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Assessing the Impact of Land Use on Arbuscular Mycorrhizal Root Colonisation Rate, Phosphorus and Nitrogen Uptake in Ife Bimpe Cowpea

Nwokocha Amarachi Grace[1]*, Ukagba Oluchi Ukamaka[1], Sani Idris[3], Briki-Okolosi Ebenezer Ogheneochuko[1], Omopariola Oluwadara[1], Oyekale Oluwafunmike[1], and Fagbola Olajire[1,2]

[1]*Department of Agriculture and Industrial Technology, Babcock University, 121103 Ogun State, Nigeria*
[2]*Department of Soil Resources Management, University of Ibadan, 200001 Ibadan, Nigeria*
[3]*Department of Soil Science, Faculty of Agriculture, Institute for Agricultural Research, Ahmadu Bello University, 1044 Samaru, Zaria, Nigeria*

ABSTRACT

Soil characteristics, microbial ecology and organic additions influence soil fertility and plant productivity. However, the effects of land use and organic amendments on arbuscular mycorrhizal fungi (AMF), which enhance nutrient uptake and tolerance to soil stress, remain insufficiently understood. This study examined the effects of land use and organic amendments on AMF spore abundance, root colonisation and nutrient uptake. Soils from African Star Apple (ASAR), Cassava (CRR) and Bush Fallow (BFR) collected from farms behind Babcock University stadium, Nigeria, were analysed for pH, organic carbon, total nitrogen and available phosphorus. AMF spore abundance was assessed at 3-week intervals over 9 weeks following application of poultry manure (5 t ha^{-1}), cow dung (10 t ha^{-1}), and poultry manure plus cow dung (5 t ha^{-1} + 10 t ha^{-1}) before planting. Soil pH ranged from 7.00 (CRR) to 5.54 (BFR). ASAR had the highest organic carbon (5.46 g/kg) and total nitrogen (0.23%), while CRR had the highest phosphorus (4.727 mg/kg). CRR recorded the highest AMF root colonisation (48%) and Gigaspora spp. abundance, whereas ASAR had the highest total spore count (62%). Poultry manure increased root colonisation (44%) but reduced spore production, while cow dung maintained higher spore abundance (57%). Plant height and leaf development varied among land-use types, with ASAR soil supporting superior growth by Week

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E-mail addresses:
nwokochaa@babcock.edu.ng (Nwokocha Amarachi Grace)
oluchichychy3@gmail.com (Ukagba Oluchi Ukamaka)
sanidris2000@gmail.com (Sani Idris)
ebenezerbrikiokolosi@gmail.com (Briki-Okolosi Ebenezer Ogheneochuko)
oluwadaraomopariola1@gmail.com (Omopariola Oluwadara)
oyekale0389@pg.babcock.edu.ng (Oyekale Oluwafunmike)
fagbola1111@gmail.com (Fagbola Olajire)
* Corresponding author

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9. AMF parameters were positively related to soil fertility indicators. Overall, cow dung promoted AMF spore abundance, whereas poultry manure facilitated root colonisation; CRR soils favoured colonisation, while ASAR soils favoured sporulation.

Keywords: Cow dung, *Gigaspora* spp., organic amendments, poultry manure, soil fertility indicators, soil origin, spore density, symbiotic fungi

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INTRODUCTION

Phosphorus (P) and nitrogen (N) deficiencies are important constraints that severely limit crop productivity and threaten food security in tropical agroecosystems (Begum et al., 2019; Rillig et al., 2019). Arbuscular mycorrhizal fungi (AMF) create symbiotic relationships with plant roots that allow for the assimilation of these essential nutrients and so promote plant tolerance to environmental stress and enhance overall productivity (Augé et al., 2015; van der Heijden et al., 2015). AMF symbiosis is an active method for sustainable enhancement of crop yields on nutrient-poor soils with increasing global food demand and decreasing soil fertility (Wang et al., 2023).

Land use changes, notably the conversion of natural habitats such as forests into agricultural lands such as shrubby pasture-lands, have major implications for AMF diversity and function (Soka & Ritchie, 2018; Turrini et al., 2018). Such changes are generally associated with reduced AMF root colonisation and disrupted nutrient cycling, largely as a result of increased soil disruption and changes in vegetation structure (Davison et al., 2015; Trejo et al., 2016). While the effects of land use on AMF communities have been extensively investigated, there is a dearth of information about the consequences of these changes for AMF-plant interactions in different crop cultivars and agro-ecological zones, particularly in tropical soils which have been mostly neglected.

Addressing this knowledge gap is important as legumes, including cowpea (Vigna unguiculata), are important for food security and soil fertility through biological nitrogen fixation and nutrient cycling. The cowpea variety 'Ife Bimpe' is widely grown in the tropics and provides an excellent model to study these relationships under different land use systems. This study evaluated the effects of soils collected from different land-use types and organic amendments (poultry manure, cow dung, and their combination) on AMF spore abundance, root colonisation, soil nutrient availability, nutrient uptake, and cowpea productivity.

MATERIALS AND METHODS

Study Sampling Location and Experimental Set-up

The experiments were conducted in the screen-house of Babcock University, Ilishan-Remo, Ogun State, Nigeria, with a mean rainfall of 2400 mm at latitude 6.8932E and longitude

3.715N. Soil samples for this study were collected from different land use types, which include African star apple soil (ASAR), fallow bush soil (BFR), and cassava root soil (CRR) Figure 1. Sampling was conducted at a depth of 0-15 cm, at farms located behind Babcock University stadium, using a soil auger at 10 randomly selected points within each rhizosphere. Poultry manure (5 t ha^{-1}), cow dung (10 t ha^{-1}), and the combined treatment of poultry manure and cow dung (5 t ha^{-1} + 10 t ha^{-1}) were thoroughly mixed with the soil one week before planting to allow for decomposition and nutrient release prior to sowing. A 3x4 factorial experiment on a Completely Randomised Design (CRD), which was replicated three times, was used to set up the experiment as shown in Table 1.

