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IMPROVING THE HYDRAULIC AND MECHANICAL PROPERTIES OF A DEGRADED PALEUSTULT: POTENTIAL OF COMBINED APPLICATION OF POUTRY MANURE AND PORTLAND CEMENT

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ABSTRACT

Physical deterioration of soil poses threat to sustainable agricultural land use and there is the need for proactive management measures to address it. Despite research indicating the benefit of using cement to enhance soil properties, there is a dearth of scientific information on its co-application with organic manure. Therefore, influence of sole and combined applications of poultry manure (PM) and Portland cement (PC) on soil aggregation, hydraulic conductivity (K) and strength was investigated. The treatments consisted of factorial combinations of PM and PC applications at four levels (0, 2.5, 5 and 10 g kg^{-1} soil) in three replicates to a Typic Paleusult in a screen house. The aggregate stability, K (6, 2 and 0.5 cm suctions) and strength were determined using standard methods. Poultry manure applied at the rate of 5 g kg^{-1} increased soil macro-aggregate stability (combined total of 40.17%) and the near saturated hydraulic conductivity (0.83 cm day^{-1}) of the soil while PC significantly increased both soil properties (combined total of 38.71% and 0.61 cm day^{-1}, respectively) at 2.5 g kg^{-1} rate. Soil strength peaked when PM (0.57 kPa) and PC (0.60 kPa) were applied at 10 and 5 g kg^{-1}, respectively. The combination of PC and PM significantly increased macro-aggregate stability and soil strength although the PM limited the potential of the PC to strengthen the soil. The treatments showed potential in improving the soil aggregate stability, near saturated hydraulic conductivity and strength of the degraded soil with little to moderate agronomic limitations.

Keywords: Poultry waste, Portland cement, soil aggregation, soil properties, Typic Paleustult.

INTRODUCTION

Considerable work has been carried out particularly in the temperate region to explore the use of organic wastes for improving soil physical and chemical conditions, enhancing crop productivity and addressing associated environmental issues. Some of the investigations clearly demonstrated the effects of different amendments on soil properties including soil structure, soil strength, water infiltration, water-holding capacity, phosphorus, potassium, calcium and nitrogen reserve (Salter and Haworth 1961; Salter and Williams 1963; Unger and Stewart 1974; Weil and Krontje 1979; Meek *et al.* 1982; Campbell *et al.* 1986; Harmel *et al.* 1997; Siddique and Robinson 2003; Idowu *et al.* 2008; Gottschall *et al.* 2009; Agomoh *et al.* 2018; Drozdz *et al.* 2020). Similary. Studies in tropical country like Nigeria have focused on the use of traditional soil amendments including organic wastes such as poultry manure, farmyard manure, cowdung manure and more recently, biochar to improve soil properties (Agbim 1981; Olayinka and Adebayo 1989; Obi and Ebo 1994; Olayinka 1996; Amujoyegbe *et al.* 2007; Are *et al.* 2017; Olakayode *et al.* 2019).

The significance of organic amendments on plant growth and the stablility of soil aggregates cannot be overemphasized in reducing soil erosion by water in humid regions and by wind in arid and semi-arid regions. Soil aggregate also plays significant role in the availability soil nutrients, including micronutrients such as zinc (Dhaliwal *et al.* 2019). Several studies have shown that the inclusion of cement and other cement-related supplementary binders improved soil mechanical properties in the context of engineering applications such as civil construction work (Consoli *et al.* 2016; Onyelowe 2018; Rimal *et al.* 2019). Portland cement is a calcined mixture of calcium, silicon and aluminum oxides (Stocker 1963; Vysvaril and Bayer 2016). It is composed predominately of four compounds, i.e. calcium disilicate, tricalcium silicate, tricalcium aluminates, and tetra calcium alumino ferrite. Portland cement acts as a binding agent when it hydrates and hardens. Hence, it could be expected to bind small soil particle into larger ones when favourable rations of cement, water and soil are mixed and allowed to react under desirable curing conditions (Ahuja and Swartzendruber, 1972). However, within an agronomic context, soil stabilization using the same level of Portland cement additions to soils as done for engineering purposes may not be desirable, but a mild application could enhance soil physical and mechanical properties of agronomic interests. For instance, in China, application of PC for soil stabilization at a rate as high as 30% has been investigated for its impact on soil strength (Wei *et al.* 2014; Yu *et al.* 2014) but a rate of 15% or less reduced soil hydraulic conductivity in the region (Terashi and Tanaka 1983; Deng *et al.* 2015). Though the effects could be beneficial for some engineering functions of soil, but the creation of hydraulic barriers by the addition of PC and other cementitious materials can limit water availability, ultimately affecting good performance and survival of crops. Therefore, an investigation on the different rates of PC application, its capacity to enhance soil physical and mechanical properties (Baghini *et al.* 2018), and its integration with traditional organic manure, which have been reported to enhance soil agronomic quality (Oyedele *et al.* 1999), seems important.

