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Impact of organic material incorporation with soil in relation to their shear strength and water properties

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A b s t r a c t. A laboratory experiment was conducted to determine the quantitative effects of incorporating groundnut haulms, cow dung and chicken dung on hydraulic properties of compacted sandy loam, clay loam and clay soils. The consistency limits, shear strength, water retention and hydraulic conductivity of the three soil textures were measured. Groundnut haulms, cow dung and chicken dung were incorporated into the three soils at 2% and 4% levels on dry mass basis. For each soil-organic matter mixtures, the consistency limits significantly increased with increase in the levels of the organic materials. The shear strength significantly decreased with increase in organic matter content. Soils incorporated with groundnut haulms had the least strength followed by cow dung and chicken dung. For all the treatments, water retention decreased with increases in pressure. For sandy loam and clay loam soils, and all organic matter types, water retention increased with increases in organic matter level while that of clay soil decreased with increase in organic matter level. For all the three soils, chicken dung incorporation gave the highest volumetric moisture content followed by cow dung and groundnut haulms. Saturated hydraulic conductivity increased with increase in organic matter level and decreased with increases in compaction level. Model equations generated for estimating maximum shear strength and the moisture contents at which they occurred gave r^2-values of 0.72 and 0.73, respectively. Measured values of volumetric moisture content were calibrated with calculated values and this resulted in an r^2-value of 0.97. This implies that the equation used could be used to estimate the volumetric moisture contents of the soils.

K e y w o r d s: organic material, soils, shear strength, water properties

INTRODUCTION

Modern agricultural production practices largely depend upon vehicle traffic. The use of large vehicles on agricultural soils could cause compaction which would consequently impact negatively on crop production (Raper, 2005). Soil compaction has been defined as the process by which the soil grains are rearranged to decrease void space and bring them into closer contact with one another, thereby increasing the bulk density (SSSA, 1996).

Soil compaction by machinery traffic has been identified as a serious threat to sustainable crop production in different parts of the world (Hamza and Anderson, 2005). The degree of soil compaction is a function of soil type and water content, vehicle weight, speed, ground contact pressure and number of passes and their interactions with cropping frequency and farming practices (Chamen *et al*., 2003). Compaction induced by vehicle traffic has adverse effects on a number of key soil properties such as bulk density, mechanical impedance, porosity and hydraulic conductivity (Hamza and Anderson, 2005). These key soil properties can potentially reduce root penetration, water extraction and plant growth (Passioura, 2002). Although tire dimensions, initial cone index, tire inflation pressure, soil moisture content and number of tire passes have a great influence on soil compaction, Canillas and Salokhe (2003) found axle load and number of tire passes to be the most important variables which influence soil compaction.

Soil compaction could cause considerable damage to the structure of the tilled soil and the subsoil and consequently to crop production, soil workability and the environment (Defossez and Richards, 2002). Sanchez-Giron *et al*. (2005) investigated the effects of soil compaction, working depth and water content of a loam soil on the forces acting on three different furrow openers and reported that soil compaction increased soil bulk density which eventually led to increases in draft and vertical forces of the drills. The combined ef-

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fects of mechanical resistance and poor aeration may restrict root growth, which especially affects the uptake of nutrients and subsequently crop yields (Lipiec and Hatano, 2003; Lipiec *et al*., 2003, Sadras *et al*., 2005). Soil compaction affected emergence, plant height, root development and dry matter yields of corn (Jayan *et al*., 2006; Mari *et al*., 2006; Munkholm *et al*., 2005). Chan *et al*. (2006) reported that canola yield decreased due to soil compaction.

Organic matter has great potential in reducing soil compaction (Mamman *et al*., 2007). The beneficial effects of organic matter addition to topsoil through incorporation of plant residues or manure application has been widely studied by many researchers (Hamza and Anderson, 2002; 2003). Maintaining an adequate amount of organic matter in the soil stabilizes soil structure and makes it more resistant to degradation, and decreases bulk density and soil strength (Carter, 2002). Sangakkara *et al*. (2004) reported that application of green manures had beneficial effects on seedling growth of maize but not on germination or establishment.

The use of crop residues as organic materials in northern Nigeria is generally low because some are used as animal feed and if left on the soil for a long period, termites destroy them. The organic materials also differ in their ability to provide nutrients to crops and enhance soil quality and these differences relate to rates of decomposition and nutrient release rate and pattern (Kumar and Goh, 2002). Although the northeast region of Nigeria have several varieties of organic materials that could be added to the soil to cushion the effects of compaction and add nutrients to the soil, their effectiveness have not been fully investigated in all the soils used for crop production in the region.

The aim of this study was therefore to investigate the effects of organic materials and compaction on some physical properties of prominent agricultural soils in the study area.

MATERIALS AND METHODS

The soils used in this study were sandy loam, clay loam and clay soil. These three soils represent a major cross-section of soils used for the production of different crops in Borno State. The sandy loam soil was collected from the University of Maiduguri research farm (Farm), the clay loam soil from Biu town (Biu) and the clay soil from Ngala town (Ngala). The soil samples were collected from the top 0.2 m depth of the soil profile, air dried and ground to pass a 0.002 m sieve. Particle size distribution was performed using the hydrometer method (Gee and Bauder, 1986). The organic matter content of the soils was assessed via the wet oxidation method of Walkley and Black (1934) described by Nelson and Sommers (1996). The organic matter content of the soils were raised to 2 and 4% on a percentage dry mass basis by incorporating groundnut haulms, cow dung and chicken dung following the procedure of Ohu (1985). The choice of 2% organic matter level as the minimum for the study was because the clay soil has about 2% organic matter content which can not be reduced for experimental purposes (Ohu, 1985). The dry densities of the organic materials were determined by the method of Lambe (1951) and were found to be 0.09, 0.24, and 0.31 Mg m^{-3} for groundnut haulms, cow dung and chicken dung, respectively. The liquid and plastic limits, soil strength, shear strength and water retention characteristics of the soil-organic matter mixtures were evaluated at different moisