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Effect of selected mycorrhizal strains and six soil series on phosphorus availability in South-Western Nigeria

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ABSTRACT

The availability of soil phosphorus is a major constraint to crop production. This could be ameliorated by mycorrhizal inoculation. This study assessed the effect of selected mycorrhizal strains and soil series on phosphorus availability in South-Western Nigeria. The study was conducted at the Teaching and Research Farm, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria. The two factors tested in the pot trials were four treatment levels, including: no mycorrhizal inoculation (control), and inoculation with *Glomus mosseae, Glomus clarum,* and *Glomus fasculatum*, respectively, and six soil series (Iwo, Apomu, Itagunmodi, Araromi, Egbeda, and Gambari series) collected from different locations in South-Western Nigeria. The experimental design was factorial, arranged in a randomized complete block design with three replications. Phosphorus (P) uptake was determined from the plant after harvesting. Root infectivity was determined using the grid-line intersection method. Data were analyzed using SAS at $P \leq 0.05$, and means were separated using the Least Significant Difference. Results showed that the Apomu series with *Glomus fasculatum* produced the highest mycorrhizal infectivity (57.42%). The highest P uptake of 5.33 g/plant was obtained from the Iwo series with *Glomus fasculatum*.
Keywords: mycorrhizal strains, phosphorus availability, root infectivity, soil series

1. Introduction

Phosphorus (P) is a crucial nutrient for plant growth in many agroecosystems, and it is vital in several physiological and biochemical processes. Moreover, the accessibility of P regulates the growth and development of all crops, as explained by [1]. Phosphorus is fixed in soils with large amounts of clay more than in soils with lower amounts of clay [2]. Soils of tropical regions have horizons of clay accumulation in the form of 1:1 clay rather than 2:1 clay, which have the potential to adsorb larger quantities of phosphorus due to the high amounts of Fe/Al they contain [3]. The availability of P is also influenced by soil types. In addition, modifications in soil chemistry result from alterations in drainage, texture, mode of soil development, and parent rock, which play a significant role in phosphorus availability. Phosphorus adsorption freely occurs on the broken ends of kaolinite clay minerals in acidic soils [4]. However, a small amount of P can be adsorbed through the displacement of CO_3^{2-} on the surface of $CaCO_3$ in calcareous soils. Arbuscular mycorrhizal fungi have been shown to enhance plant growth and heavy metal tolerance by increasing plant access to relatively immobile nutrients, increasing plant growth hormones, affecting the uptake and distribution of heavy metals in plant tissues [5], and ameliorating the condition of the soil micro-environment in the rhizosphere.

One of the major cereals worldwide is maize (*Zea mays* L.), which is ranked first among all cereal crops [6]. USA, China, and Brazil contribute largely, about 63%, of the overall maize production, though Mexico, Argentina, India, Ukraine, Indonesia, France, Canada, and South Africa are also main maize - producing countries [7]. For regular growth, maize needs a wide range of well-drained soils, from clayey loam to sandy loam high in organic matter and plant nutrients. Maize thrives poorly on heavy, sandy, or gravelly soil, and it thrives amid pH 4 and pH 7. Annual rainfall distribution and optimum temperature also affect maize growth. The quality of grain crops like maize is improved when these crops have satisfactory P nutrition. Deficiency of P in maize and some other grain species is expressed by purple colouration of either the whole leaves or leaf edges. Even though maize is planted all over Western Nigeria, the available nutrients vary from one place to the other. This is a result of dissimilarities in soil types, based on different parent rock materials (among others). These differences may affect P availability in maize and hence their responses to mycorrhizal infectivity, as well as the application of P fertilizer. The general objective of this research is to assess the rate of phosphorus availability in mycorrhizal-inoculated maize plants grown on selected soil series in the study areas. Meanwhile, the specific objective is to determine the most suitable mycorrhizal strain and soil series that will supply adequate nutrients for improved performance of maize in the study area.