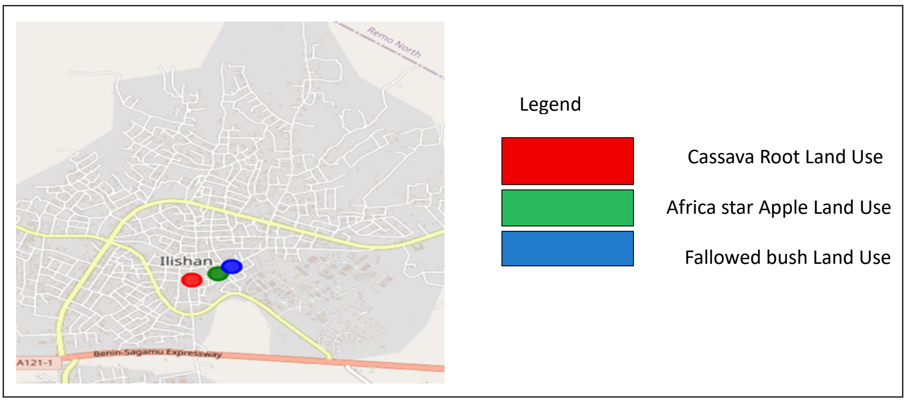

Figure 1. Satellite map of the study site behind Babcock University (Latitude: 6.8932° N, Longitude: 3.715° E), showing sampling locations for the three land use types: ASAR (African star apple), BFR (fallowed bush), and CRR (cassava root) plantations.
Source: Google Earth Pro satellite imagery (Google, 2025)

Table 1
Completely randomised design (CRD) layout of the experiment

Different Rhizosphere Soil Sources	**B0 (None)**	**B1 (PM @ 5 t/ha)**	**B2 (CD @ 10 t/ha)**	**B3 (PM + CD Mixture)**
ASAR	T1	T4	T7	T10
CRR	T2	T5	T8	T11
BFR	T3	T6	T9	T12

Note. Legend: ASAR = soil sampled from African star apple, BFR = soil sampled from Fallowed bush, CRR = soil sampled from Cassava root, B0 = No manure (sole AMF soil), B1 = Poultry Manure (PM) @ 5 t/ha, B2 = Cow Dung (CD) @ 10 t/ha, B3 = Mix of PM + CD @ 5 t/ha and 10 t/ha respectively

Organic Amendment Characterisation

The physicochemical properties of the organic amendments are presented in Table 2. Cow dung exhibited an alkaline pH, whereas poultry droppings showed near-neutral to slightly alkaline characteristics. Poultry droppings had higher nitrogen, phosphorus, magnesium, and calcium contents compared with cow dung, while cow dung recorded a higher potassium content.

Table 2
Organic amendment

Properties	Poultry Manure	Cowdung
pH in H_2O	6.52	9.24
Total nitrogen (%)	4.41	5.03
Organic carbon (%)	35.50	23.78
Total P (%)	0.85	0.31
Ca (Cmol/kg)	3.56	0.71
Mg (Cmol/kg)	1.54	1.11
K (Cmol/kg)	0.53	3.13

Screenhouse Experiment

A five-kilogram (5 kg) portion of the soil from different treatment combinations was introduced into 7kg pots (7-litre bucket), perforated basally to facilitate drainage of any excess water. For Muriate of potash, straight fertiliser was applied at a standard rate of 30 kg/ha on each of the experimental pots. However, Nitrogen and phosphate fertilisers were not applied to observe the level of abundance of AMF spores, how they can colonise cowpea roots, their level of influence on phosphorus and nitrogen absorption by the cowpea crop, as well as their influence on different soil phosphorus and nitrogen availability. The soil was watered, and after a week, seven seeds of cowpea were planted, and it was thinned down to five seedlings at week two after planting.

Laboratory Analysis

Soil samples were air-dried and sieved in preparation for subsequent physical and chemical analyses. Particle size distribution was assessed using the hydrometer method (Agbenin, 1995; Bouyoucos, 1962), with a 5% Calgon solution as the dispersing agent. The organic carbon content was determined by the potassium dichromate method (Walkley & Black, 1934), where one gram of soil was mixed with $K_2Cr_2O_7$ and H_2SO_4, incubated, and then titrated with $FeSO_4$. Soil pH was measured using a pH meter in a 1:1 soil-to-water ratio (Thomas, 1996). Available phosphorus was extracted using Bray 1 solution (Murphy & Riley, 1962) by mixing one gram of soil with 7 mL of the Bray solution. Exchangeable bases were extracted with 1N ammonium acetate at pH 7 (Okalebo et al., 1993), and potassium (K) and sodium (Na) concentrations were quantified using flame photometry, while calcium (Ca) and magnesium (Mg) were analysed via Atomic Absorption Spectroscopy (AAS). Exchangeable acidity, comprising Al^{3+} and H^+, was determined by extraction with 1N KCl followed by titration (McLean, 1965). Total nitrogen content was quantified using the Kjeldahl digestion method (Bremner, 1965). Mycorrhizal propagule density and diversity were determined using wet sieving and decanting methods as described by Gerdemann and Nicolson (1963). AMF root colonisation was examined using the gridline intersect method according to Giovannetti and Mosse (1980).

The characteristics of the organic amendments were determined before application using the same analytical procedures described for the soil samples. The measured properties are presented in Table 2.

