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Research Article

Improvement of Chemical Properties of Ultisol Affected by Arbuscular Mycorrhizal Fungal Inoculation and Poultry Manure Application

[1]Aniefiok Effiong Uko, [1]Emmanuel Bassey Effa, [2]Isong Abraham Isong and [2]Joyce Fidelis Akpan

[1]Department of Crop Science, Faculty of Agriculture, University of Calabar, P.M.B. 1115, Calabar, Nigeria
[2]Department of Soil Science, Faculty of Agriculture, University of Calabar, P.M.B. 1115, Calabar, Nigeria

Abstract

Background and Objective: Application of organic amendments and arbuscular mycorrhizal fungal inoculants is a reliable agronomic practice that could restore and maintain soil quality sustainably. This study determined the effect of arbuscular mycorrhizal fungal inoculation and poultry manure application on soil chemical properties. **Materials and Methods:** The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Treatments included four levels of Poultry Manure (PM) (0, 4, 8 and 12 t ha^{-1}) inoculated with five species of AMF (*Glomus mosseae*, *Glomus deserticola, Glomus clarum, Gigaspora gigantea* plus an un-inoculated soil serving as the control). Soil samples (0-20 cm) were collected from experimental plots after the Bambara groundnut harvest and analyzed for post-harvest soil chemical properties. **Results:** In both 2016 and 2017 growing seasons the observed pH for un-inoculated and un-amended soils were strongly acidic, however, after inoculation with AMF and amendment with poultry manure, some treatments were able to raise pH from strongly acidic to moderately acid level. Plot amended with poultry manure and inoculated with AMF showed no significant (p>0.05) difference in exchangeable Na values. The results showed significant (p<0.05) differences in other soil properties especially pH, organic carbon, total nitrogen and available P. The inoculation of *Glomus clarum* and *Gigaspora gigantea* with poultry manure at 12 t ha^{-1} proved to be the most effective in increasing soil chemical properties. **Conclusion:** Therefore, from the result, it can be seen that the application of poultry manure and AMF inoculation has improved soil chemical properties; hence, it should be utilized as a sustainable option for soil fertility improvement.

Key words: Arbuscular mycorrhizal fungi, inoculation, amendment, poultry manure, soil properties

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Corresponding Author: Isong Abraham Isong, Department of Soil Science, Faculty of Agriculture, University of Calabar, P.M.B. 1115, Calabar, Nigeria

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Undisputedly, chemical fertilizer has played a significant role in boosting crop production over the past decades. However, its continuous use is already fraught with numerous challenges including its attendant effect on increased soil acidity and pollution of groundwater especially in the humid tropical environment where nutrient leaching is inevitable and temperature and rainfall are excessively high.

Hence, a good agronomic practice that would restore and maintain soil quality sustainably to improve crop production in mind is crucial. According to Abdullahi *et al.*[1], the application of organic carbon-rich materials to the soil is the initial step to restore, improve and conserve soil quality due to positive influence in improving soil structure and aggregation, improve soil fertility, microbial community and activities. Scientific studies and research for several decades now have shown the application of poultry manure to enhance soil quality by improving soil properties such as water and nutrient retention, stimulating microbial activities, increasing pH and organic carbon levels, improving soil quality and also increasing the yield of crops[2,3].

Similar to poultry manure application is a growing recognition in utilizing Arbuscular mycorrhizal fungi (AMF) in crop production. AMF is known to provide a direct physical link between soil and plant roots[4] and can promote plant growth by increasing plant access to relatively immobile nutrients[5]. AMF inoculation is a reliable strategy for the maintenance of soil quality[1]. AMF plant-soil relationship can help mediate soil stabilization that could prevent erosion, reduce leaching of soil nutrients through the extension of extra-radical hyphae scavenging for nutrients and water beyond the reach of plant root hairs[6,7]. The benefit of AMF in Agriculture cannot be overemphasis, excellent reports were found from other studies[8-10].

Several agricultural and crop management practices in time past have exerted either positive or negative influence on soil properties, which the long term effect can affect soil functionality. The previous study by Sabrina *et al.*[11] revealed that inoculation of AMF with earthworms and phosphate rock has improved soil phosphorus availability. In like manner, investigations by Yusif and Dare[12] showed mycorrhizal inoculation in biochar amended soil to contribute to the improvement of soil available phosphorus including soil pH and organic carbon. Similarly, studies by Abdullahi *et al.*[1] showed improvement in soil properties due to poultry manure applications alongside with AMF compared to control and chemical fertilizer. Several types of research have also shown a positive effect of poultry manure in combination with AMF[1,9,13] on plant growth. However, there is a paucity of information on the effect of poultry manure and AMF inoculation on soil quality indicators in the study area and elsewhere.

Hence, there is a need to understand the optimum rate of poultry manure applications that could enhance maximum benefits from AMF. Nevertheless, it is believed that the addition of poultry manure and AMF could enhance the quality of the studied soil after the Bambara groundnut harvest. This study was undertaken to investigate the changes in soil properties as influenced by arbuscular mycorrhizal fungal inoculation in poultry manure amended ultisol.

