

Correlation Between Integrated Soil Fertility Management (ISFM) Induced Selected Soil Chemical Properties, Crop Yields and Nutrients Uptake in Sweet potato/Soybean Intercrop

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Abstract

The productivity of sweet potato and soybean intercropping systems in tropical agroecological zones is frequently constrained by low soil fertility, inadequate nutrient cycling, and the high cost of mineral fertilizers. Therefore, sweet potato/soybean intercrop was subjected to integrated soil fertility management at the Teaching and Research Farm, Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Nigeria, in 2024 and 2025. Twelve treatments (*Glomus funneliformis* (AMF1), *Rhizophagus irregularis* (AMF2), 45-30-150 kg NPK/ha, 5 ton/ha poultry manure (PM), AMF1 + NPK, AMF2 + NPK, PM+AMF1, PM+AMF2, $\frac{1}{2}$ (PM + NPK), $\frac{1}{2}$ (PM + NPK)+AMF1, $\frac{1}{2}$ (PM + NPK)+AMF2 and control (no amendment) were laid out in a Randomized Complete Block Design replicated thrice.

The control influenced the highest post-harvest soil pH in both 2024 and 2025 (6.31; 6.32), K-content (1.0 cmol/kg in 2024), NPK and AMF1 had the highest N-content (0.02; 0.016 g/kg) respectively, PM+AMF2 had the highest P-content (20.3; 37.3 mg/kg) in both years, seed yield (1,332 kg/ha). Sole application of AMF2 and control had the highest soil organic carbon (OC) (3.80; 1.93 g/kg) in 2024 and 2025. PM+AMF2 + NPK produced the highest sweet potato tuber yield (7,250 and 12,542 kg/ha in 2024 and 2025 respectively), while the control had the least (2,167 and 3,083 kg/ha). PM+AMF2 (1332 kg/ha) and sole NPK (163 kg/ha) influenced the highest seed yield in 2024 and 2025 respectively, while AMF1 + NPK (160 kg/ha) and AMF1 (24 kg/ha) had the least respectively. Tuber yield was positively and significantly correlated with number of tubers ($r = 0.503^* 0.680^*$); N, P and K uptakes ($r = 0.778^*$; 0.927^* and 0.934^* in 2024; $r = 0.938^*$; 0.979^* and 0.957^* in 2025) and negatively correlated with exchangeable K, seed yield and N-fixed ($r = -0.183$; -0.021 and -0.234 in 2024). N-fixed by soybean was negatively and significantly correlated with soil total N ($r = -0.391^*$). Soil total N was negatively and significantly correlated with number of tubers; N, P and K uptakes ($r = -0.414^*$; -0.426^* ; -0.446^* and -0.512^* in 2025).

In the sweet potato/soybean intercropping system, integrated soil fertility management influenced post-harvest soil chemical properties and yield performance, with PM+AMF2 + NPK producing the highest sweet potato tuber yield and NPK uptake, AMF (*Rhizophagus irregularis*) and poultry manure combinations enhanced phosphorus and organic carbon in the derived savanna of southwestern Nigeria.

1.0 INTRODUCTION

Sweet potato and soybean, as essential food security crops in tropical and subtropical regions, offer complementary agronomic traits with sweet potato being a heavy nutrient-demanding root crop (Sapakhova et al., 2023) and soybean a leguminous nitrogen-fixer (Islam et al., 2022). Despite this synergy, the productivity of their intercropping systems remains suboptimal due to inherent nutrient constraints, inefficient nutrient cycling, and substandard soil management practices. While NPK mineral fertilizers provide essential nutrients in immediately available forms, their escalating cost and long-term degradation of soil quality raise concerns about their sustainability. Organic amendments and biofertilizers such as arbuscular mycorrhizal fungi (AMF) present viable alternatives, offering ecological benefits like improved nutrient cycling and soil structure enhancement (Yuan et al., 2023). However, their nutrient release is slow, which may not meet the immediate demands of fast-growing crops like sweet potato and soybean.

Integrated Soil Fertility Management (ISFM), which promotes the combined use of organic, biological, and mineral inputs, have been proven to improve nutrient-use efficiency, increase microbial activity, and enhance crop yields (Bayu, 2020). However, while numerous studies have assessed mineral-organic combinations, there is limited research evaluating the synergistic effects of combining AMF biofertilizers, poultry manure with NPK mineral fertilizers specifically in intercropping systems of sweet potato and soybean. Therefore, the objective of this study was to evaluate the effects of ISFM on selected soil chemical properties, yields and nutrients uptake in sweet potato/soybean intercropping system.