Data Collection and Statistical Analysis

Data were collected on plant height and number of leaves from 3 WAP, while from weeks 6 to 9, data were collected on root colonisation rate and phosphorus uptake. Nevertheless, from weeks 9 to 12, data were collected on biomass accumulation and yield (Dry shoot weight, pod weight, number of pods). Data collected were subjected to analysis of variance and correlation, while means were separated using the Duncan Multiple Range Test (DMRT) at 5%, and using Statistical Analysis Software 9.4. Graphs were plotted using the OriginPro 2024 software.

RESULTS AND DISCUSSION

Physical and Chemical Soil Properties of Various Land-Use Types

Table 3 shows the physical and chemical properties of soils collected from three different land-use types: African Star Apple soil (ASAR), Bush Fallow soil (BFR), and Cassava soil (CRR). The pH values indicated slightly acidic conditions in ASAR (5.56) and BFR (5.54), while the CRR soil was neutral (7.00). ASAR had the highest organic carbon (5.56 g/kg) and total nitrogen (1.25 g/kg), followed by BFR (3.59 g/kg OC; 0.74 g/kg N), with CRR having the lowest values (2.19 g/kg OC; 0.25 g/kg N). ASAR and BFR soils recorded limited concentrations of available phosphorus compared to CRR soil, with the highest P concentration (4.727 mg/kg). The improved nutrient availability and microbial activity observed in soil collected from the CRR land use system could be due to its near-neutral pH (Havlin & Heiniger, 2020; Weil & Brady, 2017), whereas the slightly acidic conditions in ASAR and BFR soils may have fixed the availability of phosphorus and micronutrients like zinc and iron, making them temporarily unavailable for immediate use. While ASAR soil's relatively higher organic carbon content may create a conducive environment for microbial activities and improve soil stability (Lal, 2020), the lower carbon levels in BFR and CRR soils may cause limitations to fertility, highlighting how vital organic amendments are in soil processes (Samson et al., 2024; Wiesmeier et al*.,* 2019). The higher nitrogen levels observed in ASAR soil highly indicate its comparative ability to support vegetative growth compared to BFR and CRR soils with critically low nitrogen content. This indicates that both BFR and CRR soils need nitrogen supplementation for optimal cowpea vegetative growth (Gadisa, 2020). Although CRR soil had higher available phosphorus, likely due to pH-mediated solubility (Braak et al., 2016), its low nitrogen and organic matter may negatively impact crop productivity. Thus, these findings reveal that ASAR soil requires limited input, whereas BFR and CRR soils may need integrated nutrient management to maintain adequate nutrient supply and support plant growth (Rahman et al., 2017).

Table 3
Physical and chemical properties of soil from different land use types

Sample	SOIL														
	pH (H2O)	**OC**	**N**	**Bray P**	**SAND**	**SILT**	**CLAY**	**Ca**	**Mg**	**K**	**Na**	**Zn**	**Cu**	**Mn**	**Fe**
	1:1	**(g/kg)**	**(g/kg)**	**(Mg/kg)**		**(g/kg)**				**(Cmol/kg)**			**(Mg/kg)**		
ASAR	5.56	5.56	1.25	1.540	690.0	90.0	220.0	1.4895	0.44	0.2835	0.064	0.03644	0.006	0.273	1.692
BFR	5.54	3.59	0.74	1.467	750.0	50.0	200.0	1.298	0.4235	0.5185	0.056	0.04145	0.004	0.346	1.571
CRR	7.00	2.19	0.25	4.727	790.0	50.0	160.0	1.966	0.4235	0.401	0.046	0.04485	0.006	0.2175	1.4425

Variation in Spore Abundance and Root Colonisation under Soils from Different Land-use Types and Organic Amendments Across Different Weeks

Differences in abundance of *Glomus* and *Gigaspora* spores and AMF root colonisation were observed across soils from different land-use types and organic amendment treatments (Table 4). At Week 3, soils from the bush fallow land-use type (BFR) recorded significantly higher *Glomus* spore counts (30.83), maintaining consistency in abundance up to Week 6 (48.92), which, however, declined to zero by Week 9. In contrast, soils from the African star apple land-use type (ASAR) maintained spore presence at Week 9 (1.17), indicating a more sustained AMF presence, suggesting that AMF propagules may persist more effectively under these soil conditions. The unamended control treatment had the highest *Glomus* counts at Weeks 3 and 6 (35.78 and 45.00), while poultry manure-amended soils (APM) retained spores (1.56) in Week 9. *Gigaspora* spores were initially more abundant in soils from the cassava land-use type (CRR) at Week 3 (3.08), while ASAR soils had the highest and most sustained sporulation at Weeks 6 and 9 (5.83 and 1.17, respectively).

Early *Gigaspora* sporulation was stimulated by cow dung (ACD, 4.11%) and poultry manure plus cow dung (APM&CD, 7.78%) at Week 3. However, only poultry manure-amended soils (APM) maintained spores at Week 9 (1.66). AMF root colonisation increased over time, with soils from the cassava and African Star Apple land-use types (CRR and ASAR) showing significantly higher colonisation (25.94% and 24.29%) than bush fallow soil (BFR; 21.73%) by Week 9. Unamended control treatments had the highest colonisation rates at all time points (7.40%, 22.79%, and 33.72%). These fertility patterns influenced mycorrhizal responses across the different land-use types and amendment treatments. In BFR soil, the increase and subsequent decline in Glomus spore abundance suggests a temporary AMF response, possibly associated with initial soil conditions (Guo et al., 2022). Conversely, soils from the African Star Apple land-use type and poultry manure-amended soils maintained Glomus spore production up to Week 9, which may reflect the sustained availability of nutrients and carbon from organic amendments that support soil microbial activity (Alzarhani et al., 2019; Enebe et al., 2025). The early and higher Gigaspora sporulation observed in soils from the cassava land-use type, together with its persistence in African Star Apple-derived soil, suggests favourable interactions between host plants and AMF communities under cowpea cultivation (Mukhongo et al., 2023). Among the organic amendment treatments, cow dung (ACD) and poultry manure combined with cow dung (APM & CD) enhanced early Gigaspora activity, while only APM maintained sporulation through Week 9, indicating a sustained effect of amendment application on AMF development (Zhang et al., 2020).

