such as *Pseudomonas spp.* prefer parking and manure, while mulching is particularly effective for the proliferation of CMA spores and root colonization.

3.2.3 Impact of Cropping Practices on Crop Yield and Biomass

The results show that millet residues alone are not sufficient to maintain soil fertility. The cultivation of sesbania is recommended for its ability to permanently improve the yield of millet, followed by dolic and niebe. In the light of the results obtained, mulching can be offered to producers in the zone of Park W of Niger which could be an alternative to the use of mineral fertilizers too expensive, not adapted to our environmental conditions and which are not within the reach of the Nigerian peasant.

3.3 In Saguia

3.3.1 Impact of Cropping Practices on the Physico-chemical Properties, Glomaline of Soils

The physicochemical properties of the studied soils reveal a sandy-loam-clay texture and an alkaline pH. The nutrient balance shows good availability of mineral elements, including calcium and magnesium, as well as carbon and major element content (nitrogen, phosphorus, and potassium), depending on the treatments applied and agricultural practices. Indeed, poultry manure provides more nutrients than other organic fertilizers, according to the soil analyses performed. The glomaline level is significant across all treatments and agricultural practices, indicating good aggregate stability in the soil structure.

Treatment with poultry manure yields more nutrients, particularly carbon and nitrogen, than other treatments. These results regarding carbon and nitrogen content corroborate those of a study on the agronomic parameters of tomato and soil fertility in the North-Central region of Burkina Faso (Tapsoba et al., 2020; Coulibaly et al., 2022). This higher content is explained by the consistent application of sufficient quantities of organic fertilizers and organic matter (Aune et Bationo, 2008; Coulibaly et al., 2022). These results also corroborate those obtained on the effects of fertilization based on Sida Cordifolia L. biomass in tomato cultivation (Hajar et al., 2015); and those of Kaho et al. (2011) on soils under maize cultivation in Cameroon. These results can be explained by the fact that the soils studied have a fairly high organic matter content. The same results were reported by Ballot et al. (2016), highlighting the importance of organic matter for the availability of assimilable phosphorus and exchangeable potassium. The supply of assimilable phosphorus is almost the same across the different organic fertilizers, demonstrating their effectiveness in improving soil fertility and yield. These results are consistent with those of the studies by Ballot et al. (2016) on cassava productivity in the Damara region of the Central African Republic.

3.3.2 Effects of Organic Manure and Crop Association on Tomato Crop, Mycorrhizal Parameters in an Experimental Field

This work aims to identify the ideal model for improving tomato production in the Saguia area, Niger. The effect of the organic manure type was evaluated on agronomic parameters, on the density of mycorrhizogenic spores, on mycorrhizal parameters, on soil properties and on the density of bacteria in the tomato rhizosphere *(Solanum Lycopercsicum)* in the area of Saguia in pure and associated culture. Based on the results obtained from the experiment and the organic fertilizers applied, the yields of each treatment are significant and more profitable compared to the yields obtained with mineral fertilizers. Poultry manure dose 3 is more effective for tomato fruit yield. Three arbuscular mycorrhizal fungal spores were extracted: *Scutellospora sp., Gigaspora sp., and Glomus sp*. For the mycorrhization parameters mycorrhizal intensity and arbuscular content the poultry manure dose 3 treatment recorded the highest values compared to the other treatments. Bacterial density is very important in all treatments. Indeed, the recommended dose, dose 3, recorded a higher bacterial density in the TSA culture medium than the recommended dose, dose 1, in the PDA culture medium.

The aim was to show the advantages of interactions (mycorrhiza and bacteria) according to the type of fertilization used and their contribution to agricultural production, especially market gardening. The correlation between AMF spore density and yield parameters is positive and highly significant, and is in contrast to that with heavy metals and other variables of AMF spore density and mycorrhization parameters.

The effect of organic fertilizers significantly influences the intensity of mycorrhization and the percentage of root arbuscules obtained through the symbiosis of endomycorrhizal fungi in tomato crops. These results obtained from mycorrhization parameters corroborate the mycorrhization parameters observed in Tetraclinia sp., where examination of thuja roots showed that all samples were well colonized by arbuscular mycorrhizal fungi (AMF) (Abbas, 2014 ; Razak et al., 2024 ; Jamilou et al., 2024). Root colonization, expressed as mycorrhizal frequency "F", can reach 100% in this study, corresponding to the case of roots harvested from Tetraclinia, as does the percentage of arbuscules "A" (Abbas, 2014; Vanlauwe et al., 20214 ; Razak et al., 2024 ; Jamilou et al., 2024). These results are consistent with those found by Füzy et al. (2014) highlighted the effect of soil moisture on sporulation and mycorrhizal parameters. The intercropping system improved arbuscular content compared to the monoculture system.

3.3.3 This Work Aims to Develop New Technologies, the Promotion and Adoption of which Will Improve Tomato Productivity in Saguia, Niger

In the Saguia area, the effects of three different fertilizers were studied: cow dung, goat crotte, and poultry droppings at three 100%, 125%, and 150% dose levels. These doses were compared with the recommended dose or peasant practice. At different levels, monitoring of parameters, agronomics and sampling of soils and radicals in the tomato rhizosphere were carried out. The granulometry, physico-chemical properties of the soil, the presence of heavy metals, the level of gl, and the stability of aggregates were determined. These results showed that the highest yield of tomato fruit was found in the Dose 3 poultry droppings: 38t.ha^{-1}; leaf biomass of 13 t.ha^{-1} and root biomass of 6 t.ha^{-1}.

