Vol. 14(4), pp. 218-225, 24 January, 2019
DOI: 10.5897/AJAR2018.13457
Article Number: D1626DF59993
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Organic amendments applied to a degraded soil: Short term effects on soil quality indicators

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Received 12 August, 2018; Accepted 5 September, 2018

Low agricultural productivity is a threat to achieving global food security. Improving productivity of degraded soils is key to achieving sustainable food production. This study investigated the effects of four organic amendments (OAs) (Mushroom Compost, MC; PAS-100 compost, PAS; Anaerobic Digestate Solid Waste, AD_SW; and Poultry Manure, PM), applied at 10 t ha^{-1} and 30 t ha^{-1} on the physical, chemical and biological Soil Quality Indicators (SQIs) of a degraded sandy loam soil. The OAs had about 76 and 49.1% ($p < 0.05$) increase in the Olsen P and soil organic matter compared to control (un-amended) treatment respectively. There were significant percent increases in the microbial biomass C, total organic C and available K associated with the OAs treatments relative to the control treatment. Applying MC, PAS, AD_SW and PM at 30 t ha^{-1} best improved the soil physical, chemical and biological SQIs. Long term field study is recommended to further evaluate the effects of these OAs on the overall soil health.

Key words: Soil quality indicators, microbial biomass, organic matter, degraded soil.

INTRODUCTION

Soil is a finite resource that is crucial to human wellbeing (Lal, 2015). However, agricultural lands are currently under threats of soil degradation. Soil degradation is characterised by declining soil organic matter, nutrient depletion and loss of soil fertility (Lal, 2015). Soil degradation has been identified as a major cause of low agricultural productivity in many developing countries (Hüttil and Frielinghaus, 1994). Loss of soil organic matter specifically affects soil biological, chemical and physical properties. Changes in soil properties due to loss of organic matter have negative impact on soil biodiversity, soil buffering capacity, cation exchange capacity, nutrient availability and water infiltration, and can also lead to increased soil compaction and erosion (Karami et al., 2012).

Annually, 3 gigatonnes (Gt) of grain crops residues are produced globally. However, these residues are often removed from the farms for alternate uses such as fuel, hay and other uses (Lal, 2004). In sub-Saharan Africa, nutrient depletion caused by low-input and extractive farming was estimated to be 40 kg of NPK ha^{-1} on cultivated land (Lal, 2004). Low crop production due to increasingly degraded agricultural soils is a threat to achieving global food security. Therefore, to satisfy the food demand of the current world population (7.3 billion and rising) and cope with the future food demand there is need to adopt techniques that maximise food production from our agricultural soils whilst improving soil quality,

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using available organic amendments. Currently, there are major agricultural developments in Africa South of the Sahara to increase crop productivity and eradicate hunger. However, such transformation can only be sustainable through improvements in soil quality rather than simply increasing the use of new crop varieties and inorganic chemical fertilizers (Sanchez, 2015). Periodic application of fresh organic matter either as litter or crop residue is an effective way of rehabilitating degraded soils (Abiven et al., 2009).

Soil organic matter is an important regulator of many environmental processes that affect crop productivity (Tejada et al., 2008) through its beneficial effects at improving soil physical properties, increasing plant growth and crop yields (Karami et al., 2012). Application of organic amendments in terms of the quantity and quality applied is critical to improve fertility of degraded soils (Abiven et al., 2009). This is because soil biological processes are influenced by the soil physical and chemical characteristics, plant communities and agricultural practices which can negatively or positively affect soil fertility. Hence, soil organic matter management through the use of organic amendments is key to alleviating soil degradation by maintaining soil organic matter, thus reclaiming degraded soils and supplying plant nutrients (Tejada et al., 2008; Unagwu et al., 2013). Also, organic matter has been reported to improve soil water retention, nutrient retention ability, soil pH, and increase soil aggregation; consequently preventing and even reversing soil degradation (Karami et al., 2012). It is therefore suggested that improving the biological, chemical, and physical soil quality indicators (SQIs) can be critical to overcoming the global soil degradation challenge. Studies on the effect of organic amendments with or without inorganic fertilizer to improve soil productivity suggest that soil management practices improve SOM, increase crop productivity and have positive effects on the soil physical, chemical, biological properties (Unagwu et al., 2013; Nwite and Okolo, 2016; Mbah et al., 2017).

