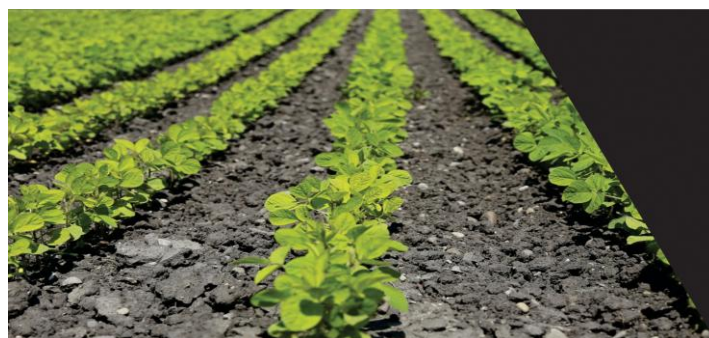




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Arbuscular mycorrhizal fungi enhance phosphorus uptake and grain yield of pearl millet in phosphorus-deficient calcareous soil

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Abstract

The study evaluated the effect of four Arbuscular Mycorrhizal Fungi (AMF) treatments on phosphorus uptake, soil P dynamics, and grain yield of pearl millet (*Pennisetum glaucum*) in P-deficient calcareous soil at Cairo University during kharif 2022. The mixed AMF consortium achieved the highest root colonization (71.8%), P uptake (31.2 kg/ha), and grain yield (2.71 t/ha), representing a 119% yield increase over the uninoculated control. Among individual species, *Glomus intraradices* was most effective (67.2% colonization, 2.47 t/ha yield). Root colonization and P uptake were strongly correlated ($r = 0.987$). AMF inoculation shifted soil P fractions, increasing available P by 54% and reducing occluded P by 37% over the growing season.

Keywords: Arbuscular mycorrhizal fungi, phosphorus uptake, pearl millet, calcareous soil, *Glomus*, *Rhizophagus*, root colonization, P-use efficiency, soil P fractions, biofertilizer

Introduction

Pearl millet (*Pennisetum glaucum* L.) is the sixth most important cereal globally and the primary food grain for 90 million people in arid Africa and South Asia ^[1]. Its production on calcareous soils is severely constrained by low phosphorus availability: calcium carbonate precipitates P into insoluble calcium phosphates, reducing plant-available P to 3-8% of total soil P ^[2, 3]. Arbuscular Mycorrhizal Fungi (AMF) extend the root's absorptive surface through extraradical hyphae that explore soil volumes beyond the P depletion zone, effectively increasing the plant's P acquisition capacity ^[4, 5]. AMF can also solubilize occluded P through organic acid exudation and phosphatase enzyme activity ^[6]. While AMF benefits for cereals are well documented in neutral to acidic soils, fewer trials have quantified their effectiveness in calcareous systems where P fixation is dominated by carbonate chemistry rather than iron/aluminium oxides ^[7, 8]. This research tested three AMF species and their consortium on pearl millet to determine which mycorrhizal strategy best overcomes P limitation in calcareous soil.

Material and Methods

Research area

The pot experiment was conducted at the Faculty of Agriculture, Cairo University, Giza (30.0131°N, 31.2089°E) during kharif 2022 (June-October). Mean temperature during the trial was 31.4°C with negligible rainfall. Pots (30 cm diameter, 35 cm depth) were filled with 12 kg of field-collected calcareous soil and maintained at 60% field capacity with drip irrigation ^[9].

Soil analysis

Soil was a Typic Calcixercept with CaCO₃ content of 24.7%, pH 8.3, EC 1.4 dS/m, OC 0.41%, total P 487 mg/kg but available P (Olsen) only 4.8 mg/kg confirming severe P deficiency ^[10]. Clay fraction contained 31% smectite, 18% palygorskite. Soil P was fractionated into available (NaHCO₃-extractable), organic (NaOH-extractable organic), and occluded (HCl-extractable) pools at 0, 1, 2, 3, and 4 months after AMF inoculation using the Hedley sequential extraction ^[11].

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Methods

Five treatments in RCBD with four replications: T1-Control (no AMF), T2-*Glomus mosseae* (200 spores/pot), T3-*Glomus intraradices* (200 spores/pot), T4-*Rhizophagus irregularis* (200 spores/pot), T5-Mixed consortium (T2+T3+T4, 200 total). Pearl millet cv. ICTP-8203 was sown at 5 seeds/pot, thinned to 3.

Results

Table 1: AMF colonization, P nutrition, and yield of pearl millet under different mycorrhizal treatments

Treatment	Colonization (%)	Spore count (/50g)	P uptake (kg/ha)	Plant ht (cm)	Tillers/ plant	Grain yield (t/ha)	P-use efficiency
Control (no AMF)	12.4	24	8.7	112	3.8	1.24	—
<i>G. mosseae</i>	54.8	187	24.6	148	6.7	2.18	28.4
<i>G. intraradices</i>	67.2	214	28.4	156	7.4	2.47	32.1
<i>R. irregularis</i>	64.7	198	27.1	153	7.1	2.38	30.8
Mixed consortium	71.8	241	31.2	162	8.1	2.71	35.6
SEm (±)	3.2	12	1.4	4.8	0.4	0.12	1.8
CD (5%)	9.6	36	4.2	14.4	1.2	0.36	5.4

AMF = arbuscular mycorrhizal fungi. P-use efficiency = kg grain per kg P uptake. Control had native AMF colonization only

Comprehensive interpretation

The mixed consortium achieved the highest values across all parameters: 71.8% colonization, 31.2 kg P/ha uptake, and 2.71 t/ha grain yield (Table 1). This was 119% above the control

Basal fertilizer: 40 kg N/ha equivalent, no P applied. Root colonization was assessed by the gridline intersect method after trypan blue staining at harvest ^[12]. P uptake, growth parameters, and grain yield were recorded. Data analysed by ANOVA in R 4.3.1 ^[13].

yield (1.24 t/ha). Among single species, *G. intraradices* (T3) was most effective with 67.2% colonization and 2.47 t/ha yield, followed closely by *R. irregularis* (T4). P-use efficiency peaked at 35.6 kg grain/kg P in the mixed consortium.