MATERIALS AND METHODS

Study site: The study was conducted during the 2016 and 2017 cropping seasons at the University of Calabar Teaching and Research Farm. The farm is located between Latitudes 04°45' and 04°57' north and Longitudes 08°21' and 08°37' east. The area is characterized by two distinct rainfall peaks. The first rainy period starts from March; reaches a peak in June/July, slows down in August and reaches another peak in September/October before it recedes into the dry season from November to early March. The mean annual rainfall of the area exceeds 2500 mm with mean annual air temperatures and relative humidity of 26.7°C and 86%, respectively[14]. The farm is located on an undulating topography, underlain by the tertiary coastal plain sands parent material, usually referred to as acid sands.

Soil and poultry manure sampling and analysis: Before seedbed preparation and after harvesting, composite soil samples were collected from 0-20 cm depth with the aid of soil auger from each experimental plot and analyzed for Physico-chemical properties using standard methods. Particle size distribution was determined by Bouyoucos hydrometer method[15]. Soil pH was measured potentiometrically in a soil: water suspension (mixed at a ratio of 1:2.5 soil: water) using glass electrode pH meter following the procedure described by Estefan *et al.*[16]. Organic carbon was determined by the dichromate wet oxidation method of Walkley and Black as outline in Nelson and Sommers[17]. Total nitrogen was determined by the micro-Kjeldahl digestion method as described by Bremner[18]. Available phosphorous was determined by Bray-1 method according to the procedure outlined in Estefan *et al.*[16]. Exchangeable bases (Ca^+, Mg^+, Na^+, and K^+) were extracted by saturating the soil with neutral 1M NH_4OAc[19] and Ca and Mg in the extract were determined using atomic absorption spectrophotometer (AAS) while K and Na were determined by flame photometry. Exchangeable acidity was determined by extracting the soil with 0.1 NKCl solution and titrating the aliquot of the extract with 1 NNaOH following the procedure outline by Estefan *et al.*[16]. Effective cation exchange capacity (ECEC) was determined by summing up exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) and exchangeable acidity (H^{+} and Al^{3+}). Base saturation was calculated as the sum of total exchangeable bases divided by ECEC and expressed as a percentage. Poultry manure was analyzed for its nutrient contents using a method described by Dede and Ozer[20].

Experimental design and treatments: Randomized complete block design (RCBD) was used for this research. The treatments comprised of 4 levels of poultry manure in tones (t) ha^{-1} (0, 4, 8 and 12) and 5 levels of AM fungi (*Glomus mosseae*, *Glomus deserticola, Glomus clarum, Gigaspora gigantea* and un-inoculated soil serving as the control). Each treatment was replicated 3 times, thus resulting in a total of 60 experimental units with a distance of 0.5 m^2 between each unit and 1 m^2 between the replicates. The experiment was conducted on a total land area of 454.25 m^2.

Application of treatments: The poultry manure was first cured for two weeks. Then the required rates were broadcasted uniformly on each plot and incorporated into the soil except in the control plot. The soil was allowed to stabilize for one week after the application of poultry manure before planting. Before the planting of seeds, planting holes were dug and partially filled with 30 g inoculum of each AMF.

Data analysis: Data collected were subjected to statistical analyses using the Analysis of Variance (ANOVA) procedures for a factorial experiment in a randomized complete block design (RCBD) using GenStat statistical package version 8.1[21]. When the F-ratio was significant, Duncan's New Multiple Range Test (DNMRT) was utilized to compare the mean.

RESULTS

The initial physico-chemical properties of the soil and chemical properties of poultry manure for both 2016 and 2017 cropping seasons are presented in Table 1. The soil was sandy loam and strongly acidic with pH of 5.2 and 5.0 for 2016 and 2017 cropping seasons, respectively, low in total N and organic C but high in available P. Exchangeable bases were equally low except Mg (1.5 cmol kg^{-1}) in 2016 which was moderate. Poultry manure (PM) had a high TN content of 3.81 and 3.80%, available P of 1.61 and 1.64 % and high OC content of 22.3 and 21.9% respectively for 2016 and 2017 seasons, respectively (Table 1).

Effects of Arbuscular Mycorrhizal Fungi (AMF) on soil chemical properties in 2016 and 2017 cropping seasons: The effects of AMF and PM on soil chemical properties in 2016 are presented in Table 2. Changes in pH among different AMF treated soils were statistically similar ($p>0.05$) and significantly higher ($p<0.05$) than pH among un-inoculated soils. Organic C was statistically similar among soils treated with *Glomus deserticola*, *Glomus clarum* and *Gigaspora gigantea,* but significantly higher ($p<0.05$) than soils that received *Glomus mosseae* or no inoculation. Inoculation with *G. mosseae, G. deserticola* and *G. clarum* significantly increased the soil TN content ($p<0.05$) relative to *G. gigantea* treated soil. Available P was statistically ($p>0.05$) similar in *G. deserticola*, *G. clarum* and *G. gigantea* inoculated soils but significantly higher than *G. mosseae* inoculated soils and the control. The effect of *G. deserticola* on Ca and Na content was not significant ($p>0.05$). Mg and K contents of soil were statistically similar ($p>0.05$) in *G. deserticola*, *G. clarum* and *G. gigantea* inoculated plots but significantly higher than soil inoculated with *G. mosseae* or no AMF. Exchangeable acidity occasioned by Al^{3+} and H^{+} were highest among untreated plots ($p<0.05$) and significantly least among plots that were inoculated with *G. mosseae* (Table 2). *G. clarum* significantly enhanced the