Table 4
Level of spore abundance and %amf root colonisation as influenced by soil from different land-use types and soil amendment across different weeks

Treatment	Glomus sppwk3	Glomus sppwk6	Glomus sppwk9	Gigaspora sppwk3	Gigaspora sppwk6	Gigaspora sppwk9	%amf root colonisedWK3	%amf root colonisedWK6	%amf root colonisedWK9
Soil									
ASAR	21.08±1.9b	36.17±2.3b	1.17±0.6a	1.92±1.0b	5.83±3.1a	1.17±0.6a	4.63±0.9b	16.64±0.7a	24.29±2.0a
BFR	30.83±4.2a	48.92±2.9a	0.00±0.0b	0.33±0.3c	3.33±1.2b	0.00±0.0b	6.13±0.5a	14.54±2.4b	21.73±2.7b
CRR	16.92±2.8c	24.75±2.3c	0.00±0.0b	3.08±1.7a	2.83±1.5b	0.00±0.0b	6.48±0.6a	16.69±2.1a	25.94±3.7a
Fertiliser									
Control	35.78±4.1a	45.00±4.9a	0.00±0.0b	0.44±0.4c	2.78±1.4c	0.00±0.0b	7.40±0.6a	22.79±1.3a	33.72±1.1a
ACD	16.33±2.7c	35.33±2.5b	0.00±0.0b	4.11±2.1a	5.44±1.8b	0.00±0.0b	5.76±0.6b	17.40±2.0b	29.18±3.0b
APM	25.22±3.1b	38.33±3.9b	1.56±0.8a	0.00±0.0c	0.00±0.0d	1.56±0.8a	5.39±b0.9c	12.30±1.3c	17.26±2.2c
APM&CD	14.44±1.0c	27.78±4.3c	0.00±0.0b	2.56±1.3b	7.78±4.0a	0.00±0.0b	4.43±0.8c	11.34±1.3c	15.79±1.7c
S*T	*	*	*	*	*	*	*	*	*

Note. Means with the same letter (s) in a column are not significantly different at the 5% level of probability by Duncan Multiple Range Test (DMRT); ns: not significant

The Interactive Effects of Land-use type and Organic Amendments on AMF Root Colonisation and Spore Abundance

Table 5 shows the effects of land-use type × organic amendment interaction on AMF colonisation and spore abundance. In the African Star Apple soil × control interaction (ASAR × Control), AMF root colonisation increased significantly from 7.94% at Week 3 to 32.39% at Week 9, exceeding the ASAR soil × poultry manure plus cow dung (APM & CD) interaction. The BFR soil× cow dung (ACD) interaction recorded a marked increase in colonisation from 3.70% to 40.01% by Week 9. Similarly, the CRR soil × Control interaction showed continuous colonisation, reaching 34.33% at Week 9. For Glomus spp., the CRR soil × Control interaction recorded the highest spore abundance at Week 3 (51.00 spores), followed by the ASAR soil × poultry manure (APM) interaction at Week 6 (45.33 spores). The BFR soil× ACD interaction recorded 27.33 spores at Week 9, indicating a delayed sporulation response. Gigaspora spp. showed higher sporulation under the ASAR soil × APM&CD interaction, with the highest value of 7.67 spores in Week 3. The BFR soil × ACD interaction also showed early sporulation, with 12.33 spores in Week 3 and 11.33 in Week 6, followed by a decline over time.

Root colonisation patterns further emphasised the influence of rhizosphere conditions on AMF development. ASAR and CRR soils recorded significantly higher AMF colonisation than BFR soil, with the unamended control treatment across the land-use types showing greater colonisation than amended treatments, highlighting the contribution of less disturbed and naturally regulated soil environments (Alguacil et al., 2017; Storer et al.,2017; Zhang et al., 2023). The higher colonisation observed in the ASAR soil × Control treatment interaction further supports the importance of stable conditions in promoting AMF symbiosis (Liu et al., 2020; Van Geel et al., 2022). In contrast, the gradual increase in colonisation under the BFR soil × ACD combination suggests that the slow nutrient release from cow dung may support progressive AMF establishment (Alguacil et al., 2017; Rillig et al., 2019). In CRR soil, the consistent colonisation observed in unamended control treatments further indicates compatibility between plant roots and native AMF communities (Wei et al., 2024).

Spore production patterns followed similar trends. The CRR soil × Control treatment interaction recorded the highest Glomus spore abundance, indicating suitable conditions for AMF multiplication. The ASAR soil × APM interaction also showed increased spore production, demonstrating the positive influence of poultry manure application (Alzarhani et al., 2019). The gradual but sustained sporulation observed in the BFR soil × ACD interaction corresponds with slower nutrient release during amendment decomposition (Storer et al., 2017). For Gigaspora, the ASAR soil × APM & CD interaction promoted higher early sporulation, suggesting combined amendment effects. However, the decline observed in BFR soil × ACD over time may reflect reduced nutrient availability as amendment resources were depleted (Mukhongo et al., 2023).