The degraded soil used in this study was characterised by poor soil structure, inadequate levels of NPK, low soil organic carbon and low microbial biomass. Unless the relevant SQIs are improved (Arthur et al., 2011) such low SQIs will affect its potential use for agricultural purposes. Hence, this study investigated the effects of Mushroom Compost, MC; PAS-100 compost, PAS; Anaerobic Digestate Solid Waste, AD_SW; and Poultry Manure, PM; applied at 10 and 30 t ha^{-1} on selected physical, chemical and biological SQIs.

METHODOLOGY

Soil sampling

The experiment was set up in a glasshouse at Cranfield University, UK, following a completely randomized design with four replications. Soils were sampled from a 0-150 cm depth of a non-agricultural field. The soil was sandy loam, it had a pH of 8.2, associated with low levels of total oxides of nitrogen, 0.45 (mg kg^{-1}); Olsen-P (32.9 mg kg^{-1}) and available-K (82.7 mg kg^{-1}) (Table 1). Prior to organic amendment application, a baseline soil samples (6 composite samples) were collected from the bulk test soil for physicochemical and biological analyses (Table 1). Postharvest, soil samples were collected for physicochemical and biological analyses. An intact soil cores (5.0cm depth x 5 0cm internal diameter) were collected from each experimental replicate for determination of bulk density. Further, a 400g 3-point composite soil sample was taken from the top 10 cm of each of the experimental treatment replicates. A portion (250 g) of the soil sample was air-dried and ground to <2.00mm for chemical analysis. The remaining portion (150 g) of each sample was stored at 4^{0}C prior to determination of microbial biomass carbon (MBc).

Experimental procedure

The treatments used in the study were four types of organic amendments namely: Mushroom Compost, MC; PAS-100 compost (compost produced based on UK standard composting regulations), PAS; Anaerobic Digestate Solid Waste, AD_SW; and Poultry Manure, PM. Prior to application, the organic amendments were air dried, ground and then to pass through a 2 mm mesh for the determination of chemical, while the fresh samples were sieved with a 4 mm mesh for the determination of biological properties. The physico-chemical and biological properties of the organic amendments are presented in Table 2. Each organic amendment was applied at two different rates 235 and 705 g pot^{-1} which is equivalent to 10 and 30 t ha^{-1} respectively. Thereafter, a 10 kg air-dried soil sample was weighed into polythene bags containing a pre-weighed amount of each of the organic amendments. Subsequently, the treatments were thoroughly mixed in the polythene bag and then transferred into 10 litre plastic pots and incubated at a moisture content of 35% for two weeks prior to sowing of the maize crop.

Laboratory analyses

Soil bulk density was calculated from the volume of soil cores (5.0 cm depth × 50 cm internal diameter) and oven-dry mass of soil cores (ISO 11272:1998).

$$\text{Bulk Density} = \text{Oven\_dry soil [g]} \Big/ \text{volume (cm}^3\text{)}$$

The particle size distribution was determined using the sieving and sedimentation method (ISO 112777:1998). Soil organic matter (SOM) was determined following loss on ignition by dehydrating the soil at 105°C and then ashing it at 450°C in a Carbolite furnace (British Standard BS EN 13039:2000). Soil pH was measured in a water extract at soil:distilled water = 1:5 (w/v); using pH meter (ISO 10390:2005) method. Also the EC was measured in water extract at soil:distilled water = 1:5 (w/v) using a pH and conductivity meter (ISO 11265:1994) method. Soil total organic carbon (TOC) was determined following ISO 10694:1995 method. Total nitrogen (Total_N) was determined using the British Standard method (BS EN 1364-2:2001). The ammonium-N (NH_4-N) and total oxides of nitrogen (TON) analysis were determined following the potassium chloride extraction method (MAFF reference book 427:1986). In addition, the available K (Av. K) was determined following British Standard method (BS 3882:1994) with soil microbial mass carbon

Table 1. Baseline characteristics of the test soil prior to application of the organic amendments.

