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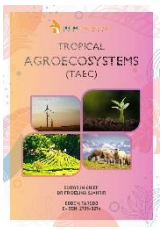

RESEARCH ARTICLE

RESPONSE OF MAIZE TO DIFFERENT SOURCES OF PHOSPHORUS AND ARBUSCULAR MYCORRHIZAL FUNGI IN SOIL OF MINNA

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ABSTRACT

At the Federal University of Technology, Minna, during the cropping season of 2021, a screen house experiment was carried out to ascertain how maize responded to various AMF and phosphorus sources. Using a sterilized auger, soil samples were collected from the Teaching and Research Farm Gidan Kwano Campus at a depth of 0 to 15 centimeters. The treatment were 3 phosphorus sources at 60 Kg P ha-1 [0 Kg P ha-1 as control, bone meal as natural source (0.34 g per 2 Kg soil) and Single super phosphate as inorganic source (0.60g per 2 Kg soil)] and 3 AMF sources [No AMF as control, Native (indigenous) AMF and known AMF species (*Glomus intaradices*) and 1 ml was used for each pot for inoculation]. Treatments were repeated 3x and fitted to a Completely Randomized Design (CRD). Seeds were sown at a rate of four seeds per pot prior to treatment, and after one week of planting, they were reduced to two seedlings. At 2 days subsequent to planting, pots were treated with basal use of 200 ml hydroponic nutrient solution per pot and seedlings were watered daily aside from when hydroponic nutrient solution was applied. At six weeks after planting, the plants were harvested, and the resulting data were analyzed using ANOVA and Least Significant Difference (LSD) was used to separate the means. The obtained results demonstrated that the interaction between P sources and AMF had a significant impact on root dry biomass, shoot Phosphorus Content, and root Phosphorus Content, but not on plant height, shoot biomass, root fresh biomass, or root length. Maize interacting with indigenous AMF worked improved more growth parameters than interaction with *Glomus intaradices* (Known AMF). Therefore, it may not be necessary to inoculate maize with known AMF strains. However, additional research with a number of known strains is required to determine whether superior strains that can outperform the indigenous AMF strain can be selected.

KEYWORDS

Glomus intaradices, Interaction, AMF.

1. INTRODUCTION

Soil as a complex universe enhances plants interact with a wide range of microbes and minerals, resulting in a true system where nothing can be modified without affecting everything else (He et al., 2021). The first are the arbuscular mycorrhizal fungi (AMF). Nearly 90% of plant species including flowering plants and ferns can develop interdependent connections with AMF (Chen et al., 2021; Wang, 2023).

Maize (*Zea Mays*) belonging to the family Poaceae and like other plants take up only a small proportion of 60kg P ha^{-1} applied to soil as fertilizer while the rest are rapidly converted into insoluble complexes (Gupta et al., 2022).

Phosphorus (P) is an essential element for plant growth, since it is involved in the most important plant biochemical processes. Plants take up only a small percentage of P applied to soil as fertilizers, while the rest is rapidly converted into insoluble complexes (Gupta et al., 2022).

This poor P availability is the reason for the required frequent applications of P fertilizers to agricultural soils in order to maintain crop productivity Therefore, an improved efficiency of P utilization in agriculture is necessary in order to substantially reduce the global P demand, and reduce the rate of depletion of fossil P reserves (Carpenter et al., 2022).

Roots of most terrestrial plants form symbiotic associations with fungi, Studies on plant–microbes interaction in the rhizosphere have increased tremendously in number and complexity in recent years (Brink, 2016). AMF form vesicles, arbuscules, and hyphae in roots, and also spores and hyphae in the rhizosphere. Formation of hyphal network by the AMF with plant roots significantly increases the access of roots to a large soil surface area, causing improvement in plant growth (Khan et al., 2023).

AMF improve plant nutrition by increasing the availability as well as translocation of various nutrients (Xu et al., 2023). AMF improve the quality of soil by influencing its structure and texture, and hence plant health (Wu et al., 2023; Douds et al., 2023).