Several studies have emphasized the importance of cement in enhancing soil physical and mechanical properties. However, there is paucity of information on the effects of Portland cement and its combination with organic amendment on soil properties for agronomic applications. This study, therefore, investigated the effects of Portland cement and poultry manure, and their possible interactions when co-applied on soil physical properties within agronomic context.

MATERIALS AND METHODS

This study was conducted in the screen house of the Faculty of Agriculture, Obafemi Awolowo University. The soil used for this study was classified at the series level as Apomu series (Okusami and Oyediran, 1985) and as Typic Paleusult according to the USDA system (Soil Survey Staff, 2022). Soil samples used were collected from a field under continuous cultivation with maize for 15 years without organic amendment (Table 1). Bulk soil was collected from surface soil to a depth of 15 cm, air dried and sieved with a 2 mm mesh sieve. The study was a 2 x 4 factorial experiment with a randomized complete block design (RCBD). The RCBD was deployed to account for the micro variability in temperature within the screenhouse. The factors are poultry manure and Portland cement each at four levels (0, 2, 5 and 10 g kg^{-1}). Each treatment combination was replicated three times making 48 experimental units. One kilogram of the sieved soil was used per experimental unit.

The antecedent soil properties determined were soil texture, bulk density, pH and organic matter (Table 1). Particle size analysis was carried out for soil textural classification using a modified Bouyoucos (1962) hydrometer method as described by (Gee and Or, 2002). Soil bulk density was determined using a core sampler technique described by Blake and Hartge (1986) and the pH determination followed Thomas (1996). The soil organic carbon content, from which soil organic matter was estimated using Van Bemmelen factor, was also determined by the Walkley-Black procedure (Walkley and Black 1947; Allison 1965).

The soil was proportionately mixed with poultry manure and Portland cement to achieve the desired mix per treatment. The soil was poured into 2-Litre plastic buckets that were perforated at the base and sealed with cotton wool to allow water drainage. They were sprinkled with distilled water and soil moisture content maintained at field capacity for the 60 days duration of the study. Soil samples were collected at the end of the 60 days and analyzed for their physical properties. Soil hydraulic conductivity was measured at matric suctions of -0.5 cm, -2 cm and -6 cm water, with the Decagon mini tension infiltrometer, 509-332-2756, Decagon Devices, Inc. USA. Aggregate stability was determined using the modified Yoder technique (Pojasok and Kay, 1990), an approach that generally adopted as an index of aggregate stability against disruptive force acting on wet or moist soil (Kemper and Rosenau 1986; Akinde *et al.* 2020). Soil strength was determined at the field capacity with a hand-held ELE cone penetrometer, ELE International, United Kingdom.

Statistical Analysis

Data collected from the study were tested for normality of distribution before they were subjected to analyses of variance using the generalized linear model procedure testing for significance of treatments and their interactions. Significant means were separated and compared with the use of Duncan multiple variables technique. Pearson correlation was run to check for possible association among the soil properties. Three-D surface plots technique was used to demonstrate the interactions of different rates of poultry manure and cement on soil properties.