Parameter	Values
Total sand (%w/w)	77 (± 1.24)
Coarse sand (%w/w)	8 (± 1.56)
Medium sand (%w/w)	46 (± 2.11)
Fine sand (%w/w)	23 (± 1.15)
Silt (%w/w)	17 (± 0.9)
Clay (%w/w)	6 (± 0.88)
Texture	Sandy loam
pH	8.2 (± 0.03)
EC (μS cm^{-1})	130 (± 0.003)
Olsen-P (mg kg^{-1})	32.9 (± 0.6)
TON (mg k g^{-1})	0.45 (±0.08)
NH_4-N (mg kg^{-1})	4.17 (± 0.33)
Available K (mg kg^{-1})	87.3 (± 1.96)
Soil organic matter (%)	2.33 (± 0.08)
Total N (%)	2.27 (± 0.093)
C:N	0.11 (± 0.03)
Total organic C (%)	0.25 (± 0.011)
Microbial biomass C (mg kg^{-1})	17.6 (± 0.06)

Values in parentheses represent +/- 1 standard error of the mean.EC = Electrical conductivity, SOM = soil organic matter; TON = Total oxides of nitrogen.

Table 2. Baseline compositions of the organic amendments.

Parameter	Amendments			
	MC	AD_SW	PAS	PM
pH	7.3^{a}	10.3^{d}	8.7^{c}	8.0^{b}
Olsen-P (mg kg^{-1})	380^{a}	1190^{b}	260^{a}	2420^{c}
TON (mg k g^{-1})	96.2^{b}	0.20^{a}	0.45^{a}	0.18^{a}
NH_4-N (mg kg^{-1})	120^{b}	700^{c}	96.7^{a}	900^{c}
Available K (mg kg^{-1})	1370^{a}	1500^{a}	4600^{b}	9140^{c}
Organic matter (%)	61.8^{c}	85.8^{a}	37.4^{b}	83.8^{a}
Total N (%)	1.90^{a}	1.99^{a}	0.98^{b}	3.14^{c}
Total organic C (%)	25.7^{b}	37.0^{c}	15.4^{a}	39.0^{d}
C:N	14.1^{ab}	19.7^{d}	15.6^{b}	12.8^{a}
Microbial biomass C (mg kg^{-1})	1358^{d}	20972^{a}	1929^{c}	23943^{a}

MC = Mushroom compost; AD_SW = Anaerobic digestate solid waste, PAS = PAS 100:2005 Quality Protocol compliant compost; PM = Poultry manure. TON = Total oxides of nitrogen. Within each column values followed by a different letter denote statistical differences ($p \leq 0.05$) following One-way ANOVA and a post-hoc Fisher LSD analysis.

(MBc) determined following the fumigation-extraction method (ISO 14240-2:1997).

Statistical analysis

Data were subjected to Analysis of Variance (ANOVA) using Statistica 12 software version 12.1. The differences between the means were tested using Duncan's multiple range test at $p < 0.05$.

RESULTS AND DISCUSSION

The soil is sandy loam and somewhat gritty texture and belongs to Tectonic series. The baseline soil

Table 3. Effect of organic amendment treatments on selected SQIs.

