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Research Article

Plastic Limits and Aggregates of Soil after Five Annual Applications of Poultry Manure and Spent Mushroom Substrate

Bassey Udom and Joy Oluchi John

Department of Crop and Soil Science, University of Port Harcourt, Rivers State, Nigeria

Abstract

Background and Objective: Information concerning moisture properties of soil on account of their direct relation with changes of soil matrix can be obtained by evaluating the Atterberg limits of the soil. The study was carried out to evaluate the influence of five annual applications of poultry manure and spent mushroom substrates on plastic limit and susceptibility of the soil to deformation during cultivation. **Materials and Methods:** The study was conducted in an experimental plots where different rates of poultry manure and spent mushroom substrates have been applied for 5 years. The treatments were: Control, 5 t ha^{-1} poultry manure (PM_5), 10 t ha^{-1} poultry manure (PM_{10}), 5 t ha^{-1} spent mushroom substrate (SMS_5), 10 t ha^{-1} spent mushroom substrate (SMS_{10}) and 5 t ha^{-1} poultry manure+5 t ha^{-1} spent mushroom substrate (PM_5+SMS_5). **Results:** Results showed that plastic limit, liquid limit and plasticity index varied significantly ($p<0.05$) due to treatments. Plastic limit was highest (16.65%) in SMS_5, followed by PM_{10} with mean value of 12.48%. Liquid limit showed the highest value of 30.0% in PM_{10} soil. Saturation water content was significantly ($p<0.05$) higher in Pm_5+SMS_5 with corresponding increase in mean weight diameter of aggregates and total porosity. **Conclusion:** Results revealed that spent mushroom substrate increased optimum cultivation water content while poultry manure increased the susceptibility of soil to deformation during cultivation. Combination of poultry manure and spent mushroom substrates increase stability of aggregates and reduced plastic index.

Key words: Organic manure, structure deformation, optimum water content, stable aggregates

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Corresponding Author: Bassey Udom, Department of Crop and Soil Science, University of Port Harcourt, Rivers State, Nigeria Tel: +234 803 5402352

INTRODUCTION

Atterberg limits (plastic limit and liquid limit) have been found to be useful especially in fine-textured soils because it describes the behavior of soil at various moisture contents which may have significant effects on soil properties and tillage operations. Atterberg limits represent the water content where the consistency of a fine-grained soil is transformed from plastic state (plastic limit PL) to a liquid state (liquid limit LL) and from a semi-solid state (shrinkage limit SL) to a plastic state as well as the water content at which different fine-grained soils have an approximately equal undrained shear strength[1,2]. Although manures have been shown to improve soil properties in many environments, little is known about its effect on Atterberg limits in sandy loam soils[3]. As the moisture content of the soil increases, the behavior of the soil changes from one state to another. Plastic limit and liquid limit suggest a method of evaluating and defining these changes at various moisture contents[4].

The behavior of a soil at optimum cultivated moisture content can be influenced by the application of manure, its dynamic properties such as bulk density and water content at different potentials, as well as inherent properties of the soil[5,6]. These investigations would lead to understanding of interaction processes on the particle-to-particle scale, mechanisms for aggregation, strengthening and microstructural stability of different soils. It can be used to evaluate the effects of water content, texture, mineralogy, concentration of salts, organic matter content and soil fertility management on these processes[7-9]. However, the geotechnical properties and field behavior of soil could differ considerably from soils of the same particle size distribution and plasticity characteristics, of the soil due to manure application and consistent manipulation[9,10].

Aggregate stability may be used as an indicator to express the ability of soil to sustain mechanical breakdown. It is an attribute that is contingent on the shear strength of a soil, on the amount and forms of organic matter prevalent in a soil, on biochemical composition of plant residues and influence on soils functional properties like soil permeability, susceptibility to surface run off during soil erosion and precipitation event and soil structure[8,11].

Application of organic manure has been considered as a valuable source of soil organic matter which enhances soil aggregate stability and soil strength by increasing friction between soil particles In which case, short-term application of organic wastes is not sufficient to explain the effects of manure on forces between soil particles[8]. However, hitherto, investigation on repeated annual applications of poultry manure and spent mushroom waste had rarely been carried out in some tropical/southern Nigerian soils although these soils are quite different from the relatively well investigated European (temperate) soils[10,12]. Authors agreed that inorganic fertilizer and biocharaffect microstructure of non-structured soils[8,13,14].