RESULTS

Effects of poultry manure on soil physical properties

Table 2 shows that cone index did not differ from the control at lower rates (i.e. 2.5 – 5 g/kg) of poultry manure (PM) application. However, only the PM application rate of 10 g kg^{-1} showed a significantly ($P<0.05$) higher influence on soil strength than the control treatment (Table 2).

The water stable aggregates greater than 250 μm (WSA>250) was significantly improved by the applied PM treatments. Macro-aggregates with a size greater than 500 μm (WSA>500), for instance, exhibited a significant increase only at a PM rate of 2.5 g kg^{-1}, but showed a significant decrease with higher application of PM. Within the WSA range of 250 – 500 μm, the PM rate at 10 g kg^{-1} showed the highest level of significance compared to all other rates, except for the PM rate at 5 g kg^{-1}. The control soils had the least WSA value. There was, however, no significant difference in the percent water stable micro-aggregates lower than 250 μm (WSA <250) as the rate of PM application increased. Interestingly, the aggregates when considered,

Table 1: Properties of the soil used.

Soil properties	Values
Sand (g/kg)	793.2
Silt (g/kg)	89.2
Clay (g/kg)	117.6
Textural class	Loamy sand
Bulk density (Mg/ m^3)	1.76
pH (0.01M $CaCl_2$)	5.3
Organic matter (g/kg)	0.5

Table 2: Effects of different rates of poultry manure application on soil strength, water stable aggregate and hydraulic conductivity

Rate of Application (g kg^{-1})	Soil shear strength (kPa)	% WSA > 500 μm	% WSA 250 - 500 μm	% WSA < 250 μm	Soil hydraulic conductivity at different matric suctions (cm day^{-1}) -6cm	-2 cm	-0.5 cm
0	0.50b	10.89ab	26.98b	34.87a	0.014c	0.163ab	0.166c
2.5	0.50b	12.91a	27.67b	34.80a	0.395ab	0.380ab	0.720ab
5.0	0.50b	10.56ab	29.61ab	34.61a	0.508a	0.424a	0.831a
10.0	0.57a	9.49b	30.61a	35.28a	0.130bc	0.072b	0.399abc

cumulatively, ranged between 74.78 – 75.38% for amended soil at 2.5 g/kg and 10.0 g/kg PM rates while the control plot had cumulative aggregates that stood at 72.74%. Soil hydraulic conductivity at suctions of 6 cm (K_6), 2 cm (K_2) and 0.5 cm (K_5) are presented in Table 2. The soil K_6 initially increased with increased rate of PM application reaching a value of 0.5 cm day^{-1}, an order of magnitude higher than the control, at the application rate of 5 g kg^{-1} before declining at higher rates. Similarly, the highest values of K_2 and $K_{0.5}$ were observed in soils treated with PM at the rate of 5 g kg^{-1} soil. At a suction of 0.5 cm ($K_{0.5}$), the highest hydraulic conductivity value of 0.83 cm day^{-1} was recorded. In contrast, soil treated with 10 g kg^{-1} PM exhibited the least hydraulic conductivity.

Effects of Portland cement on soil physical properties

Response of soil physical properties to different rates of Portland cement (PC) application are presented in Table 3. The soil cone penetrometer index, a key measure of soil strength, initially increased with increasing rate of PC application, reaching its peak at the rate of 5 g kg^{-1}.

The WSA > 500 μm showed a significant increase in the absence of cement application reaching its peak at a PC application rate of 0 and 2.5 g kg^{-1}, before declining at higher application rates. The application of PC at 2.5 g kg^{-1} was sufficient to significantly improved WSA 250 -500 μm compared to the control, as further increment of PC did not differ significantly from this rate (2.5 g kg^{-1}).