Treatments	pH	SOM (%)	Olsen-P (mg kg^{-1})	Av. K (mg kg^{-1})	TN (mg kg^{-1})	TOC (mg kg^{-1})	MBc (mg kg^{-1})	BD (mg cm^{-3})
Control	8.10^{a}	1.97^{b}	28.8^{a}	86^{a}	374^{a}	830^{a}	22^{a}	1.86^{c}
PM	8.14^{a}	3.74^{a}	121^{e}	188^{b}	1597^{c}	8220^{b}	371^{c}	1.36^{ab}
PAS	8.29^{b}	3.22^{c}	47.3^{b}	215^{b}	963^{b}	7480^{b}	150^{b}	1.40^{ab}
AD_SW	8.10^{a}	3.64^{a}	85.0^{d}	475^{d}	1161^{b}	9320^{c}	432^{c}	1.26^{a}
MC	8.10^{a}	3.39^{ac}	59.4^{c}	365^{c}	1136^{b}	9890^{c}	141^{b}	1.56^{b}
Rates	NS	*	*	*	*	*	*	NS
T x R	*	*	*	*	*	*	*	*

PM = Poultry manure, PAS = PAS 100:2005 compliant compost; AD_SW = Anaerobic digested solid, waste; MC = Mushroom compost; SOM = soil organic matter; Av. K = available K; TN = total N; Rates = treatment applications rates (10 t ha^{-1} and 30 t ha^{-1}); T x R = Treatment xApplication rate-interaction MBc= Microbial biomass C, BD = bulk density. Within each column values followed by a different letter denote statistical differences ($p \leq 0.05$) following Two-way ANOVA and post-hoc Fisher LSD analysis. NS = not significant; * = significant at ($P<0.05$).

characteristics are shown in Table 1. The soil is alkaline with a pH of 8.2 and has low levels of TON, Olsen-P and Av. K, TOC and MBc.

Soil response-changes in chemical SQIs

pH

Fourteen weeks after the amendments were added to the soil, no significant difference ($p < 0.05$) in the soil pH was observed between the amended treatments and the un-amended control except for the PAS treatment which had a significantly higher ($p < 0.05$) pH as compared with all other treatments (Table 3). Similarly, treatment application rates were not associated with significant difference ($p < 0.05$) in the soil pH. There was a significant interaction effect ($p < 0.05$) between amendment type and application rate on soil pH, because the soil pH is associated with the PAS treatment. The non-significant difference in the pH observed for the treatments except the PAS treatment may be due to the buffering capacity of the soil which resisted change in the soil pH. Bedada et al. (2014) found no significant difference in the soil pH with the application of compost manure. However, Arthur et al. (2011) reported a significantly higher pH of 0.5 pH unit with the long term application of 30 m^3 ha^{-1} of composts as compared with the un-amended acid soil. The long term compost application in addition to the high compost application rates and acidic soil (pH of 5.5) may account for the observed significant increase in soil pH reported by Arthur et al. (2011).

Soil organic matter (SOM) and total organic carbon (TOC)

Across both application rates, PM, PAS, AD_SW and MC treatments had significantly ($p < 0.05$) higher SOM than the Control treatment (Table 3). The PM treatment, across both application rates, recorded the highest (3.74%); although that was not significantly higher ($p < 0.05$) as compared with the AD_SW and MC treatments. The PM, PAS, AD_SW and MC treatments, across application rates, had 47.3, 38.8, 46 and 42% higher ($p < 0.05$) SOM as compared with the Control treatment respectively. The significantly higher SOM values recorded for the organic amendment treatments were due to the high organic matter levels associated with the amendments applied (Tables 1 and 2). This result is similar to the findings of Hati et al. (2006) who reported 41% increase in organic carbon content after three years application of 10 t ha^{-1} farmyard manure. Compared with an untreated plot, Guo et al. (2016) reported that the SOM in cattle manure compost fertilized plots increased significantly ($p < 0.05$) by more than 28% at 0-20 cm soil depth.

Furthermore, across both application rates, the organic amendments significantly increased ($p < 0.05$) soil TOC. The Control treatment recorded a significantly lower ($p < 0.05$) TOC content as compared with all amended treatments. The result indicated that TOC content was in the order: MC = AD_SW > PM = PAS > Control (Table 3).