The growing interest in understanding the rheological properties in soil research and its changes due to long-term applications of poultry manure and spent mushroom substrate is the major drive of this study. Thus, the main objective of this study was to evaluate the influence of five annual applications of poultry manure and spent mushroom substrate on the behavior of soil aggregates to deformation under certain moisture content. This will help researchers to uncover the critical levels of these organic manures that could be applied alone or in combination to improve optimal cultivation water content.

MATERIALS AND METHODS

Study area, experimental design and treatments: The study was conducted in experimental plots at the University of Port-Harcourt, Teaching and Research Farm (Latitude 4°15N, Longitude 7°15E), where different rates of poultry manure (PM) and spent mushroom substrate (SMS) have been repeatedly applied for 5 years (between March 2013-April 2018) to improve the soil fertility. The experiment involved 6 treatments laid out in randomized complete block design (RCBD) with replications. The land area has previously been cropped to mays (*Zea mays* L.). The treatments were: the control, without PM nor SMS, 5 t ha^{-1} poultry manure (PM$_5$), 10 t ha^{-1} poultry manure (PM$_{10}$), 5 t ha^{-1} spent mushroom substrate (SMS$_5$), 10 t ha^{-1} spent mushroom substrate (SMS$_{10}$) and 5 t ha^{-1} poultry manure+5 t ha^{-1} spent mushroom substrate (PM$_5$+SMS$_5$).

Soil sampling: Bulk and core soil samples were collected from the experimental field at 0-15 cm depth after 5 planting seasons. The bulk samples were air dried at room temperature, sieved through 4.75 and 2 mm sieves and stored in labeled containers for laboratory analysis.

Laboratory analysis

Determination of plastic limit, liquid limit and plasticity index: Plastic limit (W_P) was determined using the Casagrande method described by Atterberg[15], modified by Casagrande[16]. The rolling method was used to determine the average moisture content at which the soil crumbled when rolled into thread of 3 mm in diameter. The liquid limit was determined by the one point method and the moisture content was calculated using the equation:

$$\mathrm{WL} = w\left(\frac{N}{25}\right)^{e} \quad (1)$$

where, w is water content (%) corresponding to N blows, e is 0.092 for soils having WL<50, 0.12 for soils having WL>50. Average value of 0.1 used for all purposes.

The plasticity index was calculated as the difference between the liquid limit and plastic limit:

$$\mathrm{Ip} = \mathrm{Wl}\text{-}\mathrm{Wp} \quad (2)$$

where, Ip is the plasticity index, Wl is the liquid limit and Wp is the plastic limit.

Determination of water stable aggregates and aggregate stability: Aggregate stability was measured using the mean weight diameter (MWD) of water stable aggregates by wet sieving method[17]. The mean weight diameter (MWD) was calculated by the following equation[18]:

$$\mathrm{MWD} = \sum_{i=1}^{n} \mathrm{XiWi} \quad (3)$$

where, Xi is mean diameter of each size fraction, Wi is weight of aggregates as a fraction of the total dry weight of the samples.

Determination of saturated hydraulic conductivity and particle size distribution: Saturated hydraulic conductivity was measured by the constant-head permeability test procedure and calculated using the transport Darcys' equation for vertical flow of liquid[19]:

$$\mathrm{Ksat} = \frac{Q}{AT} \times \frac{L}{\Delta H} \quad (4)$$

where, Ksat is saturated hydraulic conductivity, Q is the volume of water that flows through a cross-sectional area, A is the cross-sectional area of core, T is the time elapse, L is the length of core and ΔH the hydraulic head difference. Particle size distribution was determined by the hydrometer[20].

Determination of bulk density and gravimetric water content: Bulk density was determined by dividing the mass of oven-dried soil at 105°C by the volume of bulk soil. Gravimetric water content at saturation (0 kpa) tension after 24 h was calculated using the equation:

$$\mathrm{WC} = \frac{\mathrm{Mw - Md}}{\mathrm{Md}} \quad (5)$$

where, WC is the gravimetric water content, Md is the mass of oven dried soil and Mw is the mass of wet soil.

Soil pH, organic matter, total nitrogen and cation exchange capacity: Soil pH was measured with a glass electrode in a 1:2.5 soil water solution[21]. Total organic carbon was determined by Walkley and Black wet dichromate oxidation method. Organic matter was obtained by multiplying the organic carbon values by a factor[22] of 1.724. Total nitrogen was determined by the modified macro Kjeldahl procedures[23]. Cation exchange capacity (CEC) was determined by ammonium acetate displacement method.