2. Materials and Methods

2.1. Description of the sample locations and soil samples collection

The experiments were carried out at the Teaching and Research Farm of the Ladoke Akintola University of Technology, Ogbomoso, at 8°10'18'' N 4°16'27'' E and 7°46'17'' N 4°26'19'' E, 308 m altitude. The Iwo series was at 7°46'17'' N 4°26'19'' E coordinate with an altitude of 308 m and characterized by sedentary soils. It was dominated by the presence of stubborn grasses like Panicum maximum, Imperata cylindrica, Sida acuta, Cyperus mexicam, and Tithonia diversifolia. The Apomu series was located at the Iwo – Osogbo axis at coordinate 7°46'13'' N 4°26'55'' E with an altitude of 312 m. It was also characterized by hill-wash soils and contains Panicum maximum, Imperata cylindrica, and Sida acuta. The Itagunmodi series is associated with hill-wash soils at coordinate 7°40'37'' N 4°42'56'' E with an altitude of 368 m, Osogbo – Ilesa road, Nigeria. It was characterized by dense vegetation, tall grasses, shrubs, trees, millipedes, and termitaria. The Araromi series was located at the Ife-Ibadan expressway, Nigeria, with 7°27'34'' N 4°17'43'' E coordinates and an altitude of 224 m. It was associated with high-creep soils and characterized by tall grasses and shrubs. Egbeda series: The sand fraction is usually very fine throughout the profile and rarely very stony. The Egbeda series was characterized by sedentary soils located at Ibodi, at the coordinates 7°36'13'' N, 4°41'55'' E, and an altitude of 393 m. It was associated with broad leaves and sedges. Gambari series: This series cut across all associations with 8°10'18'' N 4°16'27'' E coordinate associated with the iron pan located at the Teaching and Research Farm of the Ladoke Akintola University of Technology, Ogbomoso, at the break of slope, before the valley bottom dominated by a high density of grasses such as Sida acuta and Pacicum maximum. Topsoil samples were taken with bulk samples using a shovel at 0-15 cm depth from six study areas. The soil types and potential land use patterns had been described [8].

2.2. Experimental design

The experiment was carried out in pots at the Teaching and Research of the Ladoke Akintola University of Technology, Ogbomoso. The experiment was a factorial arrangement in a Randomized Complete Block Design (RCBD) with three replications. The treatments were: six soil series (Iwo, Apomu, Itagunmodi, Araromi, Egbeda, and Gambari series), four levels of mycorrhizal strains without mycorrhizal inoculation (control), 20 g/15 kg soil (Glomus mosseae, Glomus clarum, and *Glomus fasculatum*). The mycorrhizal strains were chosen because – Glomus is known for symbiosis and readily forms an association with the roots of higher plants. It is the largest genus of Verricular-Arbuscular Mycorrhizal fungi. It can also be found in the surrounding soil as spores and hyphae, which can form a large network called mycelium; however, the majority of Glomus biomass occurs within the roots of host plants.

2.3. Field preparation and planting

Sterilized soil samples of 15 kg were measured into 72 black polythene bags perforated at the bottom for free exchange of air. Three seeds of maize (*Zea mays L.*, var. SWAN-1-SRY) were sown per pot after pre-inoculating them with strains of mycorrhiza (*Glomus mosseae, Glomus clarum, and Glomus fasculatum*) at the rate of 20 g of soil culture per hole. The mycorrhizae were to facilitate the absorption of nutrients from the soil through their hyphal networks. The pots were watered to 75% of the field moisture capacity (FMC) every other day, and the seedlings were thinned to two per pot at 2 weeks after sowing (2 WAS). At 2 weeks after sowing, urea at a rate of 75 kg N/ha (1.25 g urea/15 kg soil) was applied to each pot as a basal treatment. The experiment was allowed to run for 10 weeks.

2.4. Laboratory analyses of the soil samples

Soil samples were analysed before sowing to know the nutrient content of the soil. They were also analysed at the end of the research. A flame photometer was used to read K and Na, while Mg and Ca were read on an atomic absorption spectrometer (AAS, 325-1100Nm, India). Tissue samples were ground using a Wiley micro-hammer stainless steel mill and passed through a 40-mesh sieve prior to chemical analyses.

Tissue total N content was determined using the macro-Kjeldahl method [9] while tissue P content was determined using the vanadomolybdate procedure after digestion with H_2O_2. Cations were also determined after dry ashing in the muffle furnace at a temperature of 500 °C. The ignited samples were moistened with 4.0 N HCl and filtered into a 50 ml volumetric flask and made up to volume. The cations were determined colorimetrically using the vanadomolydate method.

2.5. Laboratory analyses of the plant tissue analyses

The plant tissue analyses were done during the vegetative stage before entering the generative stage. After harvesting at 10 WAS, all shoots and roots were oven dried at a temperature of 80 °C to a constant weight for five days, for the determination of dry weight and total biomass production. The plant samples were milled in a Wiley mill to pass through a 1 mm sieve, and the plant samples were analyzed for phosphorus according to the plant analysis procedure outlined in [10]. A 4.0 ml Nitric/Perchloric acid mixture (ratio 3:1) was added to 0.2 g of each sample in a 25 ml conical flask and left overnight. The content was heated until the white fuming stage, the point at which 1.0 ml of Hydrochloric acid/distilled water mixture (ratio 1:1) was added and heated for a further 30 minutes before the heat was removed. Distilled water was added to the digest and shaken before cooling down to room temperature to avoid the formation of insoluble perchlorate compounds. The digest was washed into a 50 ml volumetric flask and made up to the mark with distilled water. Total phosphorus was determined by the Vanadomolybdate colorimetric method on a spectrophotometer.