The high TOC associated with these amended treatments can be attributed to the high OM content associated with the organic amendments (Table 2). Hati et al. (2007) reported similar findings following long time (28 years) application of farm yard manure at 15 Mg ha-1, with or without inorganic fertilizer. Lal (2015) suggested that restoring the soil organic carbon (SOC) pool to a threshold level of about 11 to 15 g kg−1 (1.1-1.5% by weight) within the root zone was critical to reducing soil degradation and protecting the environment from potential degradation risks. Guo et al. (2016) found that the 5-year application of cattle manure compost resulted in a 28% increase in TOC as compared with the control. Studies have reported higher TOC with organic fertilizer application as compared with the un- amended control treatment (Hati et al., 2007; Ding et al., 2012; Guo

Table 4. Correlation between selected SQIs.

	MBc	TN	TOC	C:N	Olsen-P	AvailableK	NH_4-N	TON
SOM	0.78*	0.86*	0.95*	0.78*	0.80*	0.67*	0.43*	0.57*
MBc		0.73*	0.73*	0.57*	0.77*	0.62*	0.23^{ns}	0.63*
TN			0.85*	0.56*	0.86*	0.54*	0.38*	0.71*
TOC				0.85*	0.70*	0.77*	0.36*	0.51*
C:N					0.45*	0.69*	0.23^{ns}	0.24^{ns}
Olsen-P						0.46*	0.42*	0.79*
AvailableK							0.19^{ns}	0.40*
NH_4-N								0.04^{ns}

* = significant ($p < 0.05$); ns = No significant difference; MBc = Microbial biomass C; TN = Total nitrogen, TOC = Total organic carbon, C:N= Carbon to nitrogen ratio, NH_4-N = Ammonium-N, TON = Total oxides of nitrogen, SOM = Soil organic matter.

et al., 2016). Furthermore, the results indicated that treatment application rates significantly affected the TOC due to a greater supply of carbon by the organic amendments at higher application rates. This is evident by the significantly strong and positive ($p < 0.05$) correlation (r = 0.95) between TOC and SOM (Table 4). Our result clearly shows that organic amendment application has positive impacts on soil organic matter and soil organic carbon.

Olsen-P

Similarly, the organic amended treatments showed significantly higher ($p < 0.05$) soil Olsen-P as compared to the Control treatment across both treatment type and application rate (Table 3). The PM treatment recorded the highest soil Olsen-P value (120.6 mg kg^{-1}) which was significantly higher than all other treatments. Olsen-P values were subsequently in the order: PAS > AD_SW > MC > PAS > Control. The high Olsen-P associated with the PM treatment is largely due to the significantly higher Olsen-P in the PM amendment (Table 2). These findings corroborate those of Bedada et al. (2014) and Unagwu (2014) who reported significantly higher soil Olsen-P values following organic treatments application. The present result demonstrates the potentials of organic amendments in improving the Olsen-P content of a degraded soil.

Available-K

The organic amended treatments, across both application rates, resulted in significantly higher Available-K as compared with the Control treatment. The AD_SW treatment recorded the highest (475 mg kg^{-1}) Available-K value as compared with the Control treatment and all other treatments (Table 3). No doubt, the high residual Available-K observed for the organic amended treatments was due to the high level of Available-K associated with the organic amendments as compared with the baseline soil values (Table 1). In addition, since soil organic matter is associated with exchange sites to bind available cations in the soil exchange complex, it is likely that the high Available-K recorded for the organic amended treatments is due to the high organic matter associated with the organic treatments. The significantly strong positive ($p < 0.05$) correlation between SOM and Available-K (r = 0.67; $p < 0.05$) thus confirmed that the organic matter contributed to the observed higher Available-K associated with the amended treatments (Table 4).