2.0 MATERIALS AND METHODS

Experimental Site

The study was conducted at the Teaching and Research Farm, Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Oyo State, Nigeria, during the 2024 and 2025 cropping seasons. Ogbomoso is located in the derived savanna agroecological zone at latitude 8°10' N and longitude 4°10' E. It is distinguished by a bimodal pattern of rainfall distribution. Late May marks the start of the early rainy season, which lasts until mid-August before a brief dry spell. September to November marks the late rainy season. It receives 1217 mm of rain on average annually, and the temperature is 26°C on average.

Source of Arbuscular Mycorrhizal Fungi and Planting Materials

Two strains of AMF, namely *Glomus funneliformis* and *Rhizophagus irregularis*, were sourced from the International Institute of Tropical Agriculture (IITA), Ibadan. Poultry manure was sourced from Adeolu poultry house, Teaching and Research Farm, LAUTECH. Locally cultivated white-fleshed sweet potato variety (TIS 87/0087) and soybean variety (TGX 1440- 2E) were cultivated.

Land preparation and plot layout

Land clearing was done manually, debris was packed after clearing, and ridging was done manually using hoe. Plots were marked out using pegs and lines. The plots measured 2 × 2 m with 1 m between plots and 1.5 m between replicates. Ridges were constructed with hoes.

Soil sampling and analysis

Soil samples were taken randomly from each plot at a depth of 0–15 cm using an Alderman auger at the beginning and the end of the research. The samples from each plot were bulked to form a composite. A sub-sample was taken for analysis of pH, available N, P, exchangeable K, and organic carbon. Soil pH was measured using a pH meter in a 1:2 soil-water ratio (Black, 1965). Organic matter content was determined using the Walkley-Black test (1934). Total nitrogen was determined using as the Kjeldahl method (Kjeldahl, 1883), the available phosphorus was extracted using Mehlich extractant and its concentration determined colorimetrically (Mehlich, 1984) and the extractable ammonium acetate NH_4OAC method for exchangeable bases (Pratt, 1965) while potassium was determined using the flame photometer.

Treatments and experimental design

The experiment was laid out in a Randomized Complete Block Design (RCBD) replicated three times with twelve (12) fertilizer treatments namely;

1. *Glomus funneliformis* (AMF 1) at 20 g/plant (Pelealu et al., 2019)
2. *Rhizophagus irregularis* (AMF 2) at 20 g/plant
3. Mineral fertilizer, 45 N, 30 P_2O_5 , and 150 K_2O in kg/ha achieved with NPK 15-15-15 (1.5 g/plant), urea (46% N at 0.25 g/plant) and muriate of potash (60% K_2O at 1.5 g/plant) fertilizers (Okanlawon and Kolawole, 2023).
4. AMF 1 + NPK
5. AMF 2 + NPK
6. Poultry manure (PM) at 5 tonnes/ha (Olusakin and Kolawole, 2023)
7. PM + AMF 1
8. PM + AMF 2
9. $\frac{1}{2}$ (PM + NPK)
10. $\frac{1}{2}$ (PM + NPK) + AMF 1
11. $\frac{1}{2}$ (PM + NPK) + AMF 2
12. Control (no amendments)

Cultural Practices

The crops were planted at a spacing of 75 × 50 cm to achieve a population of 26,667 plants/hectare

Poultry manure was applied to designated plots two (2) weeks before planting and incorporated into the soil using hoe. Sweet potato vine cuttings with at least 3 to 5 nodes were planted on the ridge at the specified spacing to obtain the required planting density. Two (2) soybean seeds were sown per hole and the seedlings were thinned to 1 plant per hill after two weeks. The NPK mineral fertilizer was applied as split dosage at planting (30:30:30 kg NPK/ha) and two weeks after planting (15:0:120 kg NPK/ha). Earthening up of the sweet potato ridges was done 8 weeks after planting (WAP) until harvest, as the need arises. Also, manual weeding was carried out when needed to remove unwanted plants. Control of insects was done using insecticide (Cypermethrin) at 800 ml/hectare (40ml/15L sprayer).

Data Collection

Vine length of five (5) tagged sweet potato and the plant height of soybean were taken using a meter rule, while the stem diameter of soybean was taken using a Vernier caliper. The number of fully opened leaves was counted for each crop. At maturity, potato tubers and soybean seeds were harvested from a net area (2 x 2 m) on each plot. The shoot weight, number of tubers, and weight of tubers of sweet potato were measured. N-fixation of soybean using Ureide method (Herridge *et al.*, 1990). The soybean pods were shelled, and the dry seed weights measured on a weighing balance. Potato tuber yield samples were washed and peeled carefully using stainless knives, and cut for size reduction. The slices were dried in a hot air oven at 70°C for 72 hours; afterward, the samples were finely ground into powder using a mortar and pestle and then stored in polyethylene plastic bags for analysis of elemental N, P, and K. (AOAC, 2012)

Nitrogen fixation by soybean

The stem and petiole were separated from the shoot after drying, ground, and taken to the laboratory for ureide analysis using a spectrophotometer. The following calculation was carried out to determine the percentage of nitrogen fixation (Herridge *et al.*, 1990)

The Relative Ureide Index (RUI) is defined as:

$$\text{RUI (\%)} = 4 \times \text{ureide concentration (mol/l)} \times 100 \dots\dots\dots \text{Eq. 1.}$$

Total N concentration(mol/l)

The factor of 4 arises from the fact that one molecule ureide contains 4 atoms of Nitrogen.

The RUI (%) was used to extrapolate the percentage N fixed from calibration curves (Herridge and People., 1990)

The N, P and K uptake in sweet potato

Nutrient uptake was calculated using the formula of Peng *et al.* (2010)

$$\text{N uptake} = \text{Weight of potato} \times \text{concentration (\%)} \text{ of N in potato} \dots\dots\dots \text{Equation 2.}$$

$$\text{P uptake} = \text{Weight of potato} \times \text{concentration (\%)} \text{ of P in potato}$$

$$\text{K uptake} = \text{Weight of potato} \times \text{concentration (\%)} \text{ of K in potato}$$

Data Analysis

Data on sweet potato tuber yield, soybean seed yield, AMF root infectivity/colonization and selected soil chemical properties were subjected to analysis of variance (ANOVA) using SAS (2009). Treatment means were separated by least

significant differences (LSD) at $p \leq 0.05$ (Kithan et al., 2026). Selected post-harvest soil chemical properties were correlated with number of tubers, tuber yield, nutrients uptake in sweet potato and soybean seed yield, and N-fixed.

3.0 RESULTS

Pre-planting soil properties

The soil was sandy near neutral in pH, low in organic carbon, nitrogen, phosphorus and had a medium content of exchangeable cations (Table 1).

Table 1
Pre-cropping soil properties of the experimental site

Parameters	Values
pH (H ₂ O) 1:2	6.27
Nitrogen (g/kg)	0.013
Organic carbon (g/kg)	1.50
Available phosphorus (mg/kg)	8.31
Exchangeable Calcium (cmol kg ⁻¹)	1.06
Exchangeable Magnesium (cmol kg ⁻¹)	0.22
Exchangeable Potassium (cmol kg ⁻¹)	0.17
Sodium (cmol kg ⁻¹)	0.08
Copper (mg/kg)	2.52
Manganese (mg/kg)	89.6
Iron (mg/kg)	53.1
Zinc (mg/kg)	1.23
Sand (g/kg)	92.0
Silt (g/kg)	2.00
Clay (g/kg)	6.00
Textural class	Sandy

Post-harvest soil properties

Fertilizer treatments significantly influenced post-harvest soil pH in 2024, soil organic carbon, N, P, and K-content in both years (Table 2). The control produced the highest post-harvest soil pH in both 2024 and 2025 (6.31; 6.32) while the combined application of AMF2 + NPK had the least in 2024 (5.99) and AMF1 + NPK (5.84) in 2025. Sole application of AMF2 the highest post-harvest soil OC in 2024 (3.80 g/kg) while AMF2 + NPK (2.50 g/kg) had the least. However, the control (1.93 g/kg) had the highest while AMF1 + NPK (0.64 g/kg) had the least in 2025. NPK influenced the highest N-content (0.02 g/kg), in 2024 while AMF1 (0.0002 g/kg) had the least, and AMF1 had the highest N-content (0.016 g/kg) while AMF2, AMF1 + NPK, AMF2 + NPK and PM + NPK had the least (0.001 g/kg), in 2025. PM+AMF2 had the highest soil available P-content (20.3; 37.3 mg/kg) in both years while AMF1 had the least (5.27; 6.77 mg/kg) respectively. The control

influenced the highest soil exchangeable K-content (1.0 cmol/kg) while AMF1 had the least (0.148 cmol/kg) in 2024, and AMF2 and AMF2 + NPK had the highest K-content (0.209 cmol/kg) while PM had the least (0.129 cmol/kg) in 2025.

Sweet potato tuber yield and NPK uptakes

The fertilizer treatments had significant influence on the number of tuber and yield in both years (Table 3). PM+AMF2 + NPK produced significantly highest number of tubers (24 tubers) while AMF1 had the least (10 tubers) in 2024, however, NPK had the highest number of tubers (17 tubers) while PM had the least (6 tubers) in 2025. PM+AMF2 + NPK influenced the highest tuber yield in both years (7250; 12542 kg/ha) respectively while the control consistently had the least (2167; 3083 kg/ha).