1.1 Statement of the Research Problem

Soil P is low to maize due to fixation of P as Aluminum hydroxy phosphate or manganese hydroxy phosphate in acid soils. Organic P is fixed and unavailable for plant uptake, inorganic P can be leached into water bodies and made unavailable to plant root. This unavailability and loss can be reduced by the interaction of nutrients with plant roots and AMF. However, there are environmental limitations to the performance of introduced AMF, hence the need to depend on indigenous AMF population.

Increasing P Fertilization in order to increase maize yield has been a concern mainly because the negative impact of phosphorus (P) losses to

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the environment necessitating appropriate use of phosphorus to avoid pollution of surface and ground water due to phosphorus leaching thereby necessitating appropriate fertilization management (Cassman et al., 2023; Cassman et al., 2023; Douds et al., 2023). It is therefore necessary to focus on appropriate nutrient management strategy that improves the efficiency of nutrients (Tittonell et al., 2023; Cassman et al., 2023). And maximize crop production without a negative impact on the environment (Tittonell et al., 2023).

1.2 Justification of the Research

Arbuscular mycorrhizal fungi (AMF) have been reported to assist host plants to grow well under stressful conditions by establishing a complex communication network between the plant and the fungus leading to enhanced photosynthetic rate and other gas exchange-related traits as well as increased water uptake (Wu et al., 2023). Phosphorus (P) as one of the most important determinants of plant growth and in most soils exists informs that are largely unavailable for plant uptake (Shaheen et al., 2021). Such is the case with Nigerian soils (Adetiloye et al., 2022). Phosphorus can be as low as 2 mg kg^{-1} in the savanna soils of Nigeria (N'Dri et al., 2023_ [18] thus, making P one of the most limiting nutrients in our soils.

AMF inoculants could serve as possible alternatives as they offer the potential to increase agricultural yields and productivity in low-input systems (Brundrett, 2022)

1.3 Aim and Objectives

1.3.1 Aim

The aim of this experiment is to determine the response of maize to different sources of phosphorus and arbuscular mycorrhizal fungi in soil of minna.

1.3.2 Objectives

The objectives of the experiment are to:

- Determine the effects of P sources on growth, shoot P and root P of maize.
- Assess the effects of AMF sources on growth, shoot P and root P of maize.
- Examine the effects of the interaction between P sources and AMF sources on growth, shoot and root P of maize.

2. Research Methodology

2.1 Study area

The soil for the screen house pot experiment was collected from Teaching and Research farm Gidan kwano, Federal University of Technology Minna, Niger State. The global positioning system (GPS) location of the sampled points in Gidan kwano coincides with latitude 9°31'6''N to 9°31'50''N and longitude 6°26'26''E to 6°27'5''E. Minna has a mean annual rainfall of about 1200mm with about 90% of the rainfall between June and August and mean daily temperature that rarely falls below 22°C reaching a peak of 36°C to 40°C between November to December and February to March respectively.

2.2 Vegetation and soil description

Within the site are arable lands where maize, rice, yam, soybean are usually cultivated and trees like mango, shear butter, teak tree, african baobab, neem tree. Shrubs like wild strawberry and wild sunflower. Grasses that are predominant include spear grass, stubborn grass and elephant grass. The soils of Minna are Alfisols developed from basement complex rocks ranging from shallow to very steep soils overlying deeply weathered gneisses and magnetite with some underlain by iron pan to varying depth.

2.3 Soil sampling and analysis

Soil samples were collected with auger diagonally from 10 points at a depth of 0 - 15cm within a plot. Before collecting the samples, soil auger was sterilized with methylated spirit to avoid contamination from previous soil sampling. The samples were collected in bags, bulked and mixed properly to obtain a composite soil sample. A sub-sample (10 grams) of the composite soil was kept in the refrigerator for AM fungi studies.

