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EFFECT OF ARBUSCULAR MYCORRHIZAL FUNGI ON PHOSPHORUS ABSORPTION AND YIELD OF COWPEA VARIETIES IN SOILS OF WUDIL AND WARAWA SUDAN SAVANNAH, NIGERIA

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ABSTRACT
A pot experiment was conducted under greenhouse conditions in 2023 at Aliko Dangote University Wudil on sandy loam soils of Wudil and Warawa to evaluate the influence of arbuscular mycorrhizal fungi on yield of two cowpea varieties as well as on soil properties and Phosphorus uptake. The treatments consisted of two levels of AMF inoculation (Mo = control, without inoculation, M1 = inoculation with AMF), Two cowpea varieties (Sampea14 and Sampea15) and soils of two location (wudil and warawa). These were laid out in completely randomized design and replicated three times. Data were collected on seeds/pod, 100-seed weight, yield/ha and P uptake. Soil analysis was also carried out before and after the application of treatments. The data were subjected to analysis of variance (ANOVA) using SAS and means were separated at 5% level of significance. Result showed significant effect of AMF on all the yield characters of cowpea ($p<0.05$). The inoculation of AMF produced higher yield/ha of sampea15 cowpea (874.56kg) than the control (550.42kg). However, there was no significant difference ($p>0.05$) between yield of the two varieties of cowpea (644.13kg and 780.85kg) used in this study. The application of AMF enhanced the pH (0.22%), organic carbon (0.15%), organic matter content (0.62%) N (0.05%), P (0.16mg/kg) and K (0.18mg/kg) contents of the soil at Wudil and Warawa. Phosphorous uptake of the two cowpea varieties at both locations were also increased more than the control treatments. The study therefore recommends further experiments to study in detail the function of AMF on the production of cowpea on the field.

Keywords: AMF, Cowpea, Greenhouse, Inoculation, Varieties

INTRODUCTION
Cowpea (*Vigna unguiculata L. Walp*.) is one of the major grain legumes growing in Africa that is rich in protein, carbohydrates, vitamins, minerals, and a major staple food crop for household nutrition in Nigeria (Omoigui *et al,* 2020). Food and Agriculture Organization (FAO) in 2017 revealed that, cowpea is a tropical crop that is tolerant to drought and poor soil, which makes its production so attractive to the arid and semi-arid region of Nigeria. The Production of cowpea in Nigeria is increasing and the rate of consumption is also increasing, raising hopes over the sustainability of an important source of plant protein for millions of Nigerians. Hence, the growth and productivity of cowpea in the country are low due to the prevalence of various diseases and insect attacks cause serious damage to the crop and yield reduction (Abiodun, *et al*., 2021).To address these challenges, majority of farmers depend on chemical and other commercial inputs such as insecticides and phosphoric fertilizers which are costly, this result in increase of production cost. Therefore, there is need to come up with a new alternatives to minimize the use of chemical input that lead to the high cost of production, soil degradation and nutritional imbalance in the soil. Such alternatives include the use of biotic processes (Shabani *et al*., 2024). Biotic processes like symbiosis relationship has the potential of improving agricultural sustainability with minimal dependence on non-renewable inputs such as chemical fertilizers. (Abd-Alla *et al*., 2023). Mycorrhizal fungi are symbiotic in relationship between a fungus and the roots of the higher plants. These associations differ in structure and functions, but the most usual interaction is the AMF association (AjemaGebisa, 2024).
The continuous use of agricultural land over several years has created an imbalance in the store of mineral nutrients available in the soil. Also, increase in cropping density and introduction of high yielding varieties have caused considerable drain of phosphorous and other primary nutrient such as nitrogen and potassium (Kartini, *et al*., 2024). The use of inorganic fertilizer alone has not been helpful always due to long term detrimental effects (Adamu and Junaidu, 2021). Hence this research will examine the impact of AMF as an alternative organic fertilizer to supplement phosphorus for sustainable yield performance.
AMF is significant for improving growth and development of various crop plants particularly in low fertile soil. The fungal external hyphae help the plant roots to explore, absorb water and nutrients from bulk soil beyond depleted root zone (Xu, *et al*, 2024). AMF when in symbiotic relationship with plant roots, it increase surface area due to the production of extensive hyphae helping plants growing under relatively harsh condition, such that more than 80% of the plants phosphorus through AMF chains can move freely toward the root from a distance more than 10 centimetres from the root surface. The increase of growth in root inoculation with AMF was because of increase of phosphorus absorption. (Zhang, *et al*, 2023), Tang, *et al*, 2022). Therefore, the use of AMF, which are biologically base will have the potential of solving the issues of soil fertility problem, drought stress and the deterioration effects of crop protection chemicals and high cost of inorganic fertilizers in the research area. Therefore this study was carryout to evaluate the influence of Arbuscular Mycorrhizal Fungi on the yield of two cowpea varieties as well as the influence of AMF on soil properties and P uptake by cowpea.

