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Effects of Different Organic Amendment Sources on the Physico Chemical Properties of A Nutrient Depleted Vertisol

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ABSTRACT

The decline in soil organic matter, nutrient depletion, and loss of soil fertility due to soil degradation contribute to low agricultural productivity. Organic amendments (OAs) have the potentials to reverse soil degradation processes by improving the soil's physical and chemical properties and consequently improve crop growth and yield performance. At Cranfield University, United Kingdom, a greenhouse study investigated the effects of Mushroom Compost, Anaerobic Digestate Waste, and Poultry Manure amendments applied at 10 t ha^{-1} and 30 t ha^{-1} equivalent rates on the physical and chemical properties of degraded soil. The treatments were laid out in the greenhouse in a completely randomized design replicated four times. The results showed that all the OA treatments significantly increased the soil water holding capacity, total porosity, and significantly reduced bulk density when compared with the un-amended control treatment. Further, the OA treatments showed significant increases in the soil Total-P, Olsen-P, Total-N, total oxides of N, ammonium-N, Available-K, and Available-Mg, relative to the control treatment. The results demonstrate the effectiveness of these OAs in improving soils' physical and chemical properties, and so enhancing soil health and overall ecosystem functioning. The study demonstrated that these OAs improve the physicochemical properties of degraded soil.

1.0. Introduction

Organic matter decline in most soils is a significant contributor to soil degradation processes, particularly in European semi-arid Mediterranean regions (Diacono and Montemurro, 2010). Similarly, soils of the humid tropical regions are low in fertility status due to the inherently low soil organic matter and available nutrient content associated with such soils. The soil fertility and productivity of most degraded soils are further reduced due to inadequate organic amendment and or chemical fertilizer application by resource-poor farmers (Unagwu et al., 2019). Degraded soils are unproductive and cannot maintain sustainable crop production to achieve the much-desired food security. Thus, soil degradation remains a threat to achieving global food security.

Soil degradation not only impacts negatively on food production but also on the environment, due to the increasing pressure and demand on land to produce. Consequently, marginal soils are put under continuous cultivation leading to further soil degradation, particularly in Sub-Saharan

Africa. It is now clear that to achieve a sustainable food production, proper use of soil resources must be accompanied by considerable management of the biological, chemical, and physical properties of soil. Soil fertility management practices are not only a key component of sustainable crop production, but they are also decisive factors that enhance soil productivity and crop quality (Juma et al., 2018). When soils are appropriately managed, they stimulate microbial soil life and enhance soil decomposition processes, which in turn reduce the incidence of soil and seed-borne diseases such as bacterial wilt (Juma et al., 2018).

Often, causes of low crop yields are due to poor agronomic (Dukuh et al., 2016) and soil management practices. Low soil nutrient status, nutrient depletion via crop removal, mineralization of soil organic matter, and continuous land cultivation without adequate nutrient replenishment contribute to low crop yield. Continuous cropping and inadequate replacement of nutrients removed via harvested crop or plant materials or lost through erosion and leaching, degrade soil physical, chemical, and biological properties (Komatsuzaki and Ohta, 2007). Organic wastes, e.g., animal manures, by-products of composted organic materials, and residues, can be used as soil amendments to improve the fertility status of degraded soils. This is because organic wastes are rich sources of nutrients for crop production and are means of enhancing the overall soil quality (Davies and Lennartsson, 2005).

In recent years, the use of organic manures as fertilizers is on the increase due to environmental severe pollution issues associated with chemical fertilizer application (Ofoefule et al., 2014). Manure application can modify soil physical and chemical properties and releases nutrients for a longer period (Ofoefule et al., 2014; Unagwu 2014). The application of organic manure increases soil resilience and productivity due to improvement in the soil's physical, chemical, and biological properties (Biau *et al.*, 2012; Unagwu, 2019). Studies on the use of organic amendments with or without inorganic fertilizer to improve soil properties (Nwite and Okolo 2016; Unagwu et al., 2013) have shown that soil management practices that improve SOM can sustain higher crop productivity (Bandyopadhyay et al., 2010; Unagwu, 2019) and have significant impacts on soil physical, chemical, biological and biochemical properties (Mbah et al., 2017).