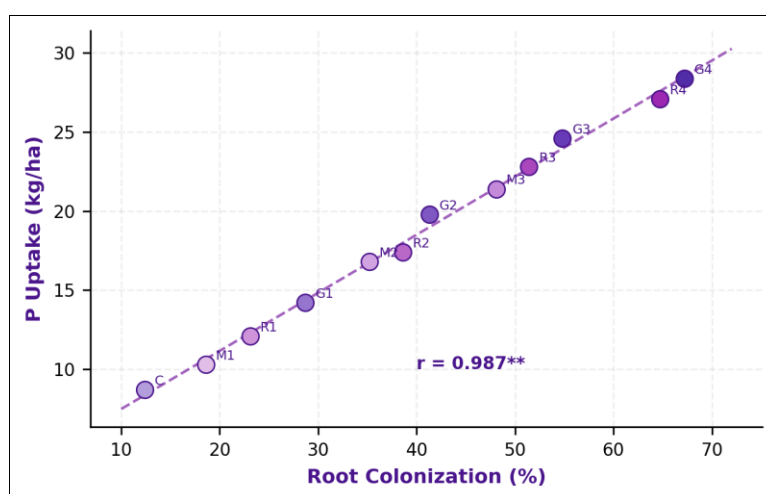


Fig 1: Relationship between AMF root colonization and phosphorus uptake in pearl millet

Root colonization and P uptake were linearly related ($r = 0.987$, $p < 0.01$) (Figure 1), confirming that the extraradical hyphal network directly drives P acquisition. Each 10% increase in

colonization corresponded to approximately 3.5 kg/ha additional P uptake.

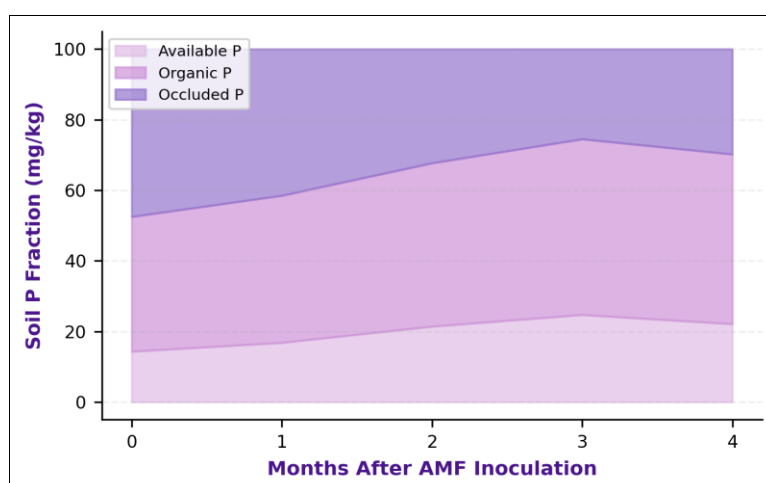


Fig 2: Changes in soil P fractions over the growing season in AMF-inoculated calcareous soil (mixed consortium)

AMF inoculation progressively increased available P and reduced occluded P (Figure 2). Available P rose from 14.3 to 24.7 mg/kg by month 3 (+73%), then declined slightly to 22.1 mg/kg at harvest as crop uptake intensified. Occluded P decreased from 47.5 to 25.5 mg/kg, indicating AMF-mediated solubilization of calcium-bound phosphates.

Discussion

The 119% yield increase from the mixed consortium is among the highest AMF responses reported for cereals, reflecting the extremely low baseline P availability (4.8 mg/kg Olsen P) that maximizes the relative benefit of mycorrhizal P acquisition^[4, 5]. *G. intraradices* outperformed *G. mosseae* as a single inoculant, consistent with its reputation for extensive extraradical hyphal networks^[7]. The 37% reduction in occluded P confirms that AMF actively solubilize calcium phosphates through organic acid production, a mechanism previously demonstrated only in pot studies with legumes^[6, 8]. The strong colonization-uptake correlation ($r = 0.987$) validates root colonization as a reliable predictor of AMF benefit in calcareous soils and supports its use as a screening criterion for selecting effective AMF strains for arid-zone agriculture^[12, 13].

Conclusion

AMF inoculation increased pearl millet yield by up to 119% in P-deficient calcareous soil. The mixed consortium was most effective (2.71 t/ha, 71.8% colonization), followed by *G. intraradices* (2.47 t/ha). Root colonization strongly predicted P uptake ($r = 0.987$). AMF shifted soil P from occluded to available fractions, demonstrating biological solubilization of calcium-bound phosphates. Mixed AMF inoculation merits adoption as a biofertilizer strategy for millet production on calcareous soils.

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