Fertilizer application had significant effect on the nutrient uptakes of sweet potato in both years (Table 4). PM+AMF2 and sole NPK (945.4; 1513 kg/ha) respectively influenced the highest N-uptake while AMF2 had the least (286.5; 348.0 kg/ha) respectively in both years. PM+AMF2 + NPK influenced the highest P-uptake (937.2; 1578 kg/ha) respectively while AMF2 consistently had the least (370.9; 444.4 kg/ha) respectively in both years. Also, PM+AMF2 + NPK (1150 kg/ha) and AMF1 + NPK (2139 kg/ha) influenced the highest K-uptake in 2024 and 2025, respectively while the control (346.1 kg/ha) and AMF1 (483.4 kg/ha) had the least in both years respectively.

Soybean seed yield, N-fixed and NPK uptakes

Fertilizer treatments significantly influenced soybean seed yield and N-fixed in 2024 only (Table 5). PM+AMF2 (1332 kg/ha) and sole NPK (163 kg/ha) influenced the highest seed yield in 2024 and 2025 respectively, while AMF1 + NPK (160 kg/ha) and AMF1 (24 kg/ha) had the least respectively. AMF2 (40.9%) and PM (56.8) fixed the highest atmospheric N in 2024 and 2025 respectively while NPK (12.1%) and PM+AMF1 (41.6%) fixed the least atmospheric N in both years respectively.

Correlation analysis

In 2024 (Table 6), sweet potato tuber yield was positively and significantly correlated with number of tubers ($r = 0.503^*$); N, P and K uptakes (0.778^* ; 0.927^* and 0.934^*) and negatively correlated with exchangeable K. N-fixed by soybean was negatively and significantly correlated with soil total N ($r = -0.391^*$).

In 2025 (Table 7), tuber yield was positively and significantly correlated with number of tubers ($r = 0.680^*$), N, P and K uptakes ($r = 0.938^*$; 0.979^* and 0.957^*), negatively and significantly correlated with soil total N ($r = -0.452^*$). Soil total N was negatively and significantly correlated with number of tubers; N, P and K uptakes ($r = -0.414^*$; -0.426^* ; -0.446^* and -0.512^*).

Table 2

Effect of ISFM on the post-harvest soil pH, organic total N, available P and exchangeable K-content in a sweet potato/soybean intercropping system in Ogbomoso, 2024 and 2025

Treatments	2024					2025				
	pH	OC	N	P	K	pH	OC	N	P	K
	(H ₂ O)	(g/kg)	(g/kg)	(mg/kg)	(cmol/kg)	(H ₂ O)	(g/kg)	(g/kg)	(mg/kg)	(cmol/kg)
AMF1	6.08	2.91	0.0002	5.27	0.148	5.86	1.28	0.016	6.77	0.192
AMF2	6.26	3.80	0.002	11.6	0.187	5.96	1.15	0.001	7.52	0.209
AMF1 + NPK	6.07	2.70	0.001	18.1	0.187	5.84	0.64	0.001	15.5	0.165
AMF2 + NPK	5.99	2.50	0.001	9.31	0.149	5.93	1.00	0.001	20.8	0.209
NPK	6.21	2.91	0.02	15.9	0.193	5.92	1.06	0.006	18.4	0.188
PM	6.24	3.19	0.005	11.8	0.208	6.05	1.28	0.007	23.2	0.129
PM+AMF1	6.22	3.70	0.004	9.16	0.302	6.04	1.49	0.006	18.7	0.187
PM+AMF2	6.26	3.19	0.006	20.3	0.233	6.08	1.28	0.010	37.3	0.144
PM + NPK	6.44	3.19	0.001	17.0	0.306	6.26	1.28	0.001	31.8	0.190
PM+AMF1 + NPK	6.17	3.66	0.002	10.2	0.299	5.99	1.47	0.003	20.4	0.186
PM+AMF2 + NPK	6.14	2.76	0.002	15.1	0.320	5.96	1.11	0.004	28.6	0.198
CONTROL	6.31	2.70	0.001	13.4	1.000	6.32	1.93	0.004	7.23	0.193
LSD _{0.05}	0.43	1.04	0.01	6.66	0.422	ns	0.52	0.0094	8.64	0.071
AMF1 = <i>Glomus funneliformis</i> , AMF2 = <i>Rhizophagus irregularis</i> , PM=Poultry manure and NPK=Mineral fertilizer										

Table 3
Effect of ISFM on the number of tubers and tuber yield of sweet potato in a sweet potato/soybean intercropping system in Ogbomoso, 2024 and 2025.