Table 1: Results of physicochemical analysis of the pre-cropping soil and poultry manure used for the experiment

	Soil values		Poultry manure values	
Properties	2016	2017	2016	2017
Physical				
Sand (g kg^{-1})	730	710		
Silt (g kg^{-1})	160	200		
Clay (g kg^{-1})	110	90		
Texture	Sandy loam	Sandy loam		
Chemical				
pH	5.2	5.0		
TN (%)	0.10	0.10	3.81%	3.80%
Av.P (mg kg^{-1})	33.25	32.2	1.61%	1.64%
OC (%)	0.93	0.91	22.30%	21.90%
Ca (Cmol kg^{-1})	4.10	3.80	2.30%	2.41%
Mg (Cmol kg^{-1})	1.50	1.46	0.84%	0.87%
K (Cmol kg^{-1})	0.11	0.12	1.10%	1.12%
Na (Cmol kg^{-1})	0.09	0.08	0.42%	0.40%
Al^{+++} (Cmol kg^{-1})	1.20	1.24		
H+ (Cmol kg^{-1})	0.16	0.18		
ECEC (Cmol kg^{-1})	7.16	6.88		
BS (%)	81.0	79.36		

TN: Total nitrogen, Av.P: Available phosphorus, OC: Organic carbon, ECEC: Exchangeable cation exchange capacity, BS: Base saturation

Table 2: Effects of arbuscular mycorrhizal fungi (AMF) and poultry manure (PM) on soil chemical properties in 2016 growing season