The nutrient accumulated in plant parts was calculated as;

$$\text{Nutrient uptake}\left(\text{Kgha}^{-1}\right) = \text{Plant Nurient concentration}(\%) \times \text{Total dry biomass } \left(\text{Kgha}^{-1}\right)/100 \text{ [11]} \quad (1)$$

Determination of mycorrhizal root infectivity was carried out by the grid line intersects method. After harvesting, root samples were cut into 1 cm lengths and stored in 50% ethanol. Root samples were later carefully rinsed with slow-running tap water to remove ethanol (before the commencement of the root-staining procedure). The root particles were put in sample bottles with 10% KOH overnight. Root particles were placed inside a water bath for steaming for 30 minutes at 80^{0}C [12] and later poured through a sieve and rinsed with running water, and put back inside sample bottles and further bleached in alkaline H_2O_2 for 10 minutes, after which they were rinsed in water and soaked in 1% HCl for 10 minutes. The staining solution, trypan blue, was used on the roots containing 0.05% trypan blue. 10 ml of 50% glycerol was added to each bottle, shaken very well, and left for 24 hours for proper staining. The stained root particles were poured into petri dishes with glycerol to prevent desiccation. The degree of mycorrhizal infectivity was assessed by spreading 25 pieces of root samples per slide and observing them under the dissecting microscope at low magnification. The total number of roots and the infected roots intersecting the grids were counted using the grid line intersect method [13]. The percentage of mycorrhizal root infectivity was calculated by the ratio between the number of intersects with infection and the total number of intersects multiplied by 100 [14].

$$\%\text{ root infectivity} = \frac{\text{Estimated population}}{\text{N} \times \text{Mp}} \times \frac{100}{1} \quad (2)$$

where: N = number of lines per slide; Mp = maximum root particles per slide

2.6. Statistical analysis

Statistical analyses of data collected were carried out using Statistical Analysis System (SAS) 2011 version. Separation of means was done using Analysis of Variance (ANOVA) at the 0.05 level of significance.

3. Results and Discussion

Table 1 shows the physical and chemical properties of the soils used for the experiments. The soil series employed for the pot experiment showed, based on the laboratory analyses, that Gambari had the highest value of sand, 87.9%. The Apomu series had the highest silt, 17.3%. The Egbeda series had the highest value of clay, 28.3%, while the Gambari series had the lowest value of clay, 3.3%. The textural classes of these soil series are sandy loam (Iwo), loamy sand (Apomu), sandy clay (Itagunmodi), clayey loam (Araromi), clayey sand (Egbeda), and sandy loam (Gambari).

The pH values of the Iwo series were neutral at 7.00, the Apomu series was alkaline at 8.10, and the others were acidic. The organic carbon content was low for all the soil series, especially Egbeda (0.24%). The available phosphorus (P) was medium for all the soil series. The total nitrogen (N) for all the soil series was low, which is typical of tropical soils and requires supplementation. The exchangeable soil cations Ca2+, Mg2+, K+, and Na+ were low, indicating low fertility.

Table 1. Physical and chemical properties of the soils used for the pot experiment

Properties	Iwo	Apomu	Itagunmodi series	Araromi	Egbeda	Gambari
Particle size analysis (%)						
Sand	80.90	78.90	73.50	69.90	63.30	87.90
Silt	14.80	17.30	4.20	5.80	8.40	8.80
Clay	4.30	3.80	22.30	24.30	28.30	3.30
Textural class	Sandy loam	Sandy loam	Sandy clay	Clayey loam	Clayey sand	Sandy loam
pH (H_2O) (1:1)	7.00	8.10	6.70	5.70	5.50	6.30
Available P (mg/kg)	32.52	30.62	22.84	23.00	8.71	24.27
Organic C (%)	1.19	1.32	1.36	0.96	0.24	0.64
Total N (%)	0.12	0.15	0.14	0.10	0.03	0.07
Exchangeable cations (cmol/kg)						
Ca^{2+}	2.32	2.10	1.86	2.73	0.33	1.32
Mg^{2+}	0.47	0.45	0.46	0.56	0.18	0.29
K^{+}	0.21	1.43	0.41	0.21	0.25	0.17
Na^{+}	0.18	0.33	0.37	0.14	0.13	0.10
Other trace elements (mg/kg)						
Mn	17.80	10.41	19.90	11.00	21.80	22.50
Fe	8.90	19.90	10.10	10.50	12.50	3.70
Cu	0.38	0.15	0.36	0.07	0.14	0.04
Zn	2.03	0.90	1.21	0.91	0.43	0.15

3.1. Phosphorus uptake

The summary of ANOVA of the main effect of soil series and mycorrhizal strains on phosphorus uptake of maize during the pot experiment is shown in Table 2. Table 3 shows the main effect of mycorrhizal strains and soil series on phosphorus uptake of maize during the pot experiment, while Figure 1 shows the effect of mycorrhizal strains on phosphorus uptake or availability. Soil series had no significant influence on the P uptake, while the Iwo series gave the highest mean phosphorus uptake (5.12 g/plant) and the least mean (4.09 g/plant) on the Apomu series. Mycorrhizal strains had a highly significant effect on phosphorus uptake, and the highest mean was recorded by *Glomus fasculatum* and the lowest mean by *Glomus clarum*. The interaction between the mycorrhizal strains and the soil series had no significant effect on phosphorus uptake of the maize plant at all periods of data collection.