Treatments	2024		2025	
	Number of Tuber (no./plot)	Tuber yield (kg/ha)	Number of Tuber (no./plot)	Tuber yield (kg/ha)
AMF1	10	2417	13	3250
AMF2	14	2667	8	3208
AMF1 + NPK	22	2833	15	9417
AMF2 + NPK	22	3083	13	8583
NPK	16	3417	17	10125
PM	12	3500	6	3458
PM+AMF1	15	4333	10	5250
PM+AMF2	17	5083	16	5417
PM + NPK	20	6167	15	11333
PM+AMF1 + NPK	22	5833	15	7500
PM+AMF2 + NPK	24	7250	12	12542
CONTROL	18	2167	8	3083
LSD _{0.05}	6	1601	13	7988

AMF1 = *Glomus funneliformis*, AMF2 = *Rhizophagus irregularis*, PM=Poultry manure and NPK=Mineral fertilizer.

Table 4
Effect of ISFM on N, P and K-Uptake of sweet potato in a sweet potato/soybean cropping system
in Ogbomoso, 2024 and 2025

Treatments	2024			2025		
	N-uptake (kg/ha)	P-uptake (kg/ha)	K-uptake (kg/ha)	N-uptake (kg/ha)	P-uptake (kg/ha)	K-uptake (kg/ha)
AMF1	308	371.6	389.7	391.9	480.5	483.4
AMF2	286.5	370.9	391.9	348	444.4	493
AMF1 + NPK	334.9	420	623.1	1103	1246	2139
AMF2 + NPK	439.5	347.9	556.9	1125	1061	1589
NPK	568.9	510.9	628.3	1513	1319	1593
PM	330.8	456.1	521.75	360.5	488.2	515.8
PM+AMF1	464.5	746.5	883.1	596.3	826.7	986.7
PM+AMF2	945.4	914.8	941	791.5	935.7	963.7
PM + NPK	827.6	771.9	807.5	1461	1471	1665
PM+AMF1 + NPK	565.5	703.3	980.2	754.7	866.3	1168
PM+AMF2 + NPK	605.1	937.2	1150	1106	1578	2098
CONTROL	302.3	242.4	346.1	400.7	377.5	515.5
LSD _{0.05}	199.7	219.4	250.5	1004	1066	1300

AMF1 = *Glomus funneliformis*, AMF2 = *Rhizophagus irregularis*, PM=Poultry manure and NPK=Mineral fertilizer.

Table 5
Effect of ISFM on the seed yield and N-fixed by soybean in a sweet potato/soybean intercropping in Ogbomoso, 2024 and 2025

Treatments	2024		2025	
	Seed yield (kg/ha)	N-fixed (%)	Seed yield (kg/ha)	N-fixed (%)
AMF1	336	32.2	24	48.3
AMF2	358	40.9	43	53.7
AMF1 + NPK	160	26.1	59	52.0
AMF2 + NPK	270	33.2	73	47.0
NPK	548	12.1	163	55.6
PM	1185	33.5	123	56.8
PM+AMF1	311	24.1	98	41.6
PM+AMF2	1332	30.6	159	52.8
PM + NPK	261	26.8	39	44.7
PM+AMF1 + NPK	582	27.1	63	44.5
PM+AMF2 + NPK	311	26.5	31	43.2
CONTROL	410	38.8	29	56.1
LSD _{0.05}	1145	12.1	ns	ns

AMF1 = *Glomus funneliformis*, AMF2 = *Rhizophagus irregularis*, PM=Poultry manure and NPK=Mineral fertilizer.

Table 6
Pearson correlation coefficients between selected soil chemical properties, tuber yield (TY), nutrient uptake of sweet potato, seed yield (SY) and N-fixed by soybean in a sweet potato/soybean intercropping system in Ogbomoso, 2024 cropping season

NOT	pH	N	P	K	OC	TY
	-0.068	0.038	0.234	-0.169	-0.074	0.503**
TY	0.127	0.037	0.203	-0.183	0.24	1.000
SY	0.09	0.112	0.155	-0.038	0.029	-0.021
N-fixed	0.084	-0.390*	-0.181	0.102	0.015	-0.234
N-uptake	0.203	0.224	0.413	-0.202	0.161	0.778***
P-uptake	0.142	0.127	0.291	-0.214	0.278	0.927***
K-uptake	0.061	0.106	0.234	-0.218	0.226	0.934***

* indicates correlation is significant at the 5% level of probability ($p \leq 0.05$).