The other portion was air dried, carefully crushed and passed through 2mm sieve to remove gravels and roots for physical and chemical properties analysis according to the method described as follows: (Peverly et al., 2022)

Soil particle size distribution was determined by Bouyoucos hydrometer method, Soil pH in 1:2.5 soil to water and $CaCl_2$ suspension with a glass electrode pH meter; soil organic matter using the Walkley and Black wet oxidation method, Total nitrogen by kjeldahl method, exchangeable bases was extracted with 1N NH_4OAC and phosphorus was extracted using Bray P-1 method and was determined using absorption spectrophotometer.

Coarse sand used for the pot experiment was washed several times using tap water to make sure that the sand was free from dissolved nutrients and sterilized using the autoclave at 121°C for 20 minutes before transferring 2 kg of sterilized sand to each pot.

2.4 AMF Carrier Preparation

Ten grams of glucose was diluted into 500ml distilled water and 0.5g of chloramphenicol was added to serve as anti-bacterial agent

2.5 AMF Spore Count

AMF count was obtained using New Plate Method described as follows: (Shamini and Amutha, 2014) Ten grams of soil was added to 90 ml of distilled water and 10 ml was promptly transferred onto a filter paper by using a pipette. The filter paper was viewed under dissecting microscope for spore count.

2.6 Seed Sowing and Crop Management

Seeds were sown at a depth of 2.5cm, and at the rate of 4 seeds per pot and each pot received a basal application of 200ml hydroponic nutrient solution (a mixture of 10g NPK 20:10:10, 10g $Ca(NO_3)$ and 5g Mg_2SO_4) and seedlings were thinned to 2 per pot at a week after planting. Thereafter pots were watered using 100ml of distilled water daily except when 200ml hydroponic nutrient solution was added at 3 days interval.

2.7 Treatments and Experimental Design

The experiment was a 2 factor layout having P sources and AMF sources as factors. The treatments were 3 phosphorus sources as 60 Kg P ha^{-1} [0 Kg P ha^{-1} as control, bone meal as organic source (0.34 g per 2 Kg soil) and Single super phosphate as inorganic source (0.60g per 2 Kg soil)] and 3 AMF sources [No AMF as control, Indigenous AMF and Known AMF species (*Glomus intaradices*) inoculated at the rate of 1 ml per pot]. Treatments were replicated 3x and fitted to a Completely Randomized Design (CRD).

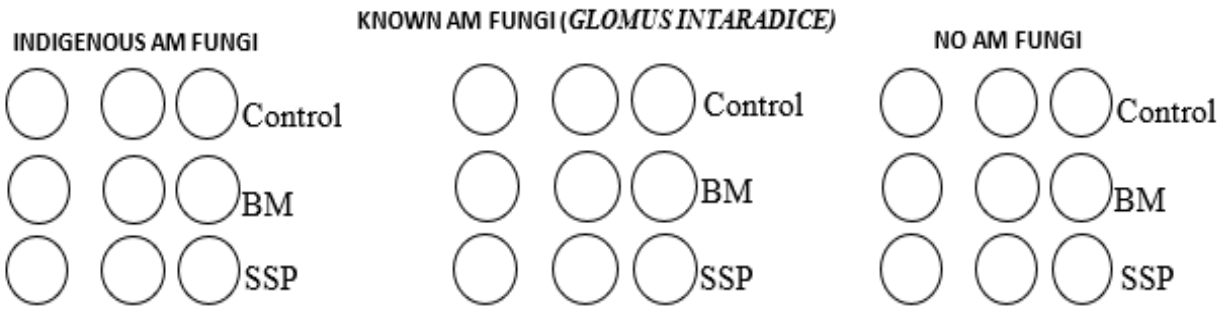

Figure 1: Completely Randomized Design (CRD).

2.8 Harvesting and Data Collection

The harvesting was done at week 6 and the data collected were as follows:

2.8.1 Plant Height per Plant

The height of the plants were measured from the base of the plants to the tip of the longest plant leaves using meter rule.

2.8.2 Shoot Fresh Weight per Plant

The shoot fresh weights were obtained by weighing the shoot of 2 plants immediately after harvest using top loading electrical balance and then dividing by 2.