Soil total nitrogen (TN) content

Compared with the un-amended control treatment, the organic amended treatments across both application rates had significantly higher ($p < 0.05$) total nitrogen (TN). The PM treatment recorded the highest TN content (~ 1600 mg kg^{-1}; $p < 0.05$) as compared with all other treatments as well the as un-amended treatment. Soil TN content in the control treatment was more than 60% lower as compared with all the organic amended treatments. The soil TN was in the order: PM > AD_SW = MC = PAS > Control. The significantly higher TN recorded for the amended treatments were linked to the higher SOM associated with the applied organic amendments. This is evident by a significant and positive correlation (r = 0.86; $p < 0.05$) between the SOM and the TN content (Table 4). This relationship explains why the organic amended treatments were associated with higher soil TN than the Control treatment. Furthermore, treatment application rates had a significant effect on the soil TN. This was no doubt due to the higher supply of N with increasing rates of organic amendment applied. This result is similar to the findings of Guo et al. (2016) who reported significant increases in soil TN with cattle manure compost application.

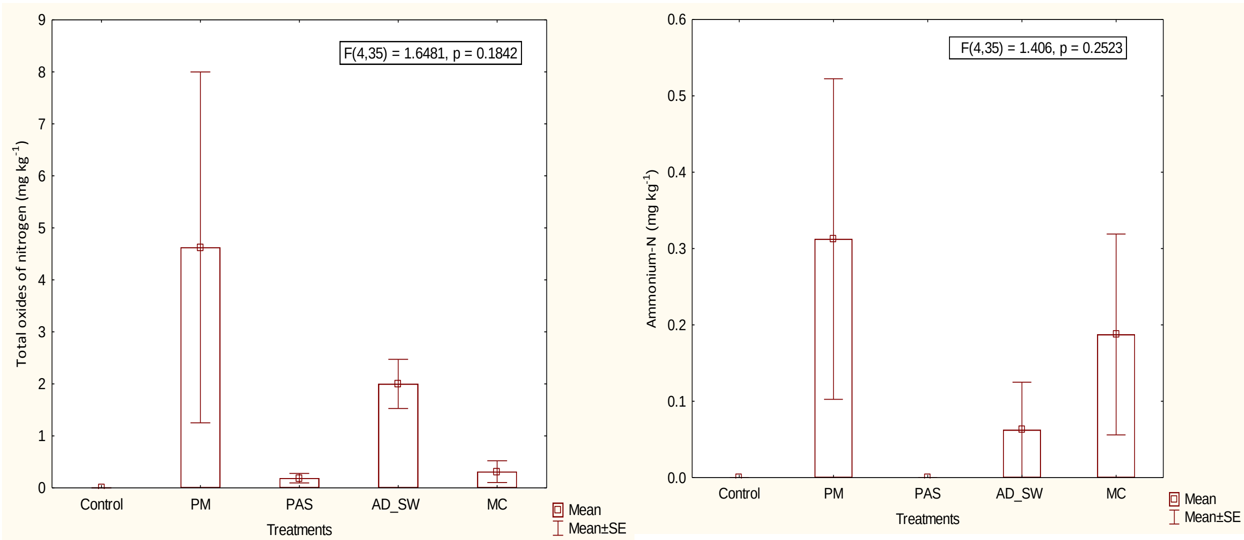

Figure 1. Effect of treatments on Total oxides of nitrogen and Ammonium-N across treatment application rates.

Total oxides of nitrogen (TON) and Ammonium-N (NH_4-N)

Across both treatment application rates, no significant difference in soil TON values was observed between treatments (Figure 1). Since N is a critical and important nutrient for maize growth, it is likely that the post-harvest non-significant difference in TON between the organic amended treatments and the control was due to plant N uptake. Further, a similar trend was observed for ammonium-N (NH_4-N). The PM, AD_SW, PAS and MC treatments across treatment were not significantly different as compared with the Control treatment. The non-significant difference in the NH_4-N between treatments and control could be due to either direct uptake by the maize plant or due to indirect uptake of NH_4-N because of microbial conversion of NH_4-N to nitrite and nitrate. More so, the wide variability in the TON and NH_4-N mean values could account for the non-significance observed between the amended treatments.