Table 7
Pearson correlation coefficients between selected soil chemical properties, tuber yield (TY), nutrient uptake of sweet potato, seed yield (SY) and N-fixed by soybean in a sweet potato/soybean intercropping system in Ogbomoso, 2025 cropping season

NOT	pH	N	P	K	OC	TY
	-0.360*	-0.414*	0.057	-0.29	-0.116	0.680***
TY	-0.307	-0.452**	0.207	-0.201	-0.195	1.000
SY	-0.19	-0.098	0.274	-0.301	-0.096	0.104
N-fixed	-0.279	-0.242	-0.15	-0.656***	0.211	0.239
N-uptake	-0.287	-0.426**	0.227	-0.25	-0.161	0.938***
P-uptake	-0.288	-0.446**	0.258	-0.253	-0.166	0.979***
K-uptake	-0.271	-0.512**	0.211	-0.178	-0.26	0.957***
*, **, *** indicates correlation is significant at the 5, 1 and 0.1% level of probability ($p \leq 0.05$)						

4.0 DISCUSSION

The influence of the fertilizer treatments on post-harvest soil pH indicated that the different nutrient sources altered the chemical properties of the soil. The higher pH in the control suggests that soil receiving fertilizer experienced higher soil acidifying processes, especially when NPK mineral fertilizer was combined with AMF. The nitrification of ammonium-based nitrogen, release of hydrogen ions during nutrient uptake, root exudation and greater biological activity under fertilized treatments can lead to reduced soil pH. This is complimented by the findings of Zhu et al. (2024), who reported that excessive mineral fertilizer application accelerated soil acidification, while manure application reduced acidification through the addition of base cations. They further noted that nitrogen transformations and crop nutrient uptake contributed to acid production in cultivated soils. Also, Adekiya et al. (2020) reported that soils treated with NPK fertilizer had lower soil pH than the control, while poultry manure, especially when combined with biochar, improved soil pH and other fertility properties. However, this result contrasts with studies of Agbede et al. (2024) who reported that poultry manure and biochar increased soil pH, organic carbon, total nitrogen, available phosphorus, exchangeable potassium, calcium and magnesium compared with the control in sweet potato production.

That sole application of *Rhizophagus irregularis* (AMF2) influenced the highest soil organic carbon in 2024 can be attributed to improved root development, hyphal growth, rhizodeposition and microbial stabilization of carbon. AMF can contribute to soil carbon accumulation through extraradical hyphae, glomalin-related soil proteins and stimulation of microbial processes. However, the lower OC under AMF2 + NPK in 2024 and AMF1 + NPK in 2025 might be as a result of faster decomposition and mineralization of organic matter under combined microbial and mineral nutrient stimulation. In 2025, the control which had the highest soil organic carbon content may suggest lower microbial decomposition, reduced crop uptake, or slower organic matter turnover compared with fertilized plots. This is supported by Dou et al. (2016), who reported that soil organic carbon response to long-term fertilization is controlled by the balance between carbon inputs from plant residues, roots and organic amendments, and carbon losses through soil organic matter decomposition. The study further indicated that fertilizer addition may produce positive, neutral or negative changes in soil organic carbon depending on how fertilization affects new carbon input and decomposition rate. Likewise, Agbede et al. (2024) reported that poultry manure and biochar improved soil organic carbon, but they also showed that the magnitude of amendment effects differed across years and locations.

The NPK mineral fertilizer supplies readily available nitrogen to the soil thereby influencing the highest soil N in 2024. However, the highest soil N under AMF1 in 2025 suggests that AMF may have improved nitrogen retention or reduced

nitrogen losses under that season's conditions. The low soil N-content under some combined treatments may be due to greater crop uptake, leaching, microbial immobilization or dilution caused by higher biomass production. This is supported by the study of Liang et al. (2013), who reported that fertilizer N in a wheat-maize system was distributed among crop uptake, soil retention, microbial immobilization and leaching pathways, indicating that low residual soil N may reflect efficient crop removal or N transformation rather than poor nutrient supply. The complementary effects of poultry manure and AMF may have affected the improved soil available P, as poultry manure supplies phosphorus and organic acids during decomposition, while AMF hyphae increase the soil volume explored by roots and enhance access to less mobile phosphorus pools. This agrees with Yuan et al. (2023), who reported that AMF-based nutrient combinations improved sweet potato root morphology, nutrient uptake and tuberous root yield. The high K in the control in 2024 might not indicate better soil fertility management; rather, it may reflect lower K removal by the crop due to lower yield and reduced nutrient uptake, as there was a negative association between exchangeable K and K uptake. In contrast, the higher K under *Rhizophagus irregularis* (AMF2)-based treatments in 2025 may suggest improved K mobilization and retention under better AMF activity. This is supported by the study of Yuan et al. (2023) who reported that AMF effects on sweet potato K accumulation depended on genotype, growth stage and K availability, therefore supporting the season-specific and treatment-specific K response observed in the study. The integrated soil fertility management of PM + AMF+NPK improved the best crop yield. The strong positive correlations between sweet potato tuber yield and N, P and K uptake in both years further confirmed that tuber yield may be driven by nutrient acquisition. Poultry manure likely improved soil organic matter (Agbede, 2025), microbial activity and gradual nutrient release; NPK supplied readily available mineral nutrients; while AMF2 probably improved root absorption efficiency, especially phosphorus acquisition, which is important for root and tuber development (Wang et al., 2023). This agrees with Mukhongo et al. (2017), who noted that combining biofertilizers with inorganic nutrients significantly increased sweet potato yield, and noted that AMF benefits are better expressed when starter nutrients are supplied in nutrient-depleted soils.