Table 5
Influence of land-use type × soil amendment interactions on AMF root colonisation and spore abundance

Soil	Fertiliser	%amf root colonisedWK3	%amf root colonisedWK6	%amf root colonisedWK9	Glomus sppwk3	Glomus sppwk6	Glomus sppwk9	Gigaspora sppwk3	Gigaspora sppwk6	Gigaspora sppwk9
ASAR	Control	7.94±0.3ab	18.86±0.6cd	32.39±1.5b	24.67±2.0bc	37.00±3.2cd	0.00±0.0b	0.00±0.0c	0.00±0.0d	0.00±0.0b
	ACD	7.05±0.1abc	15.23±2.3de	26.38±3.6c	17.00±1.2cd	36.33±1.5cd	0.00±0.0b	0.00±0.0c	0.00±0.0d	0.00±0.0b
	APM	2.14±0.01ef	16.76±0.8de	21.21±0.6d	28.67±1.2bc	45.33±1.2b	4.67±0.8a	0.00±0.0c	0.00±0.0d	4.67±0.9a
	APM&CD	1.40±0.03f	15.73±0.9de	17.18±1.8d	14.00±2.5e	26.00±1.2e	0.00±0.0b	7.67±1.3b	23.33±2.9a	0.00±0.0b
BFR	Control	8.36±0.4a	22.20±1.1bc	34.44±2.0b	31.67±2.2b	34.00±1.5d	0.00±0.0b	0.00±0.0c	0.00±0.0d	0.00±0.0b
	ACD	3.70±1.1def	24.20±1.6ab	40.01±0.8a	7.67±1.5f	27.33±2.7e	0.00±0.0b	12.33±2.0a	11.33±0.7b	0.00±0.0b
	APM	7.48±0.7abc	9.28±2.1gh	8.68±0.1e	13.67±1.5e	23.00±0.6e	0.00±0.0b	0.00±0.0c	0.00±0.0d	0.00±0.0b
	APM&CD	6.37±0.2abc	11.08±0.8gh	20.64±0.9d	14.67±1.8d	14.67±1.8f	0.00±0.0b	0.00±0.0c	0.00±0.0d	0.00±0.0b
CRR	Control	5.92 ±1.7bc	27.32±1.1a	34.33±2.7b	51.00±2.9a	64.00±2.5a	0.00±0.0b	1.33±1.3c	8.33±1.2bc	0.00±0.0b
	ACD	6.53±0.7abc	12.76±1.9ef	21.16±0.7d	24.33±c3.3d	42.33±2.3bc	0.00±0.0b	0.00±0.0c	5.00±2.7c	0.00±0.0b
	APM	6.54±0.4abc	10.88±0.6gh	21.90±0.7cd	33.33±2.6b	46.67±1.5b	0.00±0.0b	0.00±0.0c	0.00±0.0d	0.00±0.0b
	APM&CD	5.52±0.7cd	7.22±0.72h	9.54±0.4e	14.67±1.8e	42.67±3.5bc	0.00±0.0b	0.00±0.0c	0.00±0.0d	0.00±0.0b

Note. Means with the same letter (s) in a column are not significantly different at the 5% level of probability by Duncan Multiple Range Test (DMRT)

Influence of Land-Use Type and Soil Amendments on Soil Available Phosphorus (P), Nitrogen (%N), and Plant Nutrient Uptake Over Weeks 3, 6, and 9

A significant variation in nutrient dynamics was observed among the land-use types and amendment treatments (Table 6). The soil from the African star apple land-use type (ASAR) recorded significantly higher available phosphorus (P) concentrations at Week 3 (55.22 mg/kg) and Week 6 (58.46 mg/kg), while the soil from the cassava land-use type (CRR) had the highest value at Week 9 (54.35 mg/kg). The soil from the bush fallow land-use type (BFR) had consistently lower P values throughout.

Among amended treatments, the combination of land-use types, poultry manure, and cow dung (APM&CD) resulted in the highest soil phosphorus concentrations, ranging from 79.25 to 78.07 mg/kg across sampling weeks. In terms of soil nitrogen (N), ASAR soil consistently recorded significantly higher values than CRR and BFR soils at all weeks.

The APM & CD amendment also significantly increased soil nitrogen levels relative to other treatments. By Week 9, ASAR soil showed the highest plant phosphorus percentage (%P = 0.29%) and nitrogen percentage (%N = 2.73%). The APM & CD treatment closely followed, with %P and %N values of 0.29% and 2.67%, respectively. These biological responses influenced nutrient dynamics. Elevated phosphorus in ASAR soil during the early weeks may be linked to soil-driven microbial solubilization (Alori et al., 2017), while CRR soil's increase by Week 9 likely reflects cumulative microbial and root activity (Richardson & Simpson, 2011). Interaction between APM & CD treatment steadily maintained phosphorus concentration, revealing a complementary role of organic amendments and AMF (Deguchi et al., 2012; Zhang et al., 2020). ASAR soil also consistently influenced higher nitrogen levels, which improved microbial transformation and nutrient cycling (Jamil et al., 2022). Likewise, APM & CD treatment interaction actively promoted nitrogen availability, reflecting microbial turnover and mineralisation (Merin et al., 2024). Higher plant %P and %N in ASAR soil and APM & CD treatments corroborates previous reports on improved nutrient uptake facilitated by AMF symbiosis (Liu et al., 2020; Xiang et al., 2020), affirming functional alignment between rhizosphere type, organic inputs, and AMF activity.