MATERIALS AND METHODS
Experimental site
The experiment was conducted at the Department of soil science, Faculty of Agriculture and Agricultural Technology,

Aliko Dangote University of Science and Technology, Wudil. It was a pot experiment that was carried out under greenhouse conditions with daytime temperatures ranging between 22 ^{0}C and 31 ^{0}C. A composite soil samples were collected in March, 2023 from farms in two different locations at Wudil and Warawa. The coordinates are (11^0 49'7.8179 N, 8^0 5020.8860 E and 11^0 52'42.600 N, 8^0 453.462 E) for Wudil and Warawa respectively.

Experimental Design

The experiment was a factorial with a layout of 2 x 2 x 2. The first factor was the two locations (Wudil and Warawa) while the second factor was the two varieties of cowpea (V_1 and V_2) then the last factor was the two levels of Arbuscular Mycorrhizal Fungi inoculation. (Mo = control, without inoculation, M_1 = inoculation with Arbuscular Mycorrhizal fungi). The treatment combinations of the three (3) factors were arranged in a completely randomized design (CRD) with 8 treatments and three (3) replications. Making a total number of about 24 treatments.

Collection and Preparation of Soil

The soil samples collected from Wudil and Warawa were air-dried, passed through a 5-mm sieve, and autoclaved at 100 ^{0}C for 60 min twice with a one-day interval to destroy the indigenous mycorrhizal fungi. The inoculum containing *Glomus species* that was used for the study was obtained from Savvy Gardens Limited Company. Plastic pots were used for this experiment, each pot was filled with 3.0 kg of dry soil. 1.0kg of the sterilized soil was taken from each of the pot and mixed thoroughly with 20g Arbuscular Mycorrhizal fungi inoculum. A total number about twelve (12) treatments pot where inoculated, while the remaining twelve (12) treatment pots were used as control. The inoculated soil was then returned back to each of the treatments pot where it was taken from. SAMPEA14 (IT99K-573-1-1) and SAMPEA15 (IT99K-573-2-1) are the two cowpea varieties that were used for the study and were obtained from International Institute for Tropical Agriculture (IITA), Kano Station.

Cultural Practice

Two cowpea Seeds per pot were sown on 11th march, 2023 two days after inoculation and later thinned to one plant per pot after emergence. Application of water started immediately after inoculation of AMF for two days before planting. It was continued after planting when necessary under controlled condition in the green house. In order to keep the soil porous and also free from weeds, hand weeding was done when necessary. To control insects pests such as white fly, imi-force (imidochloprid) was applied at the rate of 30g per 15 litres of water using knapsack sprayer at the vegetative stage. The crop was due for harvest at 86 to 90 days after sowing (DAS). Hand was used to remove the pod from the plant and the yield were weight and recorded the means value.