The highest soybean seed yield under PM+AMF2 in 2024 indicates that poultry manure and AMF2 enabled a favourable condition for soybean growth, probably through improved P availability, better root development and enhanced symbiotic activity. Soybean nitrogen fixation requires adequate phosphorus because nodulation and nitrogenase activity are energy-demanding processes. This agrees with Soretire et al. (2020), who observed that phosphorus fertilization and arbuscular mycorrhizal fungi inoculation significantly influenced soybean nodulation, biological nitrogen fixation and growth under phosphorus-deficient soil conditions. Also, Wen et al. (2024) reported that in available phosphorus-deficient acidic soil, AMF inoculation improved the growth advantage of soybean more effectively than phosphorus fertilization alone, indicating that AMF can enhance soybean performance under P-limited conditions. Furthermore, Santachiara et al. (2019), reported in a meta-analysis that nitrogen fertilization reduced soybean N₂ fixation, confirming that high soil N availability can suppress soybean dependence on atmospheric nitrogen fixation.

5.0 CONCLUSION

Integrated soil fertility management significantly improved soil chemical properties in the sweet potato/soybean intercropping system, with AMF and poultry manure combinations enhancing soil phosphorus and organic carbon. Furthermore, integrated combination of poultry manure, *Rhizophagus irregularis* and reduced NPK mineral fertilizer improved sweet potato yield, mainly through enhanced tuber formation and NPK uptake. Therefore, it is recommended that farmers in the derived savanna agroecology adopt poultry manure, AMF and reduced mineral fertilizer combinations for sweet potato/soybean intercropping.

REFERENCES

1. Adekiya AO, Agbede TM, Olayanju A, Ejue WS, Adekanye TA, Adenusi TT, Ayeni JF (2020) Effect of biochar on soil properties, soil loss, and cocoyam yield on a tropical sandy loam Alfisol. Sci World J 2020(1):9391630