In this study, P uptake for the soil series was not significant. Although the highest uptakes were recorded in the Iwo series (Table 3). The experiment had the highest P uptake on the Iwo series and the lowest on the Egbeda series. Soil texture plays a significant role in P uptake or availability for plant use [15], Iwo series is sandy, while the Egbeda series is clay. This explains why P uptake was higher in Iwo compared to the Egbeda series. Phosphorus is fixed easily by the Egbeda series as a result of clay content, making it unavailable for plant use [16]. Despite the fact that Egbeda is more fertile than the Iwo series, the available P for plant use tends to be trapped by the soil and unavailable for plant use. Soil pH also explains why the Iwo series had the highest P uptake; the Iwo series pH value is 7, compared to the Egbeda series 5.50, as explained by Baquy M et al. [17]. However, clayey soils, despite their fertility status, are not the best soil for plant growth, unlike sandy soils, which are less fertile. Soil acidity can result from a high cation exchange capacity and high clay content of the soil (see values of CEC and pH in Table 1). Phosphate immobility readily occurs by cation percolation as a result of high soil acidity. Availability of soil P is determined by soil pH value. Phosphorus is fixed when soil pH is low, and therefore, the lower its availability to the plant.

Table 2. Summary of ANOVA of the main effect of mycorrhizal strains and soil series on the phosphorus uptake (g/plant) of the maize plant

Source of Variation	Degree of freedom	Phosphorus uptake
Rep	2	5.64**
Soil series	5	0.94^{ns}
Mycorrhizal	3	3.11**
Soil series X Mycorrhizal	15	1.08^{ns}

Note: **= highly significant at 0.01 probability level, ns = not significant at 0.05 probability level.

Table 3. Main effect of mycorrhizal strains and soil series on the phosphorus uptake (g/plant) of the maize plant

Treatment	g/plant
Soil series (S)	
S1	5.12
S2	4.20
S3	4.74
S4	4.40
S5	4.09
S6	4.82
Mean	4.56
LSD (P = 0.05)	ns
Mycorrhizal (M)	
M0	4.29
M1	4.67
M2	3.96
M3	5.33
Mean	4.56
LSD (P = 0.05)	0.95
Interaction	
LSD SXM	ns

Note: M0 = control, M1 = *Glomus mosseae*, M2 = *Glomus clarum*, M3 = *Glomus fasculatum*, S1 = Iwo series, S2 = Apomu series, S3 = Itagunmodi series, S4 = Araromi series, S5 = Egbeda series, S6 = Gambari series, ns = not significant at 0.05 probability level

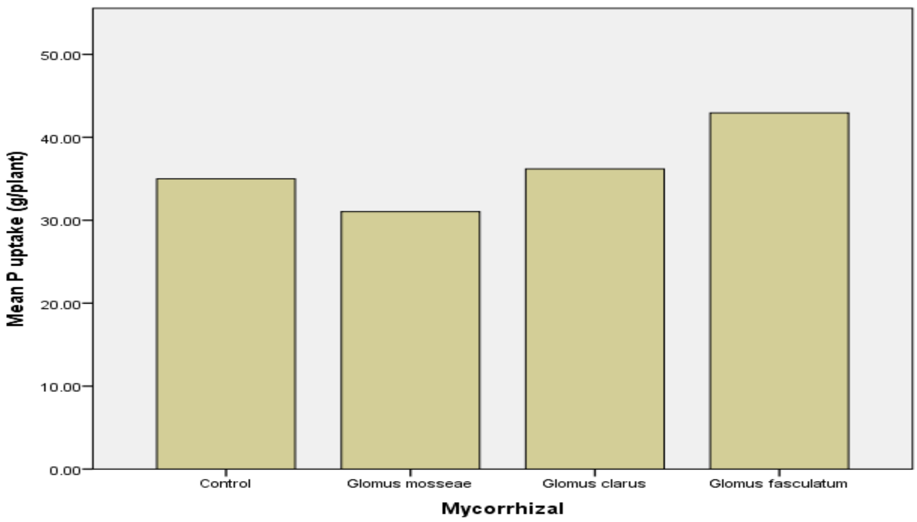

Figure 1. Effect of mycorrhizal strains on phosphorus uptake (g/plant) by maize plant; Note: M1 = control, M2 = *Glomus mosseae*, M3 = *Glomus clarum,* M4 = *Glomus fasculatum*

3.2. Root infectivity

The summary of the ANOVA of soil series and mycorrhizal strains on the mycorrhizal root infectivity on maize plant root during the experiment is represented in Table 4. The main effect of soil series and mycorrhizal strains on the mycorrhizal root infectivity on the maize plant root during the experiment is presented in Table 5. Both the soil series and mycorrhizal strains had no significant influence on the root infectivity. The interaction between the mycorrhizal strains and the soil series was highly significant on mycorrhizal infectivity of the maize plant at a 0.05 probability level.