Table 3: Effects of different rates of Portland cement application on soil strength, water stable aggregates and hydraulic conductivity

Rate of Application g kg^{-1}	Soil strength kPa	% WSA > 500 μm	% WSA 250 - 500 μm	% WSA < 250 μm	Soil hydraulic conductivity at different matric suctions (cm day^{-1})		
					-6cm	-2 cm	-0.5 cm
0	0.50bc	10.89a	26.98b	34.87a	0.014b	0.163ab	0.166b
2.5	0.43c	10.19a	28.52a	33.54a	0.186a	0.380a	0.609a
5.0	0.60a	9.37ab	29.19a	34.66a	0.097ab	0.255ab	0.498ab
10.0	0.50b	8.98b	27.77a	36.00a	0.068ab	0.040b	0.548ab

Table 4: Correlations among different soil properties in response to the application of poultry manure and Portland cement.

	Shear Strength	WSA500	WSA250	K_{6cm}	K_{2cm}	$K_{0.5cm}$
Shear Strength	1.00	-0.18	0.15	-0.27*	-0.25*	-0.28*
WSA500		1.00	-0.51**	-0.01	0.05	0.11
WSA250			1.00	0.14	0.15	0.09
K_{6cm}				1.00	0.51**	0.44**
K_{2cm}					1.00	0.52**
$K_{0.5cm}$						1.00

The application of different PC rates had no effect on WSA < 250 μm. Overall, the total soil water stable aggregates (WSA) ranged between 72.25 – 73.22%.

The soil hydraulic conductivities at different suctions were significantly influenced by the rates of PC treatment applied. Expectedly, the $K_{0.5}$ values were approximately two (2) times higher than the values at K_2 and four (4) times higher than the values of K_6, as this was nearing saturation where water movement is fastest. The highest $K_{0.5}$, K_2, and K_6 were recorded at the PC application rate of 2.5 g kg^{-1} with the soil hydraulic conductivity reaching its upper limit of 0.61 cm day^{-1} at $K_{0.5,}$ but dropping to the lowest level at 10 g kg^{-1} rate for K_6 and K_2 and under the control plot for $K_{0.5}$. There was negative correlation between soil strength and moisture as shown in Table 4. The least value was recorded when the soil was wettest ($K_{0.5}$).

The negative correlation between soil strength and hydraulic conductivity presented in Table 4 corroborates the popular theory that associated weaker soil strength to higher soil moisture content. At $K_{0.5}$ the soil was nearest to saturation and strength of the wettest soil thus dropped.

Interaction effects of combined application of poultry manure and Portland cement on soil

The combined effects of PM and PC at various proportions on soil strength and hydraulic conductivities are presented in Figs. 1 and Table 5. The highest ($P<0.05$) soil strength of 0.67 mPa was attained, in this study, under the maximum combination of applied PM and PC (10 g kg^{-1} each). The result also shows a slight enhancement of PM-induced soil strength with increased rate of PC application. Although not statistically significant ($P>0.05$), poultry manure applied at 5 g kg^{-1} with little or no PC application showed the potential to enhance all near saturation hydraulic conductivities considered. In addition the percent WSA>500 also showed an increasing trend starting from 5 g kg^{-1} PM and at 2.5 g kg^{-1} PC treated soil, with the increase driven by the increase in PM application rate (Fig. 2). Generally, the impact of PC in enhancing soil macro-aggregate stability appeared to be limited when compared to PM in a combined application The co-application of PM and PC up to about 7.5 g kg^{-1} raised the percent WSA<250 before it dipped at 10 g kg^{-1} rate.

DISCUSSION

Soil antecedent properties

The soil bulk density (1.76 Mg/m^3) was high above 1.2 Mg/m^3, beyond which there is tendency for impediment to root elongation and reduction of soil aeration (Reynold *et al.*, 2003). The soil was of medium acidity (pH 5.3) against a soil critical value for pH (pH 5.0) (Adepetu and Adebusuyi 1985; Adepetu 1990; Adepetu *et al.* 2014) and low in organic matter content (0.5%) against a critical value of 2.0% (Sobulo and Adepetu 1987; Adepetu *et al.* 2014), confirming the fragile nature of the soil used for the experiment.