Data Collection

Before and after the cropping a composite soil sample was taken from two different locations (Wudil and Warawa) for laboratory analysis of the nutrient composition. At three weeks after planting, leaf samples were collected for Plant analysis to determine the uptake of P by the plant. Numbers of seeds per pod was obtained by opening the pod when dry and count the number of seeds per each pod of the plant and record the mean number.100 seeds were selected at random from the pod of each of the plant, weight and recorded the mean value.The yield was obtained by weighing the seeds using (Metlar MT-200). Grain yield per hectare was also obtained by extrapolating the yield per pot to hectare.

All soil and plant samples collected from the study area were subjected to Laboratory Analysis using a standard procedure to obtain the nutrient composition. The data obtained from yield parameter were subjected to analysis of variance (ANOVA) using SAS to compute the mean squares of each of the experimental treatments. Means were separated using Student-Newman-Keuls Test (SNK) at a 5% level of significance.

RESULTS AND DISCUSSION

Table1 presents the physical and chemical properties of the soil at Wudil and Warawa experimental sites. The soil at Wudil was slightly alkaline (7.62). It was loamy sand in texture with a particle size distribution of 56, 34 and 10% for sand, silt and clay respectively. The EC was 1.51 dS m^{-1} while CEC was 13.06 cmol kg^{-1}. The soil contains an Organic Carbon of 0.12%, OM of 0.21% and total N was 0.012. The available P content was 3.50mg kg^{-1} while the K^+, Na^+, Ca^{2+} and Mg^{2+} contents were 0.70, 0.23, 9.30 and 1.67 cmol kg^{-1} respectively. Similarly at Warawa, the soil was more alkaline (7.77) than at Wudil. It was loamy sand in texture with a particle size distribution of 64, 24 and 12% for sand, silt and clay respectively. The EC was lower than that Wudil (0.12 dS m^{-1}) while the CEC was higher (15.25 cmol kg^{-1}). The soil contains similar OC (0.12%) and OM (0.21%) to Wudil and a total N was 0.010 which was lesser than at Wudil. The available P content was 0.75mg kg^{-1} while the K^+, Na^+, Ca^{2+} and Mg^{2+} contents were 0.36, 0.23, 10.66 and 2.84 cmol kg^{-1} respectively.

Table2 shows the end line changes in the physical and chemical properties of the soil of the two locations. At Wudil, the application of Mycorrhizal to the soil increased the pH of the soil by 0.22. Organic carbon of the soil was also increased by 0.15%. The application of Mycorrhizal to the soil increased the organic matter by 0.62% more than the control (0.41%). Result also shows increase in N (0.05%) and P (0.16mg/kg) in soils applied with Mycorrhizal unlike the control with decrease in N (0.045) and P (1.68). Na and Mg increased more in the control plot than the soil applied with Mycorrhizal at Wudil. The application of Mycorrhizal however increased the CEC by 0.685cmol/kg of the soil and reduced the EC by 1.02. At Warawa, the pH reduced more in the control plot (0.26) than the plots applied with Mycorrhizal. Organic carbon and OM increased more in the soils applied with Mycorrhizal (0.21 and 0.36 respectively) than the control plot (0.17 and 0.17 respectively). Similarly, the application of Mycorrhizal increased the N, P and K content of the soil more than the control plot. Na increased more in the control plot than the plots applied with Mycorrhizal while EC was increased more in plots applied with Mycorrhizal.

Several physical and chemical characteristics of the soil were enhanced in this study by the addition of arbuscular mycorrhizal. When compared to the soils without Arbuscular mycorrhizal, the results indicated that the application of Arbuscular mycorrhizal at Wudil and Warawa enhanced the pH, organic carbon, organic matter content, Ca, Mg, and macronutrients (N, P, and K). This study supports the findings of (Zhang, *et al*. (2024), who found that soils treated with arbuscular mycorrhizal had a considerable increase in their organic matter (OM) content and pH, as well as an improvement in their soil chemical characteristics (macronutrients).