					Exch. Cations				Exch. Acidity			
Treatment	pH (H_2O)	OC	TN	AV. P (mg kg^{-1})	Ca	Mg	K	Na	Al^{3+}	H^+	ECEC	BS (%)
		(%)			(cmol^{+} kg^{-1})							
AMF												
AM_0	4.94^{b}	1.73^{c}	0.14^{d}	41.61^{c}	3.16^{a}	1.47^{b}	0.14^{b}	0.089^{a}	1.22^{a}	0.76^{a}	6.83^{c}	70.79^{c}
AM_1	5.28^{a}	1.83^{b}	0.16^{c}	44.14^{b}	3.31^{a}	1.49^{b}	0.16^{a}	0.099^{a}	1.14^{c}	0.68^{c}	6.89^{bc}	73.37^{b}
AM_2	5.41^{a}	1.88^{ab}	0.17^{b}	45.10^{a}	3.47^{a}	1.54^{a}	0.18^{a}	0.10^{a}	1.19^{ab}	0.71^{c}	7.17^{ab}	73.55^{b}
AM_3	5.46^{a}	1.89^{a}	0.18^{a}	45.46^{a}	3.54^{a}	1.55^{a}	0.18^{a}	0.10^{a}	1.17^{bc}	0.72^{ab}	7.25^{a}	73.89^{b}
AM_4	5.43^{a}	1.89^{a}	0.17^{b}	45.30^{a}	3.51^{a}	1.53^{a}	0.17^{a}	0.10^{a}	1.15^{bc}	0.56^{c}	7.02^{abc}	75.48^{a}
PM												
P_0	5.08^{c}	1.75^{b}	0.15^{c}	37.06^{c}	2.94^{b}	1.47^{b}	0.14^{d}	0.092^{a}	1.22^{a}	0.75^{a}	6.62^{b}	70.15^{b}
P_1	5.27^{b}	1.85^{a}	0.17^{b}	44.53^{b}	3.40^{a}	1.52^{a}	0.16^{c}	0.10^{a}	1.17^{b}	0.69^{b}	7.05^{a}	73.43^{b}
P_2	5.39^{a}	1.89^{a}	0.17^{b}	47.68^{a}	3.63^{a}	1.53^{a}	0.17^{b}	0.10^{a}	1.16^{b}	0.65^{c}	7.24^{a}	74.89^{a}
P_3	5.47^{a}	1.89^{a}	0.18^{a}	48.02^{a}	3.62^{a}	1.53^{a}	0.18^{a}	0.099^{a}	1.14^{b}	0.64^{c}	7.22^{a}	75.20^{a}
AMF×P												
AM_0P_0	4.67^{a}	1.56^{a}	0.12^{f}	34.73^{i}	3.10^{a}	1.41	0.11^{f}	0.08^{a}	1.33^{a}	0.87^{a}	6.91^{a}	67.82^{a}
AM_0P_1	4.87^{a}	1.77^{a}	0.14^{e}	39.47^{g}	2.92^{a}	1.47	0.13^{ef}	0.093^{a}	1.21^{a}	0.74^{a}	6.56^{a}	70.32^{a}
AM_0P_2	5.10^{a}	1.77^{a}	0.15^{d}	44.97^{f}	3.25^{a}	1.50	0.14^{def}	0.09^{a}	1.17^{a}	0.73^{a}	6.87^{a}	72.08^{a}
AM_0P_3	5.13^{a}	1.82^{a}	0.15^{d}	47.27^{abcd}	3.35^{a}	1.49	0.16^{cd}	0.093^{a}	1.16^{a}	0.72^{a}	6.97^{a}	72.93^{a}
AM_1P_0	5.07^{a}	1.75^{a}	0.14^{e}	36.67^{h}	2.81^{a}	1.42	0.13^{ef}	0.093^{a}	1.17^{a}	0.71^{a}	6.34^{a}	70.23^{a}
AM_1P_1	5.23^{a}	1.82^{a}	0.16^{cd}	45.30^{ef}	3.43^{a}	1.50	0.14^{def}	0.11^{a}	1.15^{a}	0.69^{a}	7.03^{a}	73.79^{a}
AM_1P_2	5.33^{a}	1.88^{a}	0.16^{cd}	46.90^{bcde}	3.53^{a}	1.52	0.17^{bc}	0.096^{a}	1.14^{a}	0.66^{a}	7.11^{a}	74.66^{a}
AM_1P_3	5.50^{a}	1.86^{a}	0.18^{ab}	47.70^{abc}	3.47^{a}	1.53	0.19^{a}	0.097^{a}	1.12^{a}	0.66^{a}	7.06^{a}	74.83^{a}
AM_2P_0	5.20^{a}	1.84^{a}	0.15^{d}	37.67^{h}	3.08^{a}	1.52	0.15^{de}	0.10^{a}	1.22^{a}	0.74^{a}	6.82^{a}	71.14^{a}
AM_2P_1	5.40^{a}	1.91^{a}	0.18^{ab}	45.87^{def}	3.47^{a}	1.53	0.18^{ab}	0.093^{a}	1.18^{a}	0.70^{a}	7.16^{a}	73.64^{a}
AM_2P_2	5.47^{a}	1.92^{a}	0.17^{bc}	48.67^{ab}	3.76^{a}	1.54	0.18^{ab}	0.11^{a}	1.17^{a}	0.70^{a}	7.46^{a}	74.85^{a}
AM_2P_3	5.57^{a}	1.86^{a}	0.18^{ab}	48.20^{ab}	3.56^{a}	1.55	0.19^{a}	0.10^{a}	1.17^{a}	0.67^{a}	7.25^{a}	74.56^{a}
AM_3P_0	5.27^{a}	1.82^{a}	0.17^{bc}	38.17^{gh}	2.87^{a}	1.52	0.15^{de}	0.09^{a}	1.20^{a}	0.75^{a}	6.58^{a}	70.36^{a}
AM_3P_1	5.43^{a}	1.88^{a}	0.19^{a}	46.13^{cdef}	3.58^{a}	1.56	0.17^{bc}	0.11^{a}	1.17^{a}	0.76^{a}	7.35^{a}	73.75^{a}
AM_3P_2	5.53^{a}	1.92^{a}	0.19^{a}	49.00^{a}	3.83^{a}	1.56	0.19^{a}	0.097^{a}	1.14^{a}	0.69^{a}	7.53^{a}	75.52^{a}
AM_3P_3	5.60^{a}	1.93	0.18^{ab}	48.53^{ab}	3.88^{a}	1.55	0.18^{ab}	0.11^{a}	1.14^{a}	0.67^{a}	7.54^{a}	75.92^{a}
AM_4P_0	5.20^{a}	1.79^{a}	0.16^{cd}	38.07^{gh}	2.83^{a}	1.50	0.16^{cd}	0.097^{a}	1.19^{a}	0.67^{a}	6.45^{a}	71.19^{a}
AM_4P_1	5.43^{a}	1.89^{a}	0.18^{ab}	45.87^{def}	3.60^{a}	1.53	0.17^{bc}	0.097^{a}	1.14^{a}	0.59^{a}	7.13^{a}	75.65^{a}
AM_4P_2	5.50^{a}	1.94^{a}	0.17^{bc}	48.87^{a}	3.76^{a}	1.54	0.17^{bc}	0.11^{a}	1.15^{a}	0.48^{a}	7.22^{a}	77.34^{a}
AM_4P_3	5.57^{a}	1.96^{a}	0.18^{ab}	48.40^{ab}	3.83^{a}	1.55	0.19^{a}	0.097^{a}	1.13^{a}	0.49^{a}	7.29^{a}	77.76^{a}

AM_0: Un-inoculated plants, AM_1: *Glomus mosseae*, AM_2: *Glomus deserticola*, AM_3: *Glomus clarum*, AM_4: *Gigaspora gigantea*, P_0: 0 t ha^{-1} PM, P_1: 4 t ha^{-1} PM, P_2: 8 t ha^{-1} PM, P_3: 12 t ha^{-1} PM, Means within a column not sharing a letter in common differ from other means significantly following Duncan's Multiple Range Test (DMRT) at 5%

ECEC status of soil ($p<0.05$) over untreated soil which had the least ECEC of 6.83. Base saturation of soil inoculated with *G. gigantea* was significantly higher ($p<0.05$) than BS in plots inoculated with *G. mosseae*, *G. deserticola* and *G. clarum* which were in turn higher than untreated control (Table 2).