Interaction Effects of Land-use Type and Organic Amendment Combinations on Spore Density, Soil Nutrients, and Plant Phosphorus Uptake

This study significantly showed the impact of land-use type interactions with organic amendments on arbuscular mycorrhizal fungi (AMF) spore counts and soil nutrient dynamics, as shown in Table 7. The interaction between soil from African star apple land-use type (ASAR) and cow dung recorded the highest AMF spore counts, 134.33 and 268.67 spores at Weeks 3 and 6, respectively. This was significantly higher compared to the control unamended treatment (79.67 and 159.33 spores) and comparable to the ASAR soil-poultry manure interaction, which had 122.33 and 244.67 spore counts. The bush

Table 6

Influence of land-use type × soil amendment interactions on soil available phosphorus, total nitrogen, and plant nutrient uptake across growth periods

Treatment	AVAILABLE Pwk3	AVAILABLE Pwk6	AVAILABLE Pwk9	S%N WK3	S%N WK6	S%N WK9	plt%P wk6	plt%P wk9	plt%N wk6	plt%N wk9
Soil										
ASAR	55.22±5.7a	58.46±7.0a	48.01±9.5b	0.27±0.01a	0.27±0.01a	0.25±0.00a	0.23±0.01	0.29±0.02a	1.48±0.03	2.73±0.04a
BFR	39.16±7.9c	50.69±7.2b	37.87±8.0c	0.14±0.00b	0.14±0.00b	0.12±0.00b	0.25±0.01	0.25±0.02b	1.45±0.06	2.51±0.07b
CRR	51.89±7.9b	51.14±8.6b	54.35±8.3a	0.12±0.00c	0.13±0.01c	0.11±0.00c	0.25±0.01	0.25±0.02b	1.40±0.04	2.45±0.08b
							ns		ns	
Fertiliser										
Control	21.35±3.6d	25.43±3.2d	9.69±0.9d	0.16±0.02c	0.17±0.02b	0.15±0.02b	0.20±0.00c	0.19±0.01c	1.43±0.03	2.54a±0.06b
ACD	40.97±2.7c	44.02±5.8c	43.65±5.0c	0.16±0.02c	0.16±0.02b	0.17±0.03a	0.24±0.01b	0.24±0.02b	1.48±0.07	2.39±0.10b
APM	53.45±8.3b	67.38±8.6b	55.58±9.5b	0.17±0.02b	0.20±0.03a	0.15±0.02b	0.25±0.01b	0.32±0.01a	1.40±0.05	2.66±0.06a
APM&CD	79.25±1.0a	76.88±2.4a	78.07±3.0a	0.20±0.02a	0.20±0.02a	0.17±0.02a	0.29±0.01a	0.29±0.02a	1.48±0.05	2.67±0.06a
									ns	
S*T	*	*	*	*	*	*	*	*	ns	ns

Note. Means with the same letter (s) in a column are not significantly different at the 5% level of probability by Duncan Multiple Range Test (DMRT); ns: not significant

Table 7
Influence of land-use type and soil amendment interactions on AMF spore abundance, soil available phosphorus, total nitrogen, and plant phosphorus uptake

Soil	Fertiliser	Total spore/50g soil dwtwk3	Total spore/50g soil dwtwk6	AVAILABLE Pwk3	AVAILABLE Pwk6	AVAILABLE Pwk9	S%N WK3	S%N WK6	S%N WK9	plt%P wk6	plt%P wk9
ASAR	Control	79.67±3.2c d	159.33±4.7d	0.25±0.017c	0.24±0.004d	0.23±0.003c	0.21±0.004ef	0.19ef±0.006	0.25±0.017c	0.24±0.004d	0.23±0.003c
	ACD	134.33±4.9 a	268.67±4.8a	0.24±0.004c	0.25±0.001c	0.27±0.002a	0.22d±0.011f	0.28±0.011bed	0.24±0.004c	0.25±0.001c	0.27±0.002a
	APM	122.33±6.5ab	244.67±5.0ab	0.26±0.001b	0.32±0.004a	0.25±0.002b	0.22±0.021ef	0.33±0.011ab	0.26±0.001b	0.32±0.004a	0.25±0.002b
	APM&CD	83.33±2.0d	166.670±2.2d	0.31±0.006a	0.28±0.004b	0.26±0.003b	0.27±0.018ab	0.34±0.023a	0.31±0.006a	0.28±0.004b	0.26±0.003b
BFR	Control	127.67±8.0a	255.33±3.8a	0.11±0.001g	0.13±0.002g	0.11±0.002f	0.20±0.005ef	0.20±0.006ef	0.11±0.001g	0.13±0.002g	0.11±0.002f
	ACD	96.67±6.2cd	193.33±3.8cd	0.12±0.001fg	0.11±0.002i	0.11±0.001f	0.23d±0.009ef	0.18±0.013g	0.12±0.001fg	0.11±0.002i	0.11±0.001f
	APM	137.00±6.7a	274.00±1.5a	0.12±0.004fg	0.13±0.002g	0.11±0.000f	0.29±0.002a	0.32±0.014ab	0.12±0.004fg	0.13±0.002g	0.11±0.000f
	APM&CD	126.33±9.4a	252.67±9.4a	0.14±0.001de	0.16±0.001e	0.12±0.003e	0.28±0.006a	0.30±0.006abc	0.14±0.001de	0.16±0.001e	0.12±0.003e
CRR	Control	92.00±19.7cd	184.00±4.9cd	0.13±0.001efg	0.12±0.003h	0.11±0.008f	0.20±0.006f	0.18±0.034g	0.13±0.001efg	0.12±0.003h	0.11±0.008f
	ACD	123.00±13.9ab	246.00±3.9ab	0.13±0.001def	0.14±0.000fg	0.13±0.003e	0.26±0.001abc	0.25±0.032cde	0.13±0.001def	0.14±0.000fg	0.13±0.003e
	APM	105.33±9.7bc	210.67±7.8bc	0.14±0.001de	0.14±0.002f	0.10±0.002g	0.24±0.005bcd	0.32±0.035ab	0.14±0.001de	0.14±0.002f	0.10±0.002g
	APM&CD	94.67±1.7cd	189.33±2.0cd	0.1500.001±d	0.16±0.001e	0.14±0.002d	0.30±0.029a	0.23±0.006def	0.1500.001±d	0.16±0.001e	0.14±0.002d

Note. Means with the same letter (s) in a column are not significantly different at the 5% level of probability by Duncan Multiple Range Test (DMRT); ns: not significant

fallow land-use type (BFR) with APM interaction also showed notably high sporulation at 137.00 and 274.00 spores at Weeks 3 and 6.