The results of this study show that poultry manure significantly increased fruit yield and biomass in tomato plants, followed by goat manure and cow manure. Regarding intercropping with tomatoes, the results indicate that intercropping is more efficient than monoculture. Similarly, the system with mycorrhizal plants proved more productive than the one with non-mycorrhizal plants. The highest fruit yield was recorded with the poultry manure treatment at dose 3, which is higher than the yield obtained by Ibrahim and al. (2018) for the Tropimech tomato variety in 2017 (24.3 t.ha^{-1}) and in 2018 (33.68 t.ha^{-1}), as well as those of Kitabala et al., (2016) (15.01 t.ha^{-1}) in a study on the evaluation of the increasing effectiveness of organic matter on the economic profitability of tomato cultivation.

4. Conclusion, Research Perspectives and Recommendations

The Sadoré study found that some species such as voandzou and natural fallow improved the accumulation of phosphorus and nitrogen in the soil, thus promoting fertility between 2013 and 2015. Natural set-aside and bare plots allowed better total nitrogen accumulation than millet monoculture, but this accumulation decreased with cultivation. Sesbania and dolique are distinguished by their ability to increase organic carbon in soil, although the soil has decreased overall during the study period. The absence of amendments, such as organic or mineral fertilizers, has led to lower mineral levels in the soil. It is therefore essential to introduce pulses into the rotation to enrich the soil with nitrogen and improve the efficiency of other inputs. The results show that millet residues alone are not sufficient to maintain soil fertility. The cultivation of sesbania is recommended for its ability to permanently improve the yield of millet, followed by dolic and niebe. The study also highlights the importance of rainfall in soil fertility and the need to use drought-resistant species. Finally, future research should explore other species to expand rotation opportunities and improve agricultural practices, including raising farmers' awareness of the importance of mycorrhizal fungi for soil fertility.

Based on the results obtained, in the area of Park W, it can be concluded that mulching is a peasant soil fertility management practice that allows good maintenance of AMF propagules. The results obtained showed that all practices allowed the proliferation of soil microorganisms, but the plating and contribution of manure did not make it possible to maintain the dynamics of the microorganisms as a function of time, unlike mulching, which allowed mycorrhizal development until the end of the trials. The lessons learned from this study are that the contribution of organic manure, such as animal parking and manure, would improve yields of millet crops and that the use of these same fertility management practices, at high doses, would reduce the mycorrhizal potential of the soil. In the light of the results obtained, mulching can be offered to producers in the zone of Park W of Niger which could be an alternative to the use of mineral fertilizers too expensive, not adapted to our environmental conditions and which are not within the reach of the Nigerian peasant.

In the Saguia area, Dose 3 poultry droppings were more effective and had the highest yield of tomato fruit of 38.23 t ha^{-1}. The soils studied have a sablo-limono-clay texture and a basic pH favourable to tomato culture. The nutrient balance shows a good availability of mineral elements released by the organic manures applied, as well as to the organic matter content. The availability of organic matter in the applied treatment shows an improvement in the stability of aggregates and microbial activity. Investigation of soil samples showed three types of spores: *Scutellospora* sp*, Gigaspora* sp*, and Glomus* sp. Under the study conditions, the genus *Glomus sp* is more widespread than the genus *Gigaspora sp* and *Scutellospora sp.* For mycorrhizal parameters of which the mycorrhizal intensity and arbuscular level were greater with the Dose 3 fodder treatment.

4.1 Research Perspectives and Recommendations

- To cultivate tomatoes with other speculations, in order to improve the yield of fruit, the incomes of farmer producers and thus restore the indicators of fertility;
- Characterize arbuscular mycorrhiza fungi in soils in the study area by biochemical, bio-molecular and hormonal analyses;
- Determine the mycorrhizal potential of the soil.
- Characterize arbuscular mycorrhiza fungi in soils in the study area by biochemical, bio-molecular and hormonal analyses;
- Determine the mycorrhizal potential of the soil.
- To initiate and raise awareness among producers of the existence and importance of arbuscular mycorrhizal fungi and of good cultural practices that preserve the survival of these fungi;
- Inform producers that the rational use of endomycorrhizals is a system for managing soil fertility and mitigating the adverse effects of climate change as an intelligent management of soil fertility.
- It would be very beneficial to extend this study to other cultivated or wild species in the Sadore area in order to broaden the list of high mycorrhizal species and include them in the pulse/cereal rotation.
- It is essential to conduct tests to compare the effects of legumes such as sesbania, dolica and niebe at different seedling densities in a biannual millet monoculture system with the effects of micro-dose urea input to identify the best seedling density with the greatest effect on soil nitrogen content.
- Better identification of spores genera of arbuscular mycorrhizal fungi could improve the assessment of soil fungal diversity.
- An initiation and awareness of the peasants of the zone to discover the existence and importance of mycorrhizal fungi with arbuscule as well as the good cultural practices preserving the survival of the mycorrhizal, would increase the potential of exploitation of the natural biofertilisers of the soil.

- The use of soil AMF is a system for managing the fertility of sandy soils that mitigates the adverse effects of climate change at a lower cost, as an intelligent fertility management because it does not generate greenhouse effects and does not pollute the environment.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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