Considering the predicted rise in global population, soil management schemes approaches, or practices that improve the functioning and productive capacity of degraded soils, are inherently vital to improving crop yields, meeting the current food demands, ensuring future global food security. Hence present study critically evaluated the effectiveness of OA application in improving the physicochemical properties of a nutrient-depleted vertisol.

2.0. Materials and Methods

2.1. Experimental setup

A glasshouse experiment was set up following a completely randomized design at Cranfield University, United Kingdom. The soil used for the study was a sandy loam that was collected from a privately-owned farm at Cranfield. The test soil had a pH of 8.2 (Table 1). The soil samples were air-dried and sieved to <2.0 mm and were thoroughly mixed to obtain a homogenous representative soil sample. The treatments used for the study were: PM_{10} (10 t ha^{-1} Poultry manure), PM_{30} (30 t ha^{-1} Poultry manure), AD_{10} (10 t ha^{-1} Anaerobic digested waste), AD_{30} (30 t ha^{-1} Anaerobic digested waste), MC_{10} (10 t ha^{-1} Mushroom compost), and MC_{30} (30 t ha^{-1} Mushroom compost). Two weeks after OA application, maize seeds were sown at 3 per pot but were later thinned down to one per pot.

2.2. Soil sampling and analyses

Soil sample (400 g) was collected before OA application and 16 weeks after OAs application (after plant harvest) for physical and chemical soil analyses. Soil bulk density was determined using an undisturbed soil core (5.0cm deep x 5.0cm internal diameter) following British Standard (BS) 7755 Section 5.0:1999 (Blake, 1965). Subsequently, total soil porosity was derived from the BD and calculated thus:

Total porosity = $$\left(1-\frac{\rho_b}{\rho_s}\right) \times 100$$

ρ_b is the bulk density, and ρ_s is the particle density of soil solids (2.65 Mg m^{-3}) (Hati *et al.,* 2007). Undisturbed BD cores, where used in determining soil water retention characteristics. Suction at 5 kPa (water content at field capacity) was used to determine the water-holding characteristics. The core samples were placed on a sand tension table set up to allow water suctions between 1 kPa to 10 kPa. Soil pH in water was determined on the soil to deionized water suspension ratio of 1:5 (w/w) using a Mettler Toledo MA 235 pH z analyzer. Soil organic matter (SOM) was determined following a loss on ignition using a Carbolite AAFF 1100 Muffle Furnace at 450°C temperature. Total-N (TN) was determined using the Vario EL III CHNOS Elemental Analyser system, Germany. Olsen-P was determined in a sodium hydrogen carbonate solution Total-P (TP) was determined via microwave acid digest. Soil available-Mg and available-K were determined using a Perkin Elmer Atomic Absorption Spectrometer (AAS) Analyst™ 800. Ammonium-N (NH_4-N) and total oxides of nitrogen (TON) were determined by the potassium chloride extract method.

2.3. Statistical Analysis

The data obtained were subjected to one-way Analysis of Variance (ANOVA) using GenStat Discovery software Edition 4. The differences between the treatment means were compared according to the Least Significant Differences (LSD) test method at 5% confidence level.

3.0 Results and Discussion

The baseline properties of the test soil are shown in Table 1. The test soil had low soil organic matter content (0.23%) and low levels of soil nutrients (Table 1). The chemical characteristics of OAs applied varied significantly in their chemical composition due to the inherent differences in the feedstocks of the OAs applied (Table 2).

Table 1. Chemical characteristics of the test soil

Parameters	Units	Values
pH	-	8.2±0.08
TON	mg kg^{-1}	0.45±0.01
NH_4-N	mg kg^{-1}	4.17±0.02
Olsen P	mg kg^{-1}	33.0±0.35
Total phosphorous	g kg^{-1}	1.64±0.05
Soil organic matter	%	0.23±0.01
Available potassium	mg kg^{-1}	87.3±0.50
Available magnesium	g kg^{-1}	0.18±0.01
Total nitrogen	g kg^{-1}	22.7±0.18
Bulk density	g cm^{-3}	1.60±0.02
Porosity	%	38.0±0.21
AWC	g g^{-1}	10.8±0.18
WC_{FC}	g g^{-1}	18.4±0.20

TON = Total oxides of nitrogen, NH_4-N = Ammonium-N, AWC = available water content, WC_{FC} = Water content at field capacity.