Table 1: Physical and Chemical Properties of the Soil of the Study area Before Cropping

Parameters	Wudil	Warawa
P^H	7.62	7.77
% O.C	0.12	0.12
% O.M	0.21	0.21
% N	0.012	0.010
P(mg/kg)	3.50	0.75
K. cmol/(+)kg	0.70	0.36
Na cmol/(+)kg	0.23	0.23
Ca cmol/(+)kg	9.30	10.66
Mg. cmol/(+)kg	1.67	2.84
C.E.C cmol/(+)kg	13.06	15.25
Al+ H cmol/(+)kg	1.16	1.16
Ec. ds/m	1.51	0.12
% Sand	56	64
% Silt	34	24
% clay	10	12
Textural Class	Sandy loam	Sandy loam

O.C = Organic Carbon, O.M=Organic Matter, C.E.C= Cation Exchange Capacity, EC=Electric Conductivity

Table 2: End Line Changes in the Physical and Chemical Properties of the Soil of two Location After Cropping.

Soil Properties	Wudil		Warawa	
	M0	M1	M0	M1
P^H	0.26	0.22	-0.26	0.11
% O.C	0.40	0.15	0.17	0.21
% O.M	0.41	0.62	0.17	0.36
% N	-0.05	0.05	0.03	0.08
P(mg/kg)	-1.68	0.16	2.14	2.62
K. cmol/(+)kg	-0.13	0.18	0.03	0.11
Na cmol/(+)kg	0.16	0.07	0.08	0.09
Ca cmol/(+)kg	0.95	-1.31	-2.56	0.19
Mg. cmol/(+)kg	0.46	0.12	-1.69	1.82
C.E.C cmol/(+)kg	-0.83	0.69	-3.23	1.31
Al+ H cmol/(+)kg	0.01	-0.08	-0.08	0.09
EC. ds/m	-1.12	-1.02	0.24	0.28

O.C = Organic Carbon, O.M=Organic Matter, C.E.C= Cation Exchange Capacity, EC=Electric Conductivity

Table 3 shows the effect of Mycorrhizal on number of seed/pod, 100 seed weight and yield/ha of cowpea varieties at Wudil and Warawa in 2023 cropping season. Result shows no significant difference among the locations and varieties for number of seed/pod, 100 seed weight and yield/ha. However, there was significant effect of Mycorrhizal on the number of seed/pod, 100 seed weight and yield/ha. Cowpea inoculated with Mycorrhizal (12.08) resulted in more number of seeds/pod than the control (9.58). Similar trend was obtained for 100 seed weight and yield/ha as cowpea inoculated with Mycorrhizal produced heavier 100 seed weight (22.40g) and higher yield (874.56 kg/ha) than the control. Result also showed significant interaction for all possible interactions for 100 seed weight and yield/ha but no significant interaction for number of seeds/pod.

The application of Mycorrhizal resulted in a significant increase in the number of pods, pod weight, seeds per pod, 100-seed weight, and overall grain yield of cowpea. This can be explained by the essential role that AMF play in the dissolution, weathering, and cycling of mineral nutrients, making them more accessible for optimal plant absorption. This is consistent with the findings of Zhang, *et al* (2023), who reported that the roots of cowpea plants that were inoculated showed a significantly greater number and weight of nodules compared to their uninoculated counterparts, with inoculated plants producing a higher number of pods per plant and greater pod weights than the control group. It is clear that the inoculation of AMF can significantly boost the levels of various macro and micro-nutrients, which leads to an increase in photosynthate production and, consequently, greater biomass accumulation (Chen *et al*., 2017; Mitra *et al*., 2019). According to reports, mycorrhizal fungi in chickpea plant roots enhance the plants' development and yield, particularly in soils lacking in phosphorus (Smith, *et al*., 2024).