2.8.3 Shoot Dry Weight per Plant

The shoot dry weight were obtained by weighing the shoots of 2 plants after oven drying for 3 days at 65 ^{o}C using top loading electronic balance and then dividing by 2.

2.8.4 Root Length per Plant

The root length were obtained by measuring the roots from the base of the plants to the tip of the longest root hair using meter rule.

2.8.5 Root Fresh Weight per Plant

The root fresh weight were obtained by weighing the root of 2 plants immediately after harvest using top loading electronic balance and then dividing values by 2.

2.8.6 Root Dry Weight per Plant

The root dry weight were obtained by weighing the roots of 2 plants after oven drying for 3 days at 65 ^{o}C using top loading electronic balance and then dividing values by 2.

2.8.7 Shoot P and Root P Content per Plant

The shoot P and root P content were obtained using Colorimetric Method.

2.9 Statistical Analysis

All data obtained were subjected to Analysis of Variance (ANOVA) using SPSS (2013 Version). Least significant difference (LSD) was used to separate means where significant differences were observed at 5% probability level.

3. Results

3.1 Selected Physical and Chemical Properties of the Soil

Table 1 shows the results of the physical and chemical properties of the soil used in carrying out the experiment. The textural class of the soil is sandy loam with the particle size distribution of clay which is 6.64g/kg, silt and sand with proportion of 7.00g/kg and 86.36g/kg respectively. The pH of the soil was 6.89 which is a slightly acidic soil reaction. The Available phosphorus of the soil was 5.83 mg/kg which is low according to the rating of (Akpan et al., 2022).

3.2 Main Effect of P Sources and AMF on Maize Growth and P Content

Plant height was not significantly affected by P sources but was significantly affected by AMF sources. Plants inoculated with indigenous AMF were significantly taller than plants inoculated with *Glomus intaradices* and uninoculated plants.

Shoot fresh biomass was not significantly affected by P sources but was significantly affected by AMF sources. Plants inoculated with *Glomus intaradices* and indigenous AMF were significantly heavier than plants not inoculated. Interaction between P sources and AMF sources did not significantly affect shoot biomass. Shoot dry biomass followed the trend of the shoot fresh biomass.

Root fresh biomass was not significantly affected by P sources but was significantly affected by AMF sources. Root fresh weight of the plant inoculated with *Glomus intaradices* and indigenous AMF were significantly higher than that of the uninoculated plants. This trend was followed by the root dry biomass. The interaction between P sources and AMF sources significantly affected root dry biomass at 1% level of significance.

Root length was not significantly affected by P sources but was significantly affected by AMF sources with the root length of plant inoculated with indigenous AMF higher than root length of plants inoculated with other AMF sources.

Shoot P content was significantly affected by P sources and AMF sources respectively. The shoot P content of plants treated with SSP were higher than shoot P of plants treated with other sources of P. On the other hand, shoot P content of plants inoculated with indigenous AMF were significantly higher than P content of plants inoculated with *Glomus intaradices* and uninoculated plant in that order. The interaction between P sources and AMF sources significantly affected shoot P content.

Root P content of plants followed the same trend observed by shoot P content except that there was a significant difference between the root P content of plant treated with bone meal and control plants. There was also no significant difference between the root P content of plant inoculated with indigenous AMF and those with *Glomus intaradices* respectively. Root P content of plants were significantly affected by the interaction between P sources and AMF sources.

3.3 Effect of Interaction between P Sources and AMF on Root Dry Biomass

Table 3 shows the effect of interaction between AMF sources and P sources on root dry biomass. Averagely, root dry biomass of plants inoculated with *Glomus intaradices* were higher than that of the indigenous AMF and non AMF treated plants in that arrangement. The highest root dry biomass was recorded when plants inoculated with *Glomus intaradices* were treated with bone meal, followed by the root dry biomass of plants inoculated with indigenous AMF and treated with bone meal.