2. Agbede TM (2025) Poultry manure improves soil properties and grain mineral composition, maize productivity and economic profitability. *Sci Rep* 15(1):16501
3. Agbede TM, Oyewumi A, Agbede GK, Adekiya AO, Adebisi OTV, Abisuwa TA, Ejue WS, Ayorinde BB, Ojeniyi SO, Oladipupo OO, Fagbohun OF, Olawoye OD, Eifediyi EK (2024) Impacts of poultry manure and biochar amendments on the nutrients in sweet potato leaves and the minerals in the storage roots. *Sci Rep* 14:16598
4. Association of Official Analytical Chemists (AOAC) (2012) *Official Methods of Analysis*, 19th edn. AOAC International
5. Bayu T (2020) Review on contribution of integrated soil fertility management for climate change mitigation and agricultural sustainability. *Cogent Environ Sci* 6(1):1823631
6. Black CA (ed) (1965) *Methods of soil analysis: Part 2. Chemical and microbiological properties*. Agronomy Monograph, vol 9. American Society of Agronomy
7. Dou X, He P, Zhu P, Zhou W (2016) Soil organic carbon dynamics under long-term fertilization in a black soil of China: Evidence from stable C isotopes. *Sci Rep* 6(1):21488
8. Herridge DF, Peoples MB (1990) Ureide assay for measuring nitrogen fixation by nodulated soybean calibrated by ^{15}N methods. *Plant Physiol* 93(2):495–503
9. Islam MS, Muhyidiyn I, Islam MR, Hasan MK, Hafeez AG, Hosen MM, Saneoka H, Ueda A, Liu L, Naz M, Barutçular C, Lone J, Raza MA, Chowdhury MK, Sabagh E, A., and, Erman M (2022) Soybean and sustainable agriculture for food security. In T. Ohshima, Y. Takahashi, N. Ohtake, T. Sato, and S. Tanabata (Eds.), *Soybean* (Chap. 1). IntechOpen
10. Kithan LM, Somasundaram E, Surya K, Palanisamy MA, Kannan R, Ponnusamy J, Sunitha R, Erui NT, Cheran E (2026) Transplanted rice response to non-chemical weed management in a degraded wetland ecosystem. *Front Sustainable Food Syst* 10:1620579
11. Kjeldahl J (1883) Neue Methode zur Bestimmung des Stickstoffs in organischen Körpern. *Z für Analytische Chemie* 22:366–382
12. Liang B, Zhao W, Yang X, Zhou J (2013) Fate of nitrogen-15 as influenced by soil and nutrient management history in a 19-year wheat–maize experiment. *Field Crops Res* 144:126–134
13. Mehlich A (1984) Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. *Commun Soil Sci Plant Anal* 15(12):1409–1416. <https://doi.org/10.1080/00103628409367568>
14. Mukhongo RW, Tumuhairwe JB, Ebanyat P, AbdelGadir AH, Thuita M, Masso C (2017) Combined application of biofertilizers and inorganic nutrients improves sweet potato yields. *Front Plant Sci* 8:219
15. Okanlawon TA, Kolawole GO (2023) Effects of potassium fertilizer rates on growth, tuber yield and quality of sweet potato (*Ipomea batatas* L) in Ogbomoso, Southwest Nigeria. *Adan J Agric*, 4(1)
16. Olusakin SG, Kolawole GO (2023) Can NPK Mineral Fertilizer and Poultry Manure Enhance Soil Carbon Sequestration and Land Productivity in Maize/Soybean Cropping Systems? *Faculty of Agricultural Sciences International Conference 2024, Ladoke Akintola University of Technology Ogbomoso, Oyo State (LAUTECH)*, 13th to 15th May 2024
17. Pelealu JJ, Wahyudi L, Tallei TE (2019) Growth response and production of purple sweet potatoes after provision of arbuscular mycorrhizal fungi and organic fertilizer. *Asian J Plant Sci* 18:123–130. <https://doi.org/10.3923/ajps.2019.123.130>
18. Peng S, Buresh RJ, Huang J, Zhong X, Zou Y, Yang J, Wang G, Liu Y (2010) Improving nitrogen fertilization in rice by site-specific N management. A review. *Agron Sustain Dev* 30(3):649–656
19. Peng S, Buresh RJ, Huang J, Zhong X, Zou Y, Yang J, Wang G, Liu Y (2010) Improving nitrogen fertilization in rice by site-specific N management. A review. *Agron Sustain Dev* 30(3):649–656
20. Pratt PF (1965) Potassium. In: Black CA (ed) *Methods of soil analysis: Part 2. Chemical and microbiological properties*. Agronomy Monograph No. 9. American Society of Agronomy, pp 1022–1030
21. Santachiara G, Salvagiotti F, Rotundo JL (2019) Nutritional and environmental effects on biological nitrogen fixation in soybean: A meta-analysis. *Field Crops Res* 240:106–115

22. Sapakhova Z, Raissova N, Daurov D, Zhapar K, Daurova A, Zhigailov A, Zhambakin K, Shamekova M (2023) Sweet potato as a key crop for food security under the conditions of global climate change: A review. *Plants* 12(13):2516
23. SAS Institute Inc (2009) SAS/STAT® 9.2 user's guide, 2nd edn. SAS Institute Inc.
24. Soretire AA, Adeyemi NO, Atayese MO, Sakariyawo OS, Adewunmi A (2020) Nodulation and biological nitrogen fixation in soybean (*Glycine max* L.) as influenced by phosphorus fertilization and arbuscular mycorrhizal inoculation. *Acta Universitatis Sapientiae Agric Environ* 12(1):22–44
25. Walkley A, Black IA (1934) An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Sci* 37(1):29–38
26. Wang G, Jin Z, George TS, Feng G, Zhang L (2023) Arbuscular mycorrhizal fungi enhance plant phosphorus uptake through stimulating hyphosphere soil microbiome functional profiles for phosphorus turnover. *New Phytol* 238(6):2578–2593
27. Wen Z, Yang M, Fazal A, Han H, Lin H, Yin T, Zhu Y, Yang S, Niu K, Sun S, Qi J, Lu G, Yang Y (2024) Harnessing the power of microbes: Enhancing soybean growth in an acidic soil through AMF inoculation rather than P-fertilization. *Hortic Res* 11(5):uhae067
28. Yuan J, Shi K, Zhou X, Wang L, Xu C, Zhang H, Zhu G, Si C, Wang J, Zhang Y (2023) Interactive impact of potassium and arbuscular mycorrhizal fungi on the root morphology and nutrient uptake of sweet potato (*Ipomoea batatas* L). *Front Microbiol* 13:1075957
29. Zhu X, Ros GH, Xu M, Xu D, Cai Z, Sun N, Duan Y, de Vries W (2024) The contribution of natural and anthropogenic causes to soil acidification rates under different fertilization practices and site conditions in southern China. *Sci Total Environ* 934:172986