Soil response-changes in biological SQI

Microbial biomass C (MBc)

The microbial biomass carbon (MBc) in the organic amended treatments was significantly higher ($p < 0.05$) than that observed in the Control treatment ($p < 0.05$). This could be attributed to the significantly higher OM associated with the applied organic amendments which enriched the soil microbes with organic C (the energy source of soil microbes). The SOC pool is a critical component of soil quality (Lal, 2015). Microbial biomass (population) is affected by several factors such as temperature, nutrient source, water content and the type of organic matter applied. Hence, the type of OM applied could have a significant effect on the MBc depending on C-availability. Labile OM is a readily available energy source which is more easily degraded by the soil microbes than the less labile or non-labile (recalcitrant) OM. The supply of readily metabolizable C from organic amendments was suggested to be the most influential factor contributing to increases in biomass-C. This was because the soil microbial biomass responds rapidly to readily available C (Tejada et al., 2006). Also, the significantly higher MBc observed for the PM and AD_SW treatments as compared with the PAS and MC treatments could suggest the comparative availability of metabolizable C. Furthermore, the significant ($p < 0.05$) positive correlation ($r = 0.73$) observed between TOC and MBc confirmed that the higher MBc (Table 4) recorded for the organic amended treatments was attributable to their higher TOC which provided easily degradable carbon that stimulated the autochthonous microbial activities (Tejada et al. 2006). A similar result was reported by Tejada et al. (2008) who observed a progressive increase in soil MBc with higher application of organic matter.

Soil response-changes in soil physical SQIs

Bulk density

Across both application rates, the bulk density recorded for the organic amended treatments were significantly lower ($p < 0.05$) as compared with the Control treatment

(Table 3). The AD_SW treatment had lowest soil bulk density (1.26 g cm-3) followed by the PM treatment (1.36 g cm-3) though both treatments were not significantly different. Organic materials are associated with low bulk density (0.8 g cm-3). Hence mixing organic materials (less dense materials) with soil (a denser material) reduced the soil bulk density. Guo et al. (2016) reported that soil bulk density was significantly and inversely related to rates of cattle manure compost applied. The significantly lower bulk density associated with the organic amended treatments could partly be due to the effect of the plant roots. Hati et al. (2006) and Guo et al. (2016) found significant reductions in the bulk density with NPK application which they attributed to increased root growth.

In addition, treatment application rates had significant effects on the soil bulk density. This could suggest that the quantity of organic amendment applied to soil had significant effects on the soil bulk density probably due to the effect of higher organic matter content. Celik et al. (2004) reported a similar result. They observed that the soil bulk density decreased with increasing application of compost and manure treatments due to increased soil organic matter concentrations. Also, a significantly lower soil bulk density following application of cattle compost and manure at 25 t ha-1 in a long term study was reported (Celik et al., 2010). However, in the present study, the bulk density did not strongly correlate with SOM (r = 0.24). This could probably be due to the short duration of the study. D'Hose et al. (2014) had a similar result with application of farm compost. They found a weak correlation between bulk density and SOC (R2 = 0.25) which they attributed to the limited range of SOCs (1.07-1.25%) in their experiment.

Conclusion

The study observes the effectiveness of the OAs in improving soil physical, chemical and biological SQIs. The results obtained indicate that the OA types have varied significant effects on the SQIs. This suggests that the type of OAs applied plays a crucial role in improving the soil properties of a degraded soil. The application of PM, PAS, AD_SW and MC at 30 t ha^{-1} best improved the soil physical, chemical and biological SQIs, which are crucial to increasing crop yield production. This study advocates for further field study to evaluate the potency of these OAs to improve the SQIs of a degraded soil.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

ACKNOWLEDGEMENT

The authors are grateful to the Tertiary Education Trust fund (TETfund) through the support of University of Nigeria, Nsukka for funding this research.

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