In 2017, results presented in Table 3 show that inoculation with *G. deserticola* resulted in statistically similar soil pH ($p>0.05$) to the pH of plots inoculated with *G. mosseae* and *G. clarum* but significantly higher than pH in *G. gigantea* inoculated soil and the control. The increase in TN, Available P and K were statistically at par ($p>0.05$) among soils inoculated with *G. deserticola*, *G. clarum*, *G. gigantea,* and significantly higher than soil inoculated with *G. mosseae* or no AMF at all. Non-significant effects of AMF ($p>0.05$) were observed for OC, Ca, Mg and Na (Table 3). The exchange acidity contribution from H^+ for the un-inoculated soils was significantly higher ($p<0.05$) compared to all the AMF treated soils, whereas for Al^{3+}, *G. mosseae* and *G. gigantea* resulted in the lowest acidity with the highest acidity occurring in the untreated plots. Acidity was therefore in the order of Control > *G. clarum* = *G. deserticola* > *G. clarum* > *G. gigantea*. The ECEC status increased significantly ($p<0.05$) when soils was inoculated with *G. clarum* though statistically at par with those of *G. gigantea* and *G. deserticola* *G. gigantea* inoculated soil had significantly higher BS compare to inoculation with other species of AMF except for *G. clarum* but the un-amended soil had the least ECEC and BS.

Effects Poultry manure on soil chemical properties in 2016 and 2017 cropping seasons: Significant increases in soil pH and available P were observed as PM rates increased from 0 to 12 t ha^{-1} in 2016 (Table 2). The application of 4-12 t ha^{-1} PM rates resulted in OC that was statistically at par ($p>0.05$) but significantly higher ($p<0.05$) than OC in unfertilized plots. A

Table 3: Effects of arbuscular mycorrhizal fungi (AMF) and poultry manure (PM) on soil chemical properties in 2017 growing season