Table 4. Summary of ANOVA of soil series and mycorrhizal strains on mycorrhizal root infectivity (%) of maize plant

Source of variation	Degree of freedom	Root infectivity (%)
Rep	2	2.38^{ns}
Soil series (S)	5	0.53^{ns}
Mycorrhizal (M)	3	0.5^{ns}
S X M	15	2.18**

Note: **= highly significant at 0.01 probability level, ns = not significant at 0.05 probability level

The minimal and maximal percentage values of root infectivity or colonization for the experiment were seen in the Egbeda series (51.42%) and the Apomu series (57.42%), respectively. The median percentage varies from 40 to 70% [18]. However, these were within the median percentage. Regarding soil texture, sandy soil enhances the development of mycorrhizal association while clayey soil inhibits it [19]. This explained the disparity observed in the experiment. A sandy soil whose texture is porous and less fertile than that of a finer texture of clay enhances arbuscular mycorrhizal fungi infectivity. Good soil aeration is also of great advantage for optimum AMF development. The experiment values of root infectivity were 57.42% on the Apomu series and 51.42% on the Egbeda series. The Egbeda series had the highest clay content (Table 1), while Apomu had low clay content. The soil texture, therefore, had a great influence on the mycorrhizal colonization or infectivity.

Table 5. Main effect of soil series and mycorrhizal strains on the mycorrhizal root infectivity (%) on the maize plant root

Treatment	Root infectivity (%)
Soil series (S)	
S1	53.75
S2	57.42
S3	52.58
S4	55.92
S5	51.42
S6	56.00
Mean	54.52
LSD S (P = 0.05)	ns
Mycorrhizal (M)	
M0	53.89
M1	53.78
M2	53.17
M3	57.22
Mean	54.52
LSD M (P = 0.05)	ns
Interaction	
LSD S X M	**

M0 = control, M1 = *Glomus mosseae*, M2 = *Glomus clarum*, M3 = *Glomus fasculatum*, S1 = Iwo series, S2 = Apomu series, S3 = Itagunmodi series, S4 = Araromi series, S5 = Egbeda series, S6 = Gambari series, WAS = week after sowing, ns = not significant at 0.05 probability level, ** = highly significant at 0.01 probability level.

Among the mycorrhizal strains, *Glomus fasculatum* gave the highest root infectivity in the experiment. This is due to the difference in soil texture, the first one being clayey (Egbeda series) while the second one sandy (Apomu series). Soils with low fertility limit plant development and increase the dependency of plants on mycorrhizal associations. Mycorrhizal responsiveness tends to favor sandy soil more than clayey soil, as clay soil has a dense structure, which limits aeration compared to sandy soil, and this often results in less exudation [20]. Whenever the soil is rich, mycorrhizal responsiveness is poor.

From Tables 4 and 5, the interaction between soil series and mycorrhizal strains shows that all data points within each group are identical. This means there's no variation within the soil series and mycorrhizal strains. It also explains the dependency of maize on mycorrhizal strains for root infectivity, and *Glomus fasculatum* shows the highest root infectivity. The LSD also shows the combinations of soil series and mycorrhizal stain levels to be minimal at 0.01 probability.

3.3. Maize growth parameters

3.3.1. Plant height (cm)

Table 6 shows the summary of the ANOVA of the main effect of soil series and mycorrhizal strains on plant height of maize during the pot experiment. Table 7 shows the main effect of soil series and mycorrhizal strains on the plant height of maize during the pot experiment. The soil series had no significant influence on the maize plant height at 3 WAS but was highly significant at 5, 7, and 9 WAS. Mycorrhizal strains also had no significant influence on the plant height at 3 WAS but were highly significant at 5, 7, and 9 WAS. Gambari series had the highest plant height at 5, 7, and 9 WAS. *Glomus fasculatum* produced the highest plant height from 5 WAS to 9 WAS. The interaction between the mycorrhizal strains and the soil series had no significant effect on the plant height of the maize plant at any period of data collection.

Table 6. Summary of ANOVA of the main effect of soil series and mycorrhizal strains on plant height (cm) of maize plants in a pot experiment

Source of variation	Degree of freedom	Plant height 3WAS	Plant height 5WAS	Plant height 7WAS	Plant height 9WAS
Rep	2	1.35ns	4.14**	12.07**	3.43**
Soil series (S)	5	1.8ns	12.93**	5.92**	5.06**
Mycorrhizal (M)	3	0.93ns	3.2**	2.91**	3.54**
S XM	15	0.67ns	0.54ns	1.01ns	0.65ns

Note: ** = highly significant at 0.01 probability level, ns = not significant at 0.05 probability level.