Data analysis: A two-way analysis of variance (ANOVA) was used to test if the treatments have significant effects on the means of measured parameters. This was followed by multiple comparisons of measured parameters using the SAS Software[24]. Means were separated according to the least significant difference using Fisher's protected test at 5% probability[25].

RESULTS

Effects on atterberg limits: The effects of five annual applications of poultry manure and spent mushroom wastes on Atterberg limits of the soil are shown in Table 1. Treatments varied significantly in their effects on plastic limit, liquid limit and plasticity index at $p<0.05$. Plastic limit was highest (16.65%) in SMS_5 followed by PM_{10} with mean value of 12.48%, while value for SMS_{10} was 10.15%. The least value of plastic limit was found in PM_5 (6.85%). However, similar trend was not observed in the liquid limit where PM_{10} and PM_5 had the highest value of 30.0 and 29.5%, respectively, while the least value of 10.2% was found in the control plot. Conversely, SMS_5 has the lowest plasticity index of 6.8%, indicating that plastic limit values were some what clustered toward the treatment means.

Table 1: Effects of treatment on plastic limit of the soil

Treatments	Plastic limit (%)	Liquid limit (%)	Plasticity index (%)
PM_5	6.85^b	29.4^a	14.5^a
SMS_5	16.65^a	27.9^a	6.8^b
PM_{10}	12.48^a	30.0^a	14.1^a
SMS_{10}	10.15^b	20.9^b	11.5^a
PM_5+SMS_5	9.93^b	17.0^b	12.6^a
Control	9.90^b	10.2^{ab}	9.4^b

Means followed by the same letters within the same parameter were not significantly different at $p<0.05$

Table 2: Effects of treatment on aggregate stability and other physical properties of the soil

Treatments	Sand (%)	Silt (%)	Clay (%)	Ksat (cm h^{-1})	BD (g cm^{-3})	WC (g g^{-1})	MWD (mm)	Total porosity (%)
PM_5	60.5^a	22.7^a	16.8^a	4.50^a	1.62^a	0.14^b	0.45^a	32.30^a
SMS_5	61.8^a	23.5^a	14.7^a	5.72^a	1.62^a	0.16^a	0.57^a	35.30^a
PM_{10}	68.5^a	16.5^a	15.0^a	5.32^a	1.57^a	0.17^a	0.49^a	33.40^a
SMS_{10}	60.5^a	20.5^a	19.0^a	4.11^a	1.60^a	0.15^b	0.49^a	33.73^a
$\text{PM}_5\text{+SMS}_5$	59.5^a	22.0^a	18.5^a	5.62^a	1.60^a	0.13^{ab}	0.47^a	35.23^a
Control	64.8^a	17.2^a	16.0^a	5.23^a	1.60^a	0.15^b	0.34^b	32.68^a

Ksat: Saturated hydraulic conductivity, BD: Bulk density, WC: Water content, MWD: Mean weight diameter. Means followed by the same letters within the same parameter were not significant at $p<0.05$

Table 3: Effects of treatments on some chemical properties of the soil

Treatments	pH (H_2O)	OM (%)	Total N (%)	CEC
PM_5	4.78^a	2.41^b	0.08^a	10.97^b
SMS_5	5.08^a	1.68^b	0.09^a	14.72^a
PM_{10}	4.21^a	3.16^a	0.10^a	13.74^b
SMS_{10}	4.31^b	3.67^a	0.14^a	15.65^a
$\text{PM}_5\text{+SMS}_5$	5.10^a	3.64^a	0.17^a	16.10^a
Control	4.18^b	2.59^a	0.14^a	13.22^b

N: Nitrogen, OM: Organic matter, CEC: Cation exchange capacity. Means followed by the same letters within the same parameter were not significantly different at $p<0.05$

Effects on aggregate stability and other physical properties of the soil: In Table 2, poultry manure and spent mushroom substrate had significant effects on water stability of aggregates measured by the mean weight diameter (MWD) of water stable aggregates and related physical properties. Sand, silt and clay were not altered significantly by the treatments although the inter-layer cementing effects of the manures had significant influence on aggregate stability and soil water content at saturation potential. Saturated hydraulic conductivity was 4.11 cm h^{-1} for SMS_5 and 4.5 cm h^{-1} for Pm_5, indicating a non-significant different among the treatments. The highest value of Ksat (5.75 cm h^{-1}) was found in SMS_{10} indicating the superior effect of SMS in enhancing soil permeability. Saturation water content was significantly ($p<0.05$) higher in $\text{Pm}_5\text{+SMS}_5$ with corresponding increase in MWD of water stable aggregates and total porosity. This showed that $\text{Pm}_5\text{+SMS}_5$ improved soil water content and aggregation due to inter-particle organelles.