					Exch. Cations				Exch. Acidity			
	pH	OC	TN	AV. P (mg kg^{-1})	Ca	Mg	K	Na	Al^{3+}	H^{+}	ECEC	
Treatment	(H_2O)	(%)			($cmol^{+}$ kg^{-1})							BS (%)
AMF												
AM_0	5.16^{c}	1.79^{a}	0.16^{c}	40.9^{b}	3.36^{a}	1.55^{a}	0.14^{b}	0.097^{a}	1.22^{a}	0.19^{a}	6.57c	78.48^{c}
AM_1	5.34^{ab}	1.81^{a}	0.17^{b}	43.53^{b}	3.43^{a}	1.58^{a}	0.16^{b}	0.099^{a}	1.17c	0.17^{b}	6.61bc	79.75^{b}
AM_2	5.38^{a}	1.85^{a}	0.18^{a}	44.57^{a}	3.49^{a}	1.67^{a}	0.18^{a}	0.10^{a}	1.19^{ab}	0.17^{b}	6.80ab	79.93^{b}
AM_3	5.36^{ab}	1.89^{a}	0.18^{b}	45.21^{a}	3.59^{a}	1.65^{a}	0.18^{a}	0.10^{a}	1.19^{b}	0.18^{b}	6.89^{a}	80.06^{ab}
AM_4	5.27^{b}	1.89^{a}	0.19^{a}	45.43^{a}	3.56^{a}	1.68^{a}	0.18^{a}	0.10^{a}	1.14^{c}	0.17^{b}	6.83ab	80.64^{a}
PM												
P_0	5.10^{c}	1.77^{b}	0.16^{c}	36.36^{d}	3.20b	1.59^{a}	0.14^{d}	0.093^{a}	1.22^{a}	0.19^{a}	6.43b	78.09^{c}
P_1	5.29^{b}	1.84^{a}	0.18^{b}	44.42^{c}	3.52^{a}	1.63^{a}	0.16^{c}	0.10^{a}	1.19^{a}	0.17^{b}	6.77^{a}	79.95^{b}
P_2	5.39^{a}	1.88^{a}	0.18^{b}	46.90^{b}	3.63^{a}	1.64^{a}	0.18^{b}	0.11^{a}	1.17^{ac}	0.17^{b}	6.89^{a}	80.45^{ab}
P_3	5.43^{a}	1.90^{a}	0.19^{a}	47.71^{a}	3.60^{a}	1.65^{a}	0.19^{a}	0.10^{a}	1.15^{c}	0.18^{ab}	6.87^{a}	80.59^{a}
AMF × P												
AM_0P_0	4.97^{a}	1.71^{a}	0.14^{e}	34.87^{h}	3.23^{a}	1.52^{a}	0.12^{a}	0.09^{a}	1.29^{a}	0.37^{a}	6.62^{a}	74.89^{cdef}
AM_0P_1	5.17^{a}	1.78^{a}	0.16^{de}	38.33^{f}	3.33^{a}	1.55^{a}	0.13^{a}	0.09^{a}	1.12^{a}	0.13^{d}	6.46^{a}	79.19^{bcde}
AM_0P_2	5.20^{a}	1.83^{a}	0.17^{cd}	42.87^{e}	3.43^{a}	1.56^{a}	0.14^{a}	0.11^{a}	1.19^{a}	0.14^{d}	6.57^{a}	79.70^{bcde}
AM_0P_3	5.30^{a}	1.85^{a}	0.18^{abc}	45.90^{de}	3.45^{a}	1.58^{a}	0.17^{a}	0.10^{a}	1.17^{a}	0.14^{d}	6.62^{a}	80.15^{abcde}
AM_1P_0	5.13^{a}	1.72^{a}	0.15^{e}	35.77^{gh}	3.20^{a}	1.51^{a}	0.14^{a}	0.09^{a}	1.19^{a}	0.14^{d}	6.28^{a}	78.77^{cdef}
AM_1P_1	5.33^{a}	1.82^{a}	0.18^{abc}	44.87^{e}	3.50^{a}	1.58^{a}	0.16^{a}	0.11^{a}	1.17^{a}	0.16^{bc}	6.68^{a}	79.95^{bcde}
AM_1P_2	5.43^{a}	1.85^{a}	0.17^{cd}	45.97^{de}	3.57^{a}	1.60^{a}	0.17^{a}	0.09^{a}	1.15^{a}	0.18^{bc}	6.76^{a}	80.22^{abcde}
AM_1P_3	5.47^{a}	1.87^{a}	0.18^{abc}	47.53^{abcd}	3.47^{a}	1.62^{a}	0.19^{a}	0.09^{a}	1.15^{a}	0.19^{bc}	6.71^{a}	80.06^{abcde}
AM_2P_0	5.20^{a}	1.76^{a}	0.17^{cd}	36.67^{fgh}	3.10^{a}	1.62^{a}	0.15^{a}	0.09^{a}	1.22^{a}	0.14^{d}	6.33^{a}	78.51^{cdef}
AM_2P_1	5.37^{a}	1.84^{a}	0.19^{ab}	45.87^{de}	3.60^{a}	1.67^{a}	0.18^{a}	0.09^{a}	1.19^{a}	0.16^{cd}	6.90^{a}	80.38^{abcde}
AM_2P_2	5.47^{a}	1.88^{a}	0.19^{ab}	48.0^{abc}	3.69^{a}	1.70^{a}	0.19^{a}	0.11^{a}	1.19^{a}	0.18^{bc}	7.07^{a}	80.61^{abcd}
AM_2P_3	5.50^{a}	1.92^{a}	0.18^{abc}	47.73^{abcd}	3.57^{a}	1.69^{a}	0.19^{a}	0.11^{a}	1.18^{a}	0.19^{bc}	6.92^{a}	80.21^{abcde}
AM_3P_0	5.13^{a}	1.82^{a}	0.17^{cd}	37.17^{fg}	3.23^{a}	1.64^{a}	0.15^{a}	0.09^{a}	1.21^{a}	0.15^{cd}	6.48^{a}	78.95^{bcde}
AM_3P_1	5.30^{a}	1.87^{a}	0.17^{cd}	46.13^{cde}	3.58^{a}	1.66^{a}	0.18^{a}	0.11^{a}	1.19^{a}	0.20^{b}	6.92^{a}	79.90^{bcde}
AM_3P_2	5.47^{a}	1.92^{a}	0.17^{cd}	48.67^{ab}	3.67^{a}	1.65^{a}	0.19^{a}	0.11^{a}	1.19^{a}	0.18^{bc}	6.98^{a}	80.38^{abcde}
AM_3P_3	5.53^{a}	1.92^{a}	0.19^{ab}	48.87^{ab}	3.88^{a}	1.65^{a}	0.19^{a}	0.11^{a}	1.18^{a}	0.19^{bc}	7.19^{a}	81.00^{abc}
AM_4P_0	5.07^{a}	1.83^{a}	0.18^{abc}	37.33^{fg}	3.23^{a}	1.63^{a}	0.16^{a}	0.09^{a}	1.18^{a}	0.14^{d}	6.44^{a}	79.35^{bcde}
AM_4P_1	5.27^{a}	1.88^{a}	0.19^{ab}	46.89^{bcd}	3.60^{a}	1.67^{a}	0.17^{a}	0.09^{a}	1.16^{a}	0.19^{bc}	6.88^{a}	80.34^{abcde}
AM_4P_2	5.37^{a}	1.92^{a}	0.20^{a}	49.00^{a}	3.76^{a}	1.70^{a}	0.19^{a}	0.11^{a}	1.14^{a}	0.18^{bc}	7.09^{a}	81.32^{ab}
AM_4P_3	5.37^{a}	1.94^{a}	0.20^{a}	48.50^{ab}	3.63^{a}	1.72^{a}	0.19^{a}	0.09^{a}	1.09^{a}	0.19^{bc}	6.91^{a}	81.54^{a}