Effects of poultry manure on soil physical properties

In contrast to reduction in soil cone index, a measure of mechanical impedance reported by Jian-bing *et al.* (2014) with the application of composted chicken manure, containing low sand content (3.48% sand, 75.76% silt and 20.76% clay), the current study showed that cone index did not show any significant differences from the control when lower rates (i.e. 2.5 – 5 g/kg) of poultry manure (PM) were applied, except at the higher rate of 10 g kg^{-1}. In this study, the loamy sand soil type characterized by a sand of 793.2 g/kg and a high bulk density of 1.76 Mg/m^3 may have blurred the effect of the PM due to the dense nature of sand minerals. At a higher application rate for this soil type, the increased soil shear strength, as measured with the cone penetrometer is attributable to either inter-particle reinforcement by the PM particle or the formation of more cohesive inter-aggregate bonds. Meanwhile, positive relationship between applied organic matter and water stable macro-aggregates have been reported (Greenland 1979; Mbagwu 1989; Shittu and Amusan 2015; Akinde *et al.* 2020). Unlike the macro-aggregates (WSA >250 μm), the apparent ineffectiveness of the PM applied on micro-aggregates (WSA <250 μm), may be due to the duration of the experiment not being long enough to permit redistribution of PM into micro-aggregate or of long-lasting cementing agents such as humic acid that contribute to micro-aggregates stabilization (Tang *et al.* 2011; Rachid *et al.* 2016). It had been reported that it takes longer time before organic amendments are redistributed into microaggregates (He *et al.* 2015) particularly, the coarse particulate soil organic matter type (Han-bing *et al.* 2021). The time variation in formation of soil aggregates seems to explain the negative correlation between micro- and macro-aggregation, as indicated in Table 4. Tisdall and Oades (1982) and Six *et al.* (1998) reported that increase in organic carbon (OC) in upland soils occurred first in macro-aggregates before it gradually reduced and then preferentially redistributed into micro-aggregates.

According to Thomsen *et al.* (1999), recently introduced OC was found in larger pores, which are characteristic of macro-aggregates. Other studies indicated that plant remains (Jastrow *et al.* 1996) or recent assimilates are first incorporated into water stable macroaggregates before being redistributed into smaller aggregates (Six *et al.* 2000; Tian *et al.* 2013; Atere *et al.* 2017; Atere *et al.* 2018a; Atere *et al.* 2018b).