3.4 Effect of Interaction between P Sources and AMF on Shoot P Content

Table 4 shows the effect of interaction between AMF sources and P sources on shoot P content. Averagely the shoot P content of plants inoculated with indigenous AMF were the highest followed by the shoot P content of plants treated with *Glomus intaradices* and that of un-inoculated plants in that order. Shoot P content were higher when plants inoculated with indigenous AMF were treated with SSP and lowest when uninoculated plants were treated with bone meal. Shoot P content of plant inoculated with *Glomus intaradices* were significantly higher than that of plants inoculated with indigenous AMF only when they received control treatment as P sources.

3.5 Effect of Interaction between P Sources and AMF on Root P Content

Effect of interaction between AMF sources and P sources on root P content is shown in Table 5. Averagely, root P content of plants inoculated with indigenous AMF were higher than that of plants inoculated with *Glomus intaradices* and uninoculated plants. Root P content were highest when plants were inoculated with *Glomus intaradices* and fertilized with SSP while the lowest was observed when uninoculated plant were treated with no P. AMF treated with SSP produced the highest root P content. With the exception of plant treated with *Glomus intaradices,* AMF treated with no P, produced the lowest root P content.

4. Discussion

The result of physical and chemical properties for the experimental soil used for inoculation of the indigenous rhizobia (Table 1) showed that the textural class of the soil was sandy loam and the pH was 6.89 which was rated slightly acidic according to (Akpan et al., 2022). This means that the soil has no problem in relation to nutrient availability. This is consistent with the report, that plant nutrients are available to plant at the optimum range of 5.5 to 7.0 (Adhikari and Bhattacharyya, 2022). The low available P of 5.83 mg/kg justifies the need for inoculation with AMF or improvement of plant association with the indigenous AMF (Gange, et al., 2021; Wang et al., 2023).

Table 1: Selected Physical and Chemical Properties of the Soil	
Soil properties	**Value**
Particle size Distribution (g/kg)	
Sand	860.36
Silt	70.00
Clay	60.64
Textural class	Sandy loam
pH in 1:2.5 soil to water	6.89
Available Phosphorus (mg/kg)	5.83

Result obtained showed that plant height of the maize inoculated with AMF were significantly taller than the un-inoculated plants (Table 2). This may be attributed to the ability of AMF to facilitate host plant growth vigorously by mediating a series of complex communication events between the plant and the fungus leading to enhanced photosynthetic rate and other gas exchange related traits (Wu et al., 2023). The shoot biomass of the maize plant inoculated with indigenous AMF and *Glomus intaradices* were significantly heavier than the un-inoculated plants (Table 2). Studies have shown that AMF have the ability to improve stomatal regulation, hyphal water uptake and osmotic adjustment of the host plant (Zhang et al., 2023). Root length was significantly higher for inoculated plants compared to un-inoculated plants (Table 2) due to efficient translocation of nutrients to roots in contact with AMF hyphae (Treu et al., 2022).

Table 2: Main Effect of P Sources and AMF Sources on Maize Growth and P Content								
	Plant Height (Cm)	**Shoot Fresh Biomass (g)**	**Shoot Dry Biomass (g)**	**Root Fresh Biomass (g)**	**Root Dry Biomass (g)**	**Root Length (Cm)**	**Shoot P Content (%)**	**Root P Content (%)**
P Sources (P)								
Control	46.72	5.88	0.91	2.81	0.88	26.33	4.36	1.40
SSP	49.32	7.40	0.96	3.29	0.81	25.49	7.78	1.89
Bone Meal	45.94	7.91	1.23	3.74	1.07	25.00	4.50	1.48
LSD (0.05)	8.58	2.93	0.39	1.77	0.37	9.12	0.22	0.07
AMF (A)								
No AMF	36.33	4.08	0.62	1.71	0.55	23.44	4.23	0.83
Known AMF	42.11	8.66	1.21	4.11	1.12	22.49	5.58	1.95
Indigenous AMF	53.54	8.45	1.27	4.02	1.09	30.89	6.83	1.98
LSD (0.05)	8.58	2.93	0.39	1.77	0.37	9.12	0.22	0.07
Interaction								
P *A	NS	NS	NS	NS	**	NS	**	**