Available phosphorus levels in the ASAR soil-PM-CD interaction were significantly higher, measuring 81.86 mg/kg and 92.25 mg/kg at Weeks 3 and 6, respectively, compared to control treatments. The BFR soil-PM-CD interaction maintained consistently high phosphorus levels throughout the sampling period, ranging from 79.82 to 80.24 mg/kg.

The soil from cassava land-use type (CRR) showed moderate phosphorus values between 76.08 and 80.23 mg/kg. Soil nitrogen content was significantly higher in the ASAR soil x PM and ASAR soil x PM-CD interactions at 0.32% and 0.31%, respectively. Increased nitrogen levels were also observed in BFR and CRR soils. Plant phosphorus absorption corresponds with these trends, with values of 0.34% in ASAR soil x PM-CD and 0.32% in BFR soil x PM. The ASAR soil x CD interaction recorded the highest AMF spore counts, supporting cow dung's main ability to facilitate the sporulation process, which had been reported by previous studies on organic amendment influence (Siegenthaler et al., 2022). ASAR soil x PM was also effective, showing poultry manure’s capability to support AMF development. The ASAR soil x PM-CD interaction recorded the highest phosphorus concentrations, revealing the combined benefits of organic inputs on nutrient mobilisation (Wu et al., 2024). Meanwhile, the BFR soil x PM-CD interaction maintained phosphorus concentrations, likely reducing cassava-induced allelopathic effects and making nutrient availability possible (Adamczyk et al., 2021). Increased nitrogen in ASAR soil x PM and ASAR soil x PM-CD also confirms the role of these combinations in improving nitrogen mineralisation and microbial turnover (Han et al., 2022). These findings affirm the effectiveness of soils from land-use types-organic amendment interactions in nutrient transfer and soil fertility enhancement (Lu et al., 2023).

Influence of Different Land-use Type on Plant Height and Number of Leaves

Plant height (PLTHt) and number of leaves (NOofLVS) were determined in three land-use types of soils, namely African star apple (ASAR), bush fallow (BFR) and cassava (CRR) at Weeks 3, 6 and 9 (Table 8). Plant height was not significantly different among land-use types in Week 3. However, plants in ASAR and BFR soil were much taller than those in CRR soil at Week 6. By Week 9, the plants supported by ASAR soil were the tallest, whereas BFR and CRR soils were comparatively less in stature.

For leaf production, ASAR and CRR soils recorded significantly higher numbers of leaves than BFR soil in Week 3. By Week 9, the application of poultry manure and cow dung (PM & CD) resulted in the significantly highest number of leaves when compared with other treatments. Although plant height was not significantly influenced by soil amendments at any growth stage, the PM & CD application led to a notable increase in leaf number by Week 9.

Table 8
Influence of different land-use types on plant height, number of leaves, shoot dry weight and pod weight

Treatment	PLTHt WK3	PLTHt WK6	PLTHt WK9	NO of LVS WK3	NO of LVS WK6	NOofLVS WK9	DRYSHTBM WK6	DRYSHTBM WK9	PODWT WK9
Soil									
ASAR	42.96±1.5	100.92±.4.6a	95.17±3.7a	11.00±0.0a	18.83±1.6	24.42±1.0	2.13±0.2	2.45±0.1	1.55±0.4
BFR	40.71±2.3	95.40±4.6a	73.67±7.2b	10.00±0.4b	15.92±1.4	26.33±1.8	1.58±0.3	2.33±0.4	1.64±0.7
CRR	41.04±1.0	77.04±4.8b	62.83±6.0b	11.42±0.3a	17.17±0.8	23.17±1.0	1.52±0.2	1.79±0.2	0.61±0.2
	ns	*	*	*	ns	ns	ns	ns	ns
Soil Amendment									
Control	38.89±0.8	93.89±2.4	69.00±6.6	10.33±0.4	14.67±1.4	22.22±1.0b	1.63±0.3	1.97±0.2	1.27±0.3
ACD	43.06±2.9	84.94±6.9	78.33±8.2	11.22±0.6	17.44±1.0	24.78±a1.3b	1.78±0.3	2.21±0.3	1.79±0.8
APM	44.39±1.8	89.64±7.0	71.89±9.9	10.67±0.3	17.00±1.2	23.67±1.6b	1.76±0.3	2.45±0.4	1.19±0.4
APM&CD	39.94±1.3	96.00±7.8	89.67±6.0	11.00±0.0	20.11±2.0	27.89±1.8a	1.79±0.3	2.12±0.2	0.83±0.5
	ns	ns	ns	ns	ns		ns	ns	ns
S*T	ns	ns	ns	ns	ns	*	ns	ns	ns

Note. Means with the same letter (s) in a column are not significantly different at the 5% level of probability by Duncan Multiple Range Test (DMRT); ns: not significant

There were no significant differences in dry shoot biomass or pod weight across the land-use type soils or amendment treatments by the end of the study period. Vegetative performance followed similar trends. Significantly taller plants in ASAR and BFR soils at Week 6 point to improved nutrient and microbial conditions in these soils (Alguacil et al., 2017; Aytenew & Bore, 2020). ASAR soil maintained a consistent increase in plant height up to Week 9, suggesting superior soil support for growth, compared to the reduced height observed in BFR and CRR soils, which may reflect nutrient depletion or biotic stress (Qu et al., 2020; Volpiano et al., 2022). Higher leaf numbers in ASAR and CRR soils at Week 3 indicate early soil advantages (Ofori et al., 2021). By Week 9, PM & CD treatment application resulted in the highest leaf production, demonstrating synergistic nutrient absorption impacts (Medina & Azcón, 2010; Pu et al., 2023). Although amendment type did not significantly affect plant height, the vegetative benefits of PM & CD treatment were apparent following their application. However, no significant gains in dry shoot biomass or pod weight were observed; this suggests there is a need for long-term investigation to evaluate yield impacts (Larkin, 2020). These outcomes point out the cruciality of integrated nutrient strategies to optimise crop productivity (Pantelides et al., 2023).