AM_0: Un-inoculated plants, AM_1: *Glomus mosseae*, AM_2: *Glomus deserticola*, AM_3: *Glomus clarum*, AM_4: *Gigaspora gigantea*, P_0: 0 t ha^{-1} PM, P_1: 4 t ha^{-1} PM, P_2: 8 t ha^{-1} PM, P_3: 12 t ha^{-1} PM, Means within a column not sharing a letter in common differ from other means significantly following Duncan's Multiple Range Test (DMRT) at 5%

similar trend was observed for Ca, Mg, ECEC and base saturation status of soils (Table 2). The increase in TN from 12 t ha^{-1} PM was significantly higher ($p<0.05$) than 4 and 8 t ha^{-1} PM followed by the unfertilized control. Although the soil content of Na was not significant ($p>0.05$), K increased significantly ($p<0.05$) with each successive increase in PM rates. The exchange acidity (Al^{3+} and H^{+}) was significantly higher ($p<0.05$) from unfertilized plots than the 4-12 t ha^{-1} PM treated plots which were statistically at par ($p>0.05$). However, in 2017, changes in pH were consistent with increasing PM rates from 0-12 t ha^{-1} PM ($p<0.05$) although statistically similar at 8 and 12 t ha^{-1} PM ($p>0.05$). Also, as rates of PM increased from 0-12 t ha^{-1} PM, soil OC content at 4-12 t ha^{-1} PM was statistically at par but significantly increased ($p<0.05$) above the control. A similar trend was observed for Ca and ECEC status of soils (Table 3). TN followed a similar trend until it peaked at 12 t ha^{-1} PM, being significantly higher ($p<0.05$) than TN from the application of 4 and 8 t ha^{-1} PM and the control bringing up the least TN values. On the other hand, available P and K increased significantly ($p<0.05$) as PM rates also increased from 0-12 t ha^{-1} PM. The exchangeable acidity of Al^{3+} was statistically similar at 0-4 t ha^{-1} PM and significantly higher than Al^{3+} content in soil at 12 t ha^{-1} PM application. H^{+} mediated acidity was highest in plots that received no PM, significantly higher ($p<0.05$) than plots that received 4-12 t ha^{-1} PM, which was statistically similar ($p>0.05$). The application of 12 t ha^{-1} PM resulted in the highest ($p<0.05$) BS, statistically similar to BS in plots that received 8 t ha^{-1} PM and higher than BS at 4 and 0 t ha^{-1} PM.

Interactive effects of AMF × PM on soil chemical properties in 2016 and 2017 growing seasons: In 2016, interactive effects of AMF × PM were significant ($p<0.05$) for TN, Available P and K only (Table 2). The interaction of *G. clarum* with each of 4 and 8 t ha^{-1} PM resulted in significantly higher ($p<0.05$) TN (0.19 %), while the lowest TN values were recorded in plots that neither received poultry manure nor inoculation with AMF species. Interaction effects of *G. clarum* × 8 t ha^{-1} PM and *G. gigantea* × 8 t ha^{-1} PM resulted in the highest ($p<0.05$) available P of 49.0 and 48.87 mg kg^{-1}, respectively. Other interactions ranked closely but the untreated controls that received neither AMF nor PM gave the lowest Available P values ($p<0.05$) observed in 2016 (Table 2). A similar trend was observed for interactive effects among AMF × PM on K. However, *G. mosseae* × 12 t ha^{-1} PM and *G. deserticola* × 12 t ha^{-1} PM, respectively were also statistically at par with the highest K values (0.19 cmol kg^{-1}) during 2016.

Significant interactive effects of AMF x PM were only observed for TN, Available P, H^+ and BS in 2017 (Table 3). In all the above situations, the zero inoculation and PM gave the lowest TN, available P and BS, but also the highest H^+. Inoculation of soil with *G. gigantea* in combination with 4 and 8 t ha^{-1} PM gave the highest TN status of soil (0.14 and 0.15%). Soil available P was maximized (49.00 mg kg^{-1}), closely followed by *G. clarum* × 12 and 8 t ha^{-1} PM, and *G. gigantea* × 12 t ha^{-1} PM interactions being statistically at par ($p>0.05$) and significantly higher ($p<0.05$) than the no AMF × no manure situation in control plots (34.87 mg kg^{-1}). H^+ induced acidity was highest among untreated plots, closely followed by *G. clarum* × 4 t ha^{-1} PM combination. The BS in plots treated with a combination of *Gi. gigantea* x 12 and 8 t ha^{-1} PM and *G. clarum* x 12 t ha^{-1} were statistically at par ($p>0.05$), changing minimally among the different combinations with zero AMF × PM, *G. mosseae* × zero PM, *G. deserticola* × zero PM being statistically similar ($p>0.05$).