Effects of treatment on some chemical properties of the soil: The effects of treatment on certain chemical properties of the soil are shown in Table 3. Soil pH, organic matter, total N and CEC varied significantly due to treatments. The $\text{PM}_5\text{+SMS}_5$ lowered the soil acidity (5.1) significantly compared to the control and PM_{10}. This result indicated that the five annual applications of PM_{10} and SMS_{10} did not benefit the soil pH and CEC of the soil compared to $\text{PM}_5\text{+SMS}_5$. Soil organic matter (SOM) and total N did not show significant increases for PM_{10}, SMS_{10} and $\text{PM}_5\text{+SMS}_5$. However, the lowest SOM was found in SMS_5 indicating that spent mushroom substrate (SMS) increased C: N ratio of the soil than poultry manure. Values tend to show little disparity in treatment means for pH, SOM and total N.

DISCUSSION

The study revealed that poultry manure and spent mushroom substrate altered the Atterberg limits of the soil, much due to contributions by other factors of the soil which varied according to the type and amount of clay and moisture content[26]. The quantity of water at the Atterberg limits and other physical properties depended on the pore-water composition of the soil as induced by the applications of PM and SMS[27]. Although the plastic and liquid limit values were below the critical values[28]. Plastic limit indicating the optimum water content for tillage was higher in SMS_5 soils while the susceptibility of the soil to structural deformation during cultivation as indicated by the liquid limit values was higher in PM_{10}. When compared to the control plots with least value of liquid limit, five annual applications of poultry manure increased has the tendency to induce destruction of soil structure during cultivation.

On the other hand, spent mushroom substrate generally induced greater optimal cultivation moisture content of the soils. The superior influence of SMS over the PM in increasing plastic limit of the soil could be attributable to the free inter-particle and inter-aggregate pore water created by the spent mushroom substrate[29,30]. Long-term application of poultry manure could lead to increasing clay dispersion index (CDI) and reduced aggregated silt and clay (ASC)[31,32].

This was further supported by the highest value of saturated hydraulic conductivity obtained in SMS_{10} soils. The increased in MWD of water stable aggregate with concomitant increases in saturation water content and total porosity due to $\text{PM}_5\text{+SMS}_5$ confirmed that combination of PM and SMS may be a superior option to improve aggregate stability of sandy loam soils. This is in agreement with previous studies that found improvement in aggregate stability, soil strength and bulk density after application of 5 t ha^{-1} of cattle manure on a hard setting and crusting chronic Luvisol in South Africa[33].

The mean-weight diameter of aggregates is widely used indices to measure macro-aggregate stability of soils probably because of the preponderance of macro-aggregate-size classes over micro-aggregate-size classes in its calculation[34]. Since saturation moisture content of soil is related to surface area of the soil and the hydraulic conductivity, they could be used to evaluate the Atterberg limits of the soil in this study. Significant improvement of SOM, N and CEC in PM_{10}, SMS_{10} and PM_5+SMS_5 further confirmed the important of these manures in improving soil properties[35,36].

CONCLUSION

Conclusions drawn from this study are that: Five annual applications of 10 t ha^{-1} of poultry manure increased the likelihood of structural deformation during cultivation. Spent mushroom substrate increased plastic limit of the soil. Although poultry manure improved soil organic matter, total N and CEC, further application of this manure may lead to mechanical deformation and structural damage. The soil is also considered to be sensitive to mechanical manipulation as well as heavy cultivation. Saturation water content and aggregate stability were positively improved by poultry manure and spent mushroom substrate. The threshold value for bulk density (indication of reduced compaction) was not exceeded due to the manure treatments. This study discovered that 5 t ha^{-1} of poultry manure, combined with 5 t ha^{-1} spent mushroom substrate improved optimal cultivation moisture content, reduced structural deformation and increase macro-aggregate-size class.

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