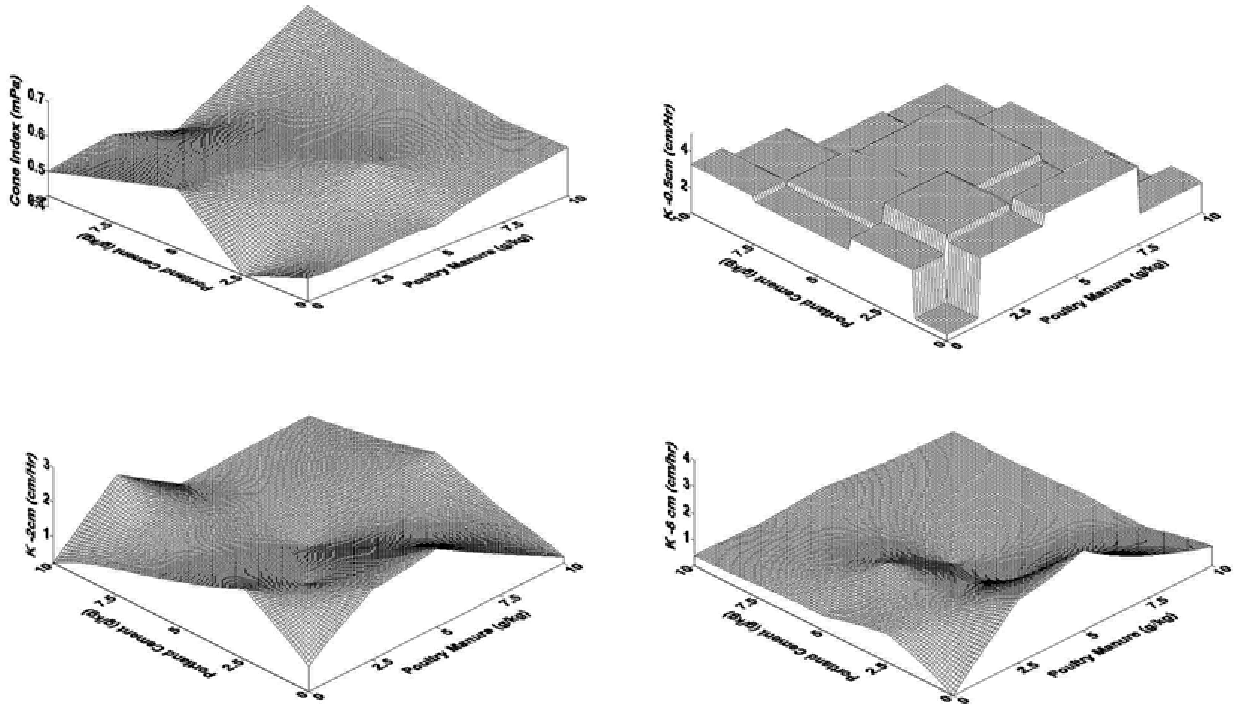

Figure 1: Effects of co-application of different rates of poultry manure and Portland cement on soil (a) cone index and (b) hydraulic conductivities at matric suctions of (i) 0.5 cm, (ii) 2.0 cm and (iii) 6.0 cm of water

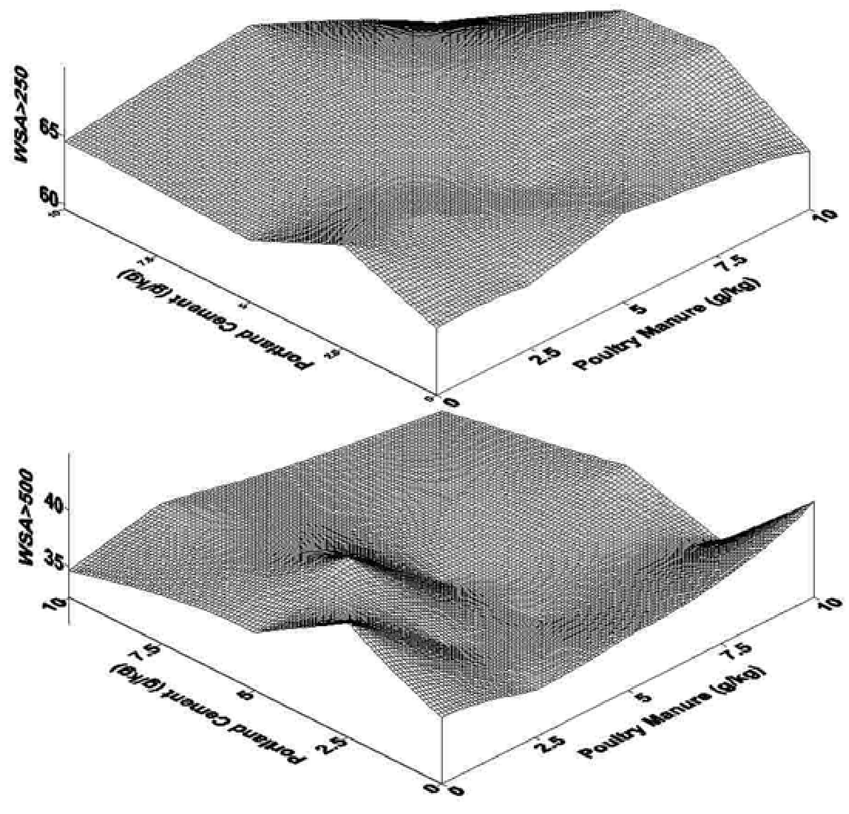

Figure 2: Effects of co-application of different rates of poultry manure and Portland cement on soil water stable aggregates greater than (a) 250 μm and (b) 500 μm.

Table 5: Summarised ANOVA table for the interaction effects of poultry manure and Portland cement on soil physical properties.