Table4 present the phosphorous uptake by crop after cropping. At Warawa, the application of Mycorrhizal increased the P uptake of Sampea14 (0.702%) and Sampea15 (0.592%) more than the control. Similarly at Wudil, P uptake of Sampea 14 and Sampea 15 when applied with Mycorrhizal (0.693 and 0.593% respectively) were higher than the control plots of both varieties. Arbuscular mycorrhizal is a P activator that can speed up the conversion of P into forms that are bioavailable through a variety of biological and chemical processes (Zhu *et al*., 2018). The study's findings indicated that cowpea seeds from Sampea 14 and Sampea 15 that were infected with Arbuscular mycorrhizal at both sites had higher P absorption than the control. This could be explained by the way arbuscular mycorrhizal hydrolyzes organic P to produce inorganic phosphorus that cowpea roots can readily absorb. These results are consistent with those of (Wu, *et al*. 2024), who examined the effects of Arbuscular mycorrhizal inoculation on the nutrient uptake, growth, and productivity of cowpea (*Vigna unguiculata*) varieties and found that mycorrhizal plants achieved maximum nutrient uptake.

Similarly, Smith *et al*., (2024) observed a similar outcome, observing a high rise in P in the aerial portion of the blackberry plant (Rubus fruticosus var. brazos) after treatment with arbuscular mycorrhizal. The increase in phosphorus (P) uptake is one of most prominent impacts of mycorrhizal infection on the host plant. This is primarily because mycorrhizal fungi have the ability to take up phosphate from the soil and transport it to the host roots (Abd-Alla *et al*., 2023). Masrahi *et al* (2023) also found that inoculating saline soils with Arbuscular mycorrhizal improved tomato P concentration and absorption. By extending the extraradical hyphae from the root surface to the soil outside the depletion zone, arbuscular mycorrhizal organisms improve the uptake of phosphorus (P).

Table 3: Number of Seed/pod, 100 Seed Weight and Yield/ha of Cowpea

Treatments	Number of Seed/pod	100 Seed Weight(g)	Yield/ha
Location			
Wudil	10.75[a]	21.42[a]	752.25[a]
Warawa	10.92[a]	19.79[a]	672.73[a]
P Value	**0.7953[NS]**	**0.1076 [NS]**	**0.3028[NS]**
SEM	**0.32**	**0.49**	**37.67**
Variety			
Sampea14	10.58[a]	20.73[a]	644.13[a]
Sampea15	11.08[a]	20.48[a]	780.85[a]
P Value	**0.4335[NS]**	**0.8116[NS]**	**0.0690[NS]**
SEM	**0.31**	**0.51**	**35.75**
Mycorrhizal			
M i	12.08[a]	22.40[a]	874.56[a]
M_0	9.58[b]	18.81[b]	550.42[b]
P Value	**<.0001**	**<.0001**	**<.0001**
SEM	**0.17**	**0.35**	**17.24**
Interaction			
L × V	0.3322	0.0021	0.0004
L × M	1.0000	0.0003	0.0003
V × M	1.0000	<.0001	<.0001
L × V× M	0.6233	0.0003	<.0001

WAS= Week After sowing, NS= Non significant Difference, M_I = with Mycorrhizal, M_0 = without Mycorrhizal. Means followed with the same letter are not significantly difference

Table 4: Phosphorous Uptake by Crop after Cropping

Treatments	Phosphorous Uptake (%)
WaV_1M_0	0.329
WaV_1M_I	0.702
WaV_2M_0	0.458
WaV_2M_I	0.592
WuV_1M_0	0.492
WuV_1M_I	0.693
WuV_2M_0	0.503
WuV_2M_I	0.593

Wu=Wudil, Wa=warawa, V1=variety 1, V2=Variety 2, M_I = with Mycorrhizal, M_0 = without Mycorrhiza

CONCLUSION

The results from this study indicated that AMF inoculated plants grew better exhibited enhanced mineral nutrition and had greater yield than non AMF plants. Furthermore, the application of AMF did not only increase important soil properties (pH, organic matter, total NPK), but it remarkably increased the phosphorus uptake of cowpea at both locations. The inoculation of AMF could be used to improve the cowpea growth and yield as well as improve the status of the soil in the study area.

RECOMMENDATION

This study recommends that farmers in wudil, warawa and similar regions can adopt AMF inoculation to boost cowpea yield and reduce reliance on chemical fertilizers. It can also be integrated into soil management practice to improve organic carbon, nutrient cycling and water retention in degraded soils.

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