Table 7. Main effect of soil series and mycorrhizal strains on plant height (cm) of maize plant in pot experiment

Treatment	3WAS	5WAS	7WAS	9WAS
Soil series (S)				
S1	21.54	36.96	59.17	71.38
S2	22.50	31.42	57.71	70.96
S3	19.54	30.67	56.25	71.67
S4	23.75	40.79	69.96	84.17
S5	19.75	29.25	60.88	77.67
S6	21.83	48.67	74.63	88.71
Mean	21.49	36.29	63.10	77.43
LSD S (P = 0.05)	ns	5.91	8.70	9.55
Mycorrhizal (M)				
M0	21.39	32.69	57.72	70.28
M1	21.28	36.92	61.64	77.31
M2	20.50	35.56	66.39	79.53
M3	22.78	40.00	66.64	82.33
Mean	21.49	36.29	63.10	77.36
LSD M (P = 0.05)	ns	4.83	7.10	7.80
Interaction				
LSD S X M	ns	ns	ns	ns

Note: M0 = control, M1 = *Glomus mosseae*, M2= *Glomus clarum*, M3 = *Glomus fasculatum*, S1 = Iwo series, S2 = Apomu series, S3 = Itagunmodi series, S4 = Araromi series, S5 = Egbeda series, S6 = Gambari series, ns = not significant at 0.05 probability level.

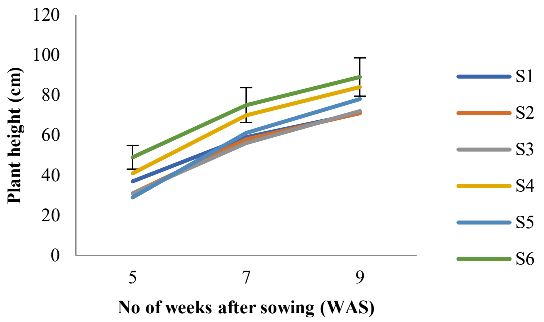

Figure 2. Effect of soil series on plant height (cm) of the maize plant; note: S1 = Iwo series, S2= Apomu series, S3 = Itagunmodi series, S4 = Araromi series, S5 = Egbeda series, S6 = Gambari series

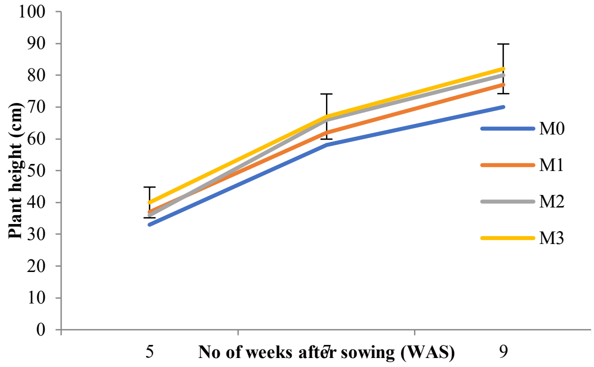

Figure 3. Effect of mycorrhizal strains on plant height (cm) of maize plant; note: M0 = Control, M1 = *Glomus mosseae*, M2 = *Glomus clarum*, M3 = *Glomus fasculatum*

3.3.2. Leaf area (cm²)

Table 8 shows the summary of the ANOVA of soil series and mycorrhizal strains on the leaf area of maize during the pot experiment. The main effect of soil series and mycorrhizal strains on the leaf area of maize during the pot experiment is presented in Table 9. Soil series had a highly significant effect on the leaf area at 3, 5, 7, and 9 WAS. Mycorrhizal strains had no significant effect on the leaf area of the maize plant at 3 and 5 WAS, but had a strong and significant influence on the leaf area of the maize plant at 7 and 9 WAS. The highest mean leaf area was recorded at 3 WAS on the Araromi series, while the Gambari series had the highest mean leaf area at 5, 7, and 9 WAS. Mycorrhizal strains control had the highest mean leaf area at 3 WAS, while Glomus clarum and Glomus fasculatum had the highest mean leaf area at 5 WAS. At 7 and 9 WAS, *Glomus fasculatum* had the highest mean leaf area. The interaction between the mycorrhizal strains and the soil series had no significant effect on the leaf area of the maize plant at any period of data collection.