Table 2. Chemical characteristics of the Amendments

Parameters	Units	PM	MC	AD	LSD
pH	-	8.0	7.3	10.3	1.12
TON	mg kg^{-1}	0.18	96.2	0.20	0.23
NH_4-N	mg kg^{-1}	0.90	0.12	0.70	0.21
Olsen P	mg kg^{-1}	2.42	0.38	1.20	1.06
Total phosphorous	g kg^{-1}	5.40	2.44	4.42	1.29
Soil organic matter	%	84.0	62.0	86.0	1.50
Available potassium	mg kg^{-1}	9.14	13.7	15.0	1.34
Available magnesium	g kg^{-1}	0.52	1.55	0.13	0.06
Total nitrogen	g kg^{-1}	31.0	19.0	20.0	1.08

TON = Total oxides of nitrogen, NH_4-N = Ammonium-N, PM = Poultry manure, MC = Mushroom compost, AD = Anaerobic digestate waste. LSD = Least significant difference

3.1. Effects of OA application on the physical soil properties

Varied effects on the physical properties of the test soil following OAs application were observed (Table 3). Across the treatments, the soil BD associated with the OA treatments was significantly ($p < 0.05$) lower compared with the Control treatment. Also, a higher OA application rate significantly ($p < 0.05$) reduced soil BD compared with lower OA rates. Overall, the OA treatments reduced the BD by over 11% relative to the Control treatment. The soil total porosity (TP) recorded for the OA treatments was significantly ($p < 0.05$) higher when compared with the Control treatment. The MC_{30} treatment had the highest ($p < 0.05$) TP (51%) compared with all other treatments. Expect for PM_{10} and PM_{30} treatments, which did not vary significantly in their TP, increasing OA application rates had a significant increase in the TP (Table 3).

Table 3. Treatment effects on the soil physical properties 16 weeks after application

Treatments	BD (g cm^{-3})	Total Porosity (%)	AWC (g g^{-1})	WC_{FC} (g g^{-1})
Control	1.65	29.9	11.6	20.0
PM_{10}	1.45	45.1	14.6	21.3
PM_{30}	1.38	47.6	23.6	29.0
AD_{10}	1.37	44.9	16.7	23.8
AD_{30}	1.25	48.1	24.2	35.4
MC_{10}	1.47	39.0	12.1	22.0
MC_{30}	1.30	51.0	15.2	24.7
LSD	**0.04**	**2.04**	**2.01**	**2.15**

PM_{10} = 10 t ha^{-1} Poultry manure, PM_{30} = 30 t ha^{-1} Poultry manure, AD_{10} = 10 t ha^{-1} Anaerobic digested waste, AD_{30} = 30 t ha^{-1} Anaerobic digested waste, MC_{10} = 10 t ha^{-1} Mushroom compost; MC_{30} = 30 t ha^{-1} Mushroom compost, BD = bulk density, AWC = available water content, WC_{FC} = Water content at field capacity.

The application of OAs significantly increased the soil available water content (AWC) relative to the Control treatment except for MC_{10} treatment (Table 3). The OA treatment increased the AWC by 4.3-109%. AD_{30} treatment recorded a significantly ($p < 0.05$) higher (24.2 g g^{-1}) AWC than all other treatments, although it was not statistically different from PM_{30} (23.6 g g^{-1}). Higher rates of OA treatments had higher ($p < 0.05$) AWC when compared with lower OA treatment rates (Table 3). PM_{30}, AD_{10}, AD_{30} and MC_{30} treatments, except PM_{10} and MC_{10} treatments, had higher ($p < 0.05$) WC_{FC} than the Control treatment (Table 3). Across all other OA treatments, AD_{30} treatment recorded a significantly ($p < 0.05$) higher WC_{FC}. Increasing OA application rates from 10 t ha^{-1} to 30 t ha^{-1} significantly increased WC_{FC} by 24-77%.

The significant effect on the soil physical properties following OA treatment application is attributed to the significantly higher OM content associated with the OAs, which increased the SOM. The results suggest that an increase in the SOM content lowers the soil BD, which in turn increases the soil pore space (porosity) by increasing soil pore size distribution and consequently increased the soil water retention. Zhou et al. (2016) reported similar findings. In another study, Hati et al. (2007) reported increases in WC_{FC} (0.033 MPa) following the application of NPK + FYM (farmyard manure). The authors attributed the increases in WC_{FC} to the increased number of soil pores, which increased soil water retention. Nwite and Okolo (2016) found higher water retention, available water capacity, and hydraulic conductivity in plots amended with burnt rice mill wastes compared to the control.