Interactions	Parameters	df	F	P
PM X PC	Soil strength	9	4.78	0.0005
	WSA<250	9	1.57	0.1707
	WSA>250	9	1.05	0.4276
	K0.5 cm	9	1.42	0.2249
	K2 cm	9	1.68	0.1391
	K 6cm	9	2.04	0.0694

Interestingly, the integration of aggregates in soil treated with PM at 2.5 g/kg and 10 g/kg yielded a range of values (74.78 – 75.38%) that are classified as having no agronomic limitation as against the control (72.74%) that had slight agronomic limitation according to Lal (1994). The increase in hydraulic conductivity at suctions of 6 cm (K_6), 2 cm (K_2) and 0.5 cm (K_5) corroborates similar studies on soil amended with PM or its variant, associating the increase in hydraulic conductivity with the applied amendment (Jian-bing *et al.* 2014; Are *et al.* 2017). However, the values signalled moderate agronomic limitations for soil water transmission (Lal 1994) and appeared reasonable, given that further improvement is expected if all the soil pores are engaged, as it is the case under saturated condition.

Effects of Portland cement on soil physical properties

With an increased rate of PC application, the soil cone penetrometer index initially increased and reached its peak at 5 g kg^{-1}. Soil stabilization, using PC, has been widely reported, particularly, within construction or engineering context, and is attributed to the formation of calcium silicate hydrate (Bahmani et al. 2014; Choobbasti and Kutanaei 2017; Mahamat et al. 2022). This study found that PC application at the rate of 2.5 g kg^{-1} provided the best stability for aggregates greater than 250 μm when agitated in water (i.e. WSA), but all the rates does not affect WSA<250 μm. Baghini et al. (2018) studied soil aggregate stability within an engineering context using California bearing ratio test etc., and despite considering a larger aggregate size than this study, they found an increase in stability of aggregate in cement-treated soil compared to the control. Similarly, Ahuja and Swartzendruber (1972) and Stivers *et al* (1977) found increases in water-stable soil aggregation and hydraulic conductivity for soil treated with cement at rate up to 1.90% by weight. Mohey and El-Sarnageiry (1985) also revealed that the highest mean value of aggregates and stable aggregates percentage were obtained when the soil was treated with 0.3% Portland cement, a rate that is approximately equivalent to the 2.5 g kg^{-1} used in the current study. According to the researchers, the soil response was caused by the presence of cement hydrates, which have the capacity to bind the soil particles together, ultimately creating favourable conditions for stable soil particles. However, when the concentration of cement was increased more than 0.3%, the percentage of stable aggregates reduced. This corroborates the decline observed, in this study, particularly when the PC application rate was raised to 10 g kg^{-1}. This may be explained by the dissociation of $CaCO_3$ to CO_2 and Ca^{2+} ions and the latter forming $Ca(OH)_2$ in the presence of water which may react with aluminum and iron oxides and reduce their efficiencies for joining the soil particles. Generally, the soil water stable aggregates (WSA), when added together ranged between 72.25 – 73.22%, only had slight agronomic limitation and rank second best according to the critical level for soil structural indicator using percent WSA (Lal, 1994).The soil hydraulic conductivities at different suctions were significantly influenced by the rates of applied PC treatment. Expectedly, the $K_{0.5}$ values were approximately two (2) times the values at K_2 and four (4) times the values of K_6 because it was the nearest to saturation when water moves fastest in soils, and only show moderate agronomic limitation (Lal, 1994). Variation in hydraulic conductivity has implication on soil strength. The negative correlation between soil strength and hydraulic conductivity presented in Table 4 corroborates the popular theory that associated weaker soil strength to higher soil moisture content. At $K_{0.5}$ the soil was nearest to saturation and strength of the wettest soil thus dropped. Increase in soil hydraulic conductivities ($K_{0.5}$, K_2, and K_6) at the PC application rate of 2.5 g kg^{-1} indicates an improved water conductivity. However, at a rate of 10 g kg^{-1}, there was a decline in hydraulic conductivities, suggesting that the pores were being clogged by the cement particles. This is particularly evident when larger conducting pores were excluded at K_2 and K_6. The obstruction in pores appeared to create a hydraulic barrier in the soil. Reduction in soil permeability when cement is added at high rate for soil stabilization has been reported (Choobbasti and Kutanaei 2017) and the permeability have been found to reduce with increase in cement application rate (Lorenzo and Bergado 2006; Kogbara *et al.* 2012; Deng *et al.* 2015). Choobasti and Kutanei (2017) explained that soil aggregate become dense due to occupation of sand grain by nano particle of cement and SiO_2. It is therefore possible that the nano particles of the cement may have clogged soil pore at relatively higher rate, in this study, leading to the reduction in K as the rate was increased to 10 g kg^{-1}.