Table 8. Summary of ANOVA of soil series and mycorrhizal strains on leaf area (cm^2) of pot experiment

Source of Variation	Degree of freedom	Leaf area 3 WAS	Leaf area 5 WAS	Leaf area 7 WAS	Leaf area 9 WAS
Rep	2	0.88ns	0.85ns	17.35**	11.09**
Soil series (S)	5	5.71**	16.31**	9.24**	6.96**
Mycorrhizal (M)	3	0.23ns	1.43ns	6.67**	14.99**
S X M	15	1.37ns	0.89ns	1.34ns	1.03ns

Note: **= highly significant at 0.01 probability level, ns = not significant at 0.05 probability level

Table 9. Main effect of soil series and mycoorhizal strains on the leaf area (cm^2) of the maize plant during the pot experiment

Treatment	3WAS	5WAS	7WAS	9WAS
Soil series (S)				
S1	69.47	125.59	258.01	348.54
S2	69.12	103.92	236.16	328.43
S3	53.45	93.07	220.47	323.84
S4	86.69	187.29	295.03	406.72
S5	56.56	100.15	263.35	365.58
S6	84.46	217.87	338.95	436.64
Mean	69.96	137.98	268.66	368.29
LSD S (P = 0.05)	16.36	36.73	40.08	48.51
Mycorrhizal (M)				
M0	71.01	119.31	226.69	299.51
M1	66.99	141.49	268.59	356.54
M2	69.53	145.94	289.09	391.35
M3	72.29	145.94	290.27	425.77

Table 9. Continued

Treatment	3WAS	5WAS	7WAS	9WAS
Mean	69.96	138.17	268.66	368.29
LSD M (P = 0.05)	ns	ns	32.72	39.61
Interaction				
LSD S X M	ns	ns	ns	ns

Note: M0 = control, M1 = *Glomus mosseae*, M2 = *Glomus clarum*, M3 = *Glomus fasculatum*, S1 = Iwo series, S2 = Apomu series, S3 = Itagunmodi series, S4 = Araromi series, S5 = Egbeda series, S6 = Gambari series, WAS = week after sowing, ns = not significant at 0.05 probability level

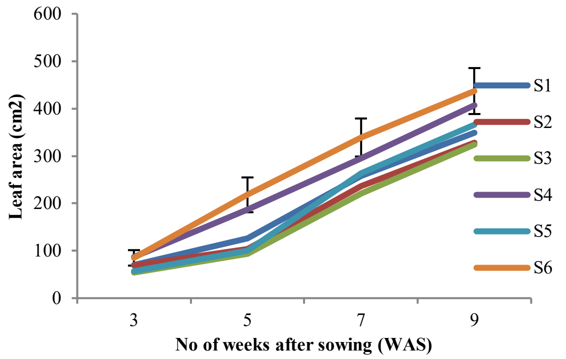

Figure 4. Effect of soil series on leaf area (cm^2) of maize plant; note: S1 = Iwo series, S2 = Apomu series, S3 = Itagunmodi, S4 = Araromi series, S5 = Egbeda series, S6 = Gambari series

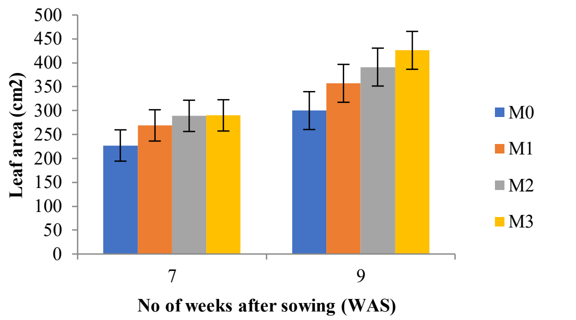

Figure 5. Effect of mycorrhizal strains on leaf area (cm^2) of maize plant; note: M0 = Control, M1 = *Glomus mosseae*, M2 = *Glomus clarum*, M3 = *Glomus fasculatum*

4. Conclusion and Recommendation

This paper shows the effect of selected mycorrhizal strains and six soil series on phosphorus availability in South-Western Nigeria. The availability of phosphorus depends on the textural class of the soil. Sandy soils released more phosphorus compared to clay soils, and the mycorrhizal strain - Glomus fasculatum gave the highest phosphorus and root infectivity. There was an interaction between mycorrhizal strains and soil series in the root infectivity; however, the significance was pronounced between the Apomu series and Glomus fasculatum. Among the mycorrhizal strains and soil series, Glomus fasculatum and the Iwo series, respectively, are recommended for phosphorus availability in South-Western Nigeria for optimum crop production.

References

[1] P. Raguet *et al*, "Mineralization and speciation of organic phosphorus in a sandy soil continuously cropped and phosphorus-fertilized for 28 years," *Soil Biology and Biochemistry*, vol. 178, p. 108938, 2023, doi: 10.1016/j.soilbio.2022.108938.

[2] J. Helfenstein *et al*, "Understanding soil phosphorus cycling for sustainable development: Review," *One Earth*, vol. 7, no. 10, pp. 1727-1740, 2024, doi: 10.1016/j.oneear.2024.07.020.

[3] G. Ashebir, K. Alemayehu, and M. Gashaw, "Changes in soil phosphorus pools and chemical properties under liming in Nitisols of Farawocha, South Ethiopia," *Applied and Environmental Soil Science*, vol. 2021, no. 1, p. 8823852, 2021, doi: 10.1155/2021/8823852.