Known AMF = *Glomus intaradices*, SSP = Single Super Phospahte. Means are not significantly different at P > 0.05. NS = Not Significant at P > 0.05. ** = highly Significant at P < 0.01

Root biomass of the Maize plant inoculated with indigenous AMF and *Glomus intaradices* were significantly higher than of the un-inoculated (Table 3). A similar observation was made and was attributed to enhanced carbohydrate storage at the roots of AMF inoculated plants (Treu et al., 2022).

Table 3: Interaction Effect between P Sources and AMF Sources on Root Dry Biomass			
		AMF	
	No AMF	**Known AMF**	**Indigenous AMF**
P Source			
Control	0.31	1.14	1.18
SSP	1.04	0.55	0.84
Bone meal	0.31	1.66	1.23
LSD (0.05)		0.49	

Known AMF = *Glomus intaradices*, SSP = Single Super Phosphate

The plants inoculated with indigenous AMF had the highest shoot P content followed by the ones inoculated with *Glomus intaradices* and the un-inoculated in that order (Table 4). The root P content exhibited the same trend as observed by shoot P content (Table 5). SSP fertilizer produced significantly higher shoot and root P content compared to other sources of P (Tables 4 and 5) due to the solubility and higher uptake of the P contained in SSP by plant root (Chien et al., 2021).

Table 4: Interaction Effect between P Sources and AMF Sources on Shoot P Content			
		AMF	
	No AMF	**Known AMF**	**Indigenous AMF**
P Source			
Control	3.86	4.91	4.31
SSP	6.25	6.92	10.17
Bone meal	2.59	4.90	6.00
LSD (0.05)		0.29	

Known AMF = *Glomus intaradices*, SSP = Single Super Phosphate

Experiment on AMF and their role in improving the nutrient uptake of agricultural crops showed that plant inoculated with AMF had increased P content and Phosphorus efficiency use compared to those without AMF inoculation (Heppell et al., 2022).

Table 5: Interaction Effect between P Sources and AMF Sources on Root P Content

		AMF	
	No AMF	**Known AMF**	**Indigenous AMF**
P Source			
Control	0.60	2.03	1.57
SSP	1.00	2.37	2.29
Bone meal	0.90	1.45	2.08
LSD (0.05)		0.09	

Known AMF = *Glomus intaradices*, SSP = Single Super Phospahte

5. Conclusion

In conclusion, interaction between P sources and AMF did not affect plant height, shoot biomass, fresh root biomass and root length significantly but affected root dry biomass, shoot P and Root P content significantly. Maize interaction with indigenous AMF improved more of the growth parameters than interaction with *Glomus intaradices* (Introduced AMF).

Recommendation

Since the indigenous AMF performed better than the introduced AMF, there may not be any need for inoculation of maize with the introduced AMF. However, further investigation should be conducted with several exotic strains to see if better strains can be selected that can outperform the indigenous AMF strain. The potentials of our local AMF strain can also be explored in the production of AMF inoculants for farmers' use in our locality.

Declarations

I, SAIDU, Zaharadeen Bala declare that this project work titled "RESPONSE OF MAIZE TO DIFFERENT SOURCES OF PHOSPHORUS AND ARBUSCULAR MYCORRHIZAL FUNGI IN SOIL OF MINNA" is a record of an original work undertaken and written by me under the guidance of Dr. A.O Uzoma and has not been presented previously for any other degree programme. Information derived from personal communication, published and unpublished works of others were duly acknowledged in the text.

Study limitations

None.

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Competing interests

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None

Ethical approval

Not required

Informed consent

I write on behalf of the authors that this research has been authorized for publication by my Supervisor, Dr Uzoma, A.O. Here is his contact email: ao.uzoma@futminna.edu.ng for verification.

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