3.2. Effects of treatment application on the chemical soil properties

Table 4 shows significant varied effects on the soil chemical properties following the OA treatment application. All the OA treatments had significantly ($p < 0.05$) higher TON, NH_4-N, as compared with the Control treatment. PM_{30} recorded the highest (7.38 mg kg^{-1}) TON while the mm gave the Control least (7.38 mg kg^{-1}) TON. Increasing OA treatment application significantly increased soil TON by over 200% relative to the control. Similarly, for NH_4-N, higher rates of OA treatment application gave higher ($p < 0.05$) NH_4-N. Across the other soil nutrients: Olsen-P, Available K, Available Mg, Total N, and Total P measured, the OA treatments consistently recorded significantly ($p < 0.05$) higher values compared with the control treatment (Table 4). The same trend was observed for SOM. The OA treatments increased the SOM by 32.6-121% relative to the Control treatment.

The significantly ($p < 0.05$) higher soil nutrients: TON, NH_4-N, Olsen-P, available K and Mg, Total N and P recorded for the OA treatments relative to the Control treatment is attributed to the inherently high nutrients associated with the OAs applied (Table 2). The high OM content of the OAs applied (Table 2) contributed to higher SOM recorded for the OA treatments relative to the Control treatment (Table 4). AD_{30} treatment had the highest ($p < 0.05$) SOM content relative to all other treatments. OAs applied at 30 t ha^{-1} significantly ($p < 0.05$) increased the soil Olsen-P content by 32-72% compared with OA applied at 10 t ha^{-1}. The present result agrees with other findings. For instance, Andrade et al. (2018) found that the concentration of P, K, Ca, and Mg increased in the soil after the industrial landfill sludge amendment application. According to the authors, the amendments were efficient in increasing the pH and to increase biomass production. Moharana et al. (2012) reported significantly higher Olsen -P when poultry manure was applied. The significantly high Olsen-P associated with the OA treatments suggests that these OAs can serve as an alternative source of P for crop production. Zhen et al. (2014) obtained higher available N following cattle manure treatment applications (3.75 kg m^{-2} equivalent to 37.5 t ha^{-1}) relative to the control treatment. The significantly higher SOM in OA treatments compared with the control treatment is linked to the high OM associated with the OAs applied (Table 4). The present study further corroborates the findings of Moharana et al. (2012) Bedada et al. (2014) and Unagwu (2019), who all reported significant increases in SOM following OA additions.

Table 4. Treatment effects on the soil chemical properties after OAs application

Treatments	TON	NH_4-N	Olsen-P	Available K	Available Mg	Total N	Total P	SOM
	(mg kg^{-1})							(%)
Control	0.10	0.05	28.8	86	193	160	1710	0.19
PM_{10}	1.54	0.78	99.0	550	340	520	2100	0.30
PM_{30}	7.38	1.57	258	1080	440	1340	3030	0.37
AD_{10}	1.89	0.58	72.8	650	290	340	1910	0.31
AD_{30}	5.78	1.45	178	3101	345	1020	2060	0.42
MC_{10}	1.37	0.48	47.4	590	197	480	1810	0.25
MC_{30}	6.67	1.77	69.5	2040	250	1130	1920	0.35
LSD	0.18	0.01	41	82.1	80	190	41	0.03

PM = Poultry manure, AD = Anaerobic digested waste, MC =Mushroom**.** TON = Total oxides of nitrogen, NH_4-N = Ammonium-N, SOM = Soil organic matter.

4.0. Conclusion

Application of OAs at different rates significantly increased the soil nutrients, SOM, total porosity, AWC, and WC_{FC} and significantly lowered the soil BD relative to the Control treatment. However, marked effects on the soil physicochemical properties were more at higher OAs application rates. This result demonstrates the potentials of these OAs in improving the physical and chemical properties of degraded soil. Although it is unlikely that the performance of the OAs achieved here (under greenhouse trial) will prove the same under field condition, therefore a long-term field study is required to validate further the effects of different OA treatments in improving the physicochemical properties of degraded soils. The result of such further studies will be useful in making appropriate OA application rates for sustainable agricultural productivity.

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