[4] A. Sandim, L. J. R. da Silva, A. C. F. Deus, C. Penn, and L. T. Büll, "Phosphorus fraction in weathered tropical soils after application of conventional and alternative phosphorus fertilizers," *Journal of Soil Science and Plant Nutrition*, vol. 23, no. 4, pp. 5621–5631, 2023, doi: 10.1007/s42729-023-01426-w.

[5] T. Gu *et al*, "Diversity of arbuscular mycorrhizal fungi in rhizosphere soil and roots in *Vetiveria zizanioides* plantation chronosequence in coal gangue heaps," *Symbiosis*, vol. 86, pp. 111–122, 2022, doi: 10.1007/s13199-022-00829-0.

[6] A. Ali, S. Zafar, and M. Y. Ashraf, "Assessment of growth and biochemical indicators for drought tolerance in maize cultivars," *Pakistan Journal of Botany*, vol. 57, no. 1, pp. 125–134, 2025, doi: 10.30848/PJB2025-1(39).

[7] Food and Agriculture Organization (FAO), "Yearbook of International Environmental Law," *Yearbook of International Environmental Law*, vol. 24, no. 1, pp. 587–602, 2013, doi: 10.1093/yiel/yvu027.

[8] A. Ogunleye and S. Agele, "GIS-based characterization of land use, land cover patterns and microclimate of agricultural and agroforestry landscapes in a rainforest zone of Nigeria," *International Journal of Environment and Climate Change*, vol. 14, no. 2, pp. 1002–1023, 2024.

[9] J. M. Bremner and C. S. Mulvaney, "Nitrogen—Total," in *Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties*, 2nd ed., Madison, WI, USA: ASA, 1982.

[10] International Institute of Tropical Agriculture, "Available phosphorus in soil (Bray No. 1 method)," in *Selected Methods for Soil and Plant Analysis*, Wallingford, U.K.: CAB International, pp. 115–147, 1979.

[11] S. Huang *et al*, "Uncovering the impact of AM fungi on wheat nutrient uptake, ion homeostasis, oxidative stress, and antioxidant defense under salinity stress," *Scientific Reports*, vol. 13, no. 1, p. 8249, 2023, doi: 10.1038/s41598-023-35148-x.

[12] J. M. Phillips and D. S. Hayman, "Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection," *Transactions of the British Mycological Society*, vol. 55, pp. 158–161, 1970.

[13] Y. Liu, M. Yang, N. Li, Y. Huang, and C. Yang, "Black ink staining protocol: A cost-effective substitute in quantifying arbuscular mycorrhizal colonization in plant roots," *Journal of Microbiological Methods*, vol. 232, p. 107141, 2025, doi: 10.1016/j.mimet.2025.107141.

[14] A. Bisht, V. Sharma, and N. Garg, "Deciphering the role of arbuscular mycorrhizal fungi in mitigating the negative effects of abiotic stresses in legume crops," in *Arbuscular Mycorrhizal Fungi in Sustainable Agriculture: Nutrient and Crop Management*, pp. 337–361, 2024, doi: 10.1007/978-981-97-0300-5_15.

[15] L. Feng *et al*, "Evaluation of soil texture classification from orthodox interpolation and machine learning techniques," *Environmental Research*, vol. 246, no. 118075, 2024, doi: 10.1016/j.envres.2023.118075.

[16] Z. Jian, L. Lei, Y. Ni, J. Xu, W. Xiao, and L. Zeng, "Soil clay is a key factor affecting soil phosphorus availability in the distribution area of Masson pine plantations across subtropical China," *Ecological Indicators*, vol. 144, no. 109482, 2022, doi: 10.1016/j.ecolind.2022.109482.

[17] M. Baquy, J. Li, J. Nkoh Nkoh, M. R. Biswash, and R. Xu, "Determining critical soil pH for phosphorus uptake efficiency in an acidic ultisol for maize," *Egyptian Journal of Soil Science*, vol. 64, no. 4, pp. 1525–1536, 2024.

[18] J. U. Haq, M. Sherif, W. A. Akbar, and Hafeez, "Arbuscular mycorrhizal fungi integrated with single super phosphate improve wheat nitrogen–phosphorus acquisition, yield, root infection activity and spore density in alkaline-calcareous soil," *Gesunde Pflanzen*, vol. 75, pp. 539–545, 2023, doi: 10.1007/s10343-022-00718-y.

[19] A. Herawati, M. Mujiyo, W. S. Dewi, J. Syamsiyah, and M. R. Romadhon, "Improving microbial properties in Psamments with mycorrhizal fungi, amendments and fertilizer," *Eurasian Journal of Soil Science*, vol. 13, no. 1, pp. 59-69, 2024, doi: 10.18393/ejss.1396572.

[20] A. Adeniji, J. Huang, and S. Li, "Hot viewpoint on how soil texture, soil nutrient availability, and root exudates interact to shape microbial dynamics and plant health," *Plant and Soil*, vol. 511, pp. 69–90, 2025, doi: 10.1007/s11104-024-07020-y.