DISCUSSION

The observed low values of soil OC, N, Ca, pH and ECEC in the control soil (Table 1) of the site used for the trial might be attributed to the inherently low nutrient status of the humid tropical environment of Calabar, high acidity, immobilization and leaching of soil and continuous cultivation of the land without fertilizer application[22]. Hence, soil enrichment was necessary. Thus, utilizing AMF and/ or poultry manure is beneficial in mobilizing nutrients bound to organic matter and soil particles for improved soil quality. The finding of this study has shown the benefits obtained from utilizing AMF and poultry manure as single and in combinations compared to no application and un-inoculation through positive and upward changes in soil chemical properties.

AM and poultry manure added to the soil caused positive changes in soil chemical properties for both years under investigation. In both 2016 and 2017 growing seasons under our experimental conditions (Table 2 and 3), the observed pH for un-inoculated and un-amended soils were strongly acidic, however, after inoculation with different species of arbuscular mycorrhizal fungi and amendment with poultry manure, *Gigaspora gigantea* plus 12 tonnes per hectare of poultry manure (PM), *Glomus clarum* plus 8 and 12 t ha^{-1} PM and *Glomus deserticola* plus12 tonnes per hectare of PM in 2016 cropping season and *Glomus clarum* plus12 tonnes per hectare of PM in 2017 cropping season were able to raise pH from strongly acidic to moderately acid level. Though the organic carbon (OC) contents for all the soils were within the moderate fertility class[23,24], soils amended with poultry manure and inoculated with AMF had the highest OC and were significantly ($p\leq 0.05$) higher compared to the control soil. The total nitrogen obtained for the soils inoculated and amended with 4, 6 and 12 tonnes per hectare of poultry manure + *Gigaspora gigantea* were higher than the control soil. Similarly, mycorrhizal inoculation in soils amended with poultry manure also resulted in changes in soil available phosphorus. The result of this study corroborates with the findings of Abdullahi *et al.*[1] who reported that integration of PM and AMF significantly increased soil pH, OC, available P and K, but contrary to the findings of Yusif and Dare[12] who reported that mycorrhizal inoculation in biochar amended soil had little or no contribution to soil pH, organic carbon and available P. Soil inoculated with AM and amended with poultry manured all had total nitrogen, exchangeable Ca, Mg and K that were significantly ($p\leq 0.05$) different from the control soil in both years. Amended soils inoculated with AM did not cause any significant changes in soil exchangeable Na. Exchangeable acidity and ECEC were low and significantly ($p\leq 0.05$) different from the control soil in both years.

The lack of significant effect of AM inoculation on some soil properties may be attributed to their adaptation to the soil where the study was conducted. Paymaneh[25] has already reported that the response of AMF is exempted to be better in slightly acidic soils, whereas most of the plot where the test was conducted was strongly acidic. In Nigeria for example, studies have shown that *G. clarum* and *G. deserticola* are more abundant in the savanna agroecology, *G. etunicatum* and *G. gigantea* adapt better to the humid forest zone, while *Glomus mosseae* occurred in a large population in all the agro-ecological zones[26]. Similarly, the lack of significant effect of AM inoculation on some soil properties could likely be that native mycorrhizae masked the effect of applied mycorrhizae[27] and the initially high soil P content. Ortas *et al.*[28] have reported that high P content in the soil strongly reduces the mycorrhizal infection. The study site had available P highly above the moderate critical level of Landon[24].

CONCLUSION

Application of poultry manure and AMF as single and in combination resulted in the improvement of soil properties. Except for the values obtained for exchangeable Na in plots amended with poultry manure and AMF which showed no significant difference, all other treated plots showed a marked improvement in soil properties compared to untreated and un-inoculated plots. The inoculation of *Glomus clarum* and *Gigaspora gigantea* with poultry manure at 12 t ha^{-1} proved to be most effective in increasing soil properties particularly pH, organic carbon, total nitrogen, and available P. It could be concluded that integration of AMF and poultry could be a good management option for improvement of soil fertility.

SIGNIFICANCE STATEMENT

This research revealed that soil amended with poultry manure at 12 t ha^{-1} and inoculated with *Glomus clarum* and *Gigaspora gigantea* proved to be beneficial in increasing soil quality, particularly pH, organic carbon, total nitrogen, available P, exchangeable Mg and base saturation without soil or groundwater pollution. The current research has demonstrated that the application of poultry manure at 12 tonnes per hectare conjunctively with either *Glomus clarum* or *Gigaspora gigantea* improved soil quality. The result of this study will be useful to agronomists, growers, and researchers at large looking for cheap and reliable alternatives for restoring, improving and maintaining soil quality sustainably with the goal of enhancing crop production.

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