Correlation Between Total Spore Count, Available Phosphorus, and Plant Phosphorus (%P) and Nitrogen (%N) Content Over Time (Weeks 3, 6, and 9)

At Week 3, a perfect correlation (r = 1.000**) was observed for AMF spore counts, confirming a consistent pattern in AMF abundance (Table 9). A strong positive correlation was also recorded between available phosphorus at Week 3 and 6 (r = 0.857**, $p < 0.01$), indicating that early higher phosphorus concentration in the experiment was maintained over time. Similarly, available phosphorus at Week 3 significantly correlated with values at Week 9 (r = 0.752**, $p < 0.01$), confirming a sustained phosphorus availability pattern. Available phosphorus at Week 6 showed a significant positive correlation with plant phosphorus uptake (r = 0.585**, p < 0.01), indicating its important role in supporting plant development. A moderate but significant correlation was also observed between available phosphorus at Week 3 and plant nitrogen at Week 6 (r = 0.353*, p < 0.05), suggesting that early phosphorus availability was associated with subsequent nitrogen assimilation.

Finally, strong correlations between available phosphorus at Weeks 3 and 6 and plant uptake support biological processes in the soil and phosphorus availability (Johnston & Poulton, 2019; Pang et al., 2024). The link between Week 6 phosphorus and plant uptake stresses the importance of nutrient timing in crop production (Khan et al., 2023). The observed association between phosphorus and nitrogen unveils their interactive influence in plant nutrition (Zhao et al., 2021), consistent with earlier reports of AMF-driven coordination of N and P uptake (Krouk & Kiba, 2020; Schleuss et al., 2020). These findings collectively demonstrate that land-use types- organic amendment interactions significantly

Table 9
Relationships between AMF spore abundance, soil available phosphorus, plant phosphorus (%) and nitrogen (%) content across sampling periods

	Total spore/50g soil dwtwk3	**Total spore/50g soil dwtwk6**	**Total spore/50g soil dwtwk9**	**AVAILABLE Pwk3**	**AVAILABLE Pwk6**	**AVAILABLE Pwk9**	**plt%P wk6**	**plt%P wk9**	**plt%N wk6**
Total spore/50g soil dwtwk3	1.000**	-	-	-	-	-	-	-	-
Total spore/50g soil dwtwk6	.248	.248	-	-	-	-	-	-	-
Total spore/50g soil dwtwk9	.163	.163	.181	-	-	-	-	-	-
AVAILABLE Pwk3	.212	.212	.278	.904**	-	-	-	-	-
AVAILABLE Pwk6	.141	.141	.405*	.849**	.869**	-	-	-	-
AVAILABLE Pwk9	.131	.131	.121	.752**	.651**	.608**	-	-	-
plt%P wk6	.322	.322	-.120	.569**	.585**	.464**	.379*	-	-
plt%P wk9	.014	.014	.090	.113	.124	.045	-.024	.008	-
plt%N wk6	.061	.061	-.201	.353*	.396*	.187	.070	.581**	.237

facilitate nutrient cycling and retention as well as plant nutrient uptake efficiency within a biodiverse ecosystem.

CONCLUSION

This study demonstrates that soils from different land-use types and organic amendments significantly influenced arbuscular mycorrhizal fungi (AMF) activity in the cowpea rhizosphere, as reflected in spore abundance, root colonisation, nutrient availability, and plant nutrient uptake. Soil from the cassava land-use type (CRR) promoted greater AMF root colonisation and favoured *Gigaspora* spp., whereas African star apple soil (ASAR) supported higher *Glomus* abundance and consistently improved soil nitrogen, plant phosphorus and nitrogen uptake, as well as vegetative growth. Cow dung enhanced AMF sporulation, while poultry manure promoted root colonisation, indicating that the organic amendments influenced different aspects of AMF development. The combined application of poultry manure and cow dung further increased soil phosphorus availability and leaf production, highlighting the benefits of integrated organic nutrient management. Although dry shoot biomass and pod weight were not significantly affected during the study period, the improvements in AMF activity, nutrient uptake, and vegetative growth suggest that combining appropriate land-use practices with organic amendments can improve the soil biological environment and has the potential to support better cowpea productivity under longer-term or field conditions. Overall, these findings emphasise the value of integrating suitable land-use systems with organic nutrient management to enhance AMF-mediated soil fertility and promote sustainable cowpea production.

IMPLICATIONS OF THE STUDY

The findings indicate that careful selection of organic amendments, combined with inherent soil properties, can enhance AMF activity, improve nutrient uptake, and support sustainable soil fertility management. Specifically, the application of cow dung in soils from African Star Apple (ASAR) and bush fallow (BFR) land-use types, and poultry manure in soil from cassava land-use type (CRR), emphasises the importance of site-specific amendment strategies for maximising AMF benefits in tropical agroecosystems.

LIMITATIONS OF THE STUDY AND RECOMMENDATIONS FOR FUTURE RESEARCH

AMF identification was based on spore morphology, which may not fully capture community diversity compared with molecular-based approaches. The experiment was conducted under specific site conditions, and responses may differ across other agroecological zones or soil parent materials. Future studies should incorporate molecular techniques (e.g., high-throughput sequencing) to provide a more detailed assessment of

AMF community composition and functional diversity. Additionally, crop yield, plant physiological responses, and AMF-mediated stress tolerance should be evaluated to further strengthen the agronomic relevance and application of AMF-based soil fertility strategies.

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