Interaction effects of the amendments on soil properties

The combination of PM and PC increased soil strength and stabilization (i.e. strength) of the soil, which increased with increase in PC, reaching its peak when 10 g kg^{-1} of each of the amendment were applied. The value of soil strength attained is not associated with agronomic limitation based on Lal (1994). Application of poultry manure tended to improve soil strength as the PC addition increased, suggesting that increase in PC subdued an inhibitory reaction. This could be linked to a reduction in calcium content in the pore solution due to its consumption at the soil exchange site. Calcium is essential for calcium silicate hydrate (C-S-H) and calcium aluminate (CAH) formation which influences soil strength and its (calcium) consumption by soil cation exchange capacity (CEC) affects soil strength (Wei *et al.* 2014; Yu *et al.* 2014). Soil organic matter, a humified form of organic materials such as PM, is known to increase soil CEC (e.g. Olakayode *et al.* 2020) and could be a factor causing the inhibition of the chemical process that enhances soil strength. For near saturation hydraulic conductivity assessed at 0.5 cm to 6 cm suctions ($K_{0.5}$, K_2, and K_6), peak water transmission was achieved in soil subjected to 5 g kg^{-1} PM treatment with little or no PC applied but the increase was not statistically significant. Absence of PC in the combination might have eliminated possible hydraulic barrier and/or caused reduction in pore connectivity and increase in the number of isolated pore or reduction in permeability that has been associated with addition of cement to soil (Deng *et al.* 2015; Choobbasti and Kutanaei 2017; Zhao *et al.*, 2022). The trend in percent WSA<250 with co-applied PM and PC, reaching a peak at around 7.5 g kg^{-1}, could be attribute to the reduction in soil hydrophilicity, an important mechanism controlling the interaction between water and soil particles (Xiong and Chen 1990; Li *et al.* 2022), thereby affecting soil aggregate breakdown (Li, *et al.* 2022). Cement is known to constitute hydraulic barrier (Choobbasti and Kutanaei 2017) which may reduce the wetting of soil particles within the aggregate and in turn limit soil hydrophilicity, slaking and/or differential swelling of soil (the internal stress) that have been reported to disintegrate soil aggregate (Li *et al.* 2022).

CONCLUSION

The study demonstrated the favourable impact of either poultry manure, Portland cement and their combinations on soil strength, aggregate stability and hydraulic conductivity when incorporated into the soil at relatively low concentration (2.5 – 5 g kg^{-1}). Poultry manure may be applied at 10 g kg^{-1} to achieve the same level of soil strength as Portland cement. Cement can constitute a hydraulic barrier, for the soil in question, at concentration above 2.5 g kg^{-1}. The beneficial effects of each of these amendments were demonstrated, although poultry manure appeared to inhibit soil strength of the investigated soil, when they were co-applied. However, this co-application may not be necessary, considering the economic implication, as there are other sole and lower application rates that can achieve comparable improvement in the soil properties. Generally, the amendments improved the soil relative to unamended soil, resulting in no agronomic limitations for soil strength and slight to moderate limitations for water stable aggregates and near saturated hydraulic conductivity.

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CONFLICT OF INTEREST/ COMPETING INTERESTS
There are none to declare

AUTHORS' CONTRIBUTIONS
F.O.T. – supervision and writing (jointly wrote the manuscript), **D.J.O.** – conceptualization, supervision and writing (jointly wrote the manuscript) and **I.V.A.** – investigation.

COMPLIANCE WITH ETHICAL STANDARD
The work does not require approval by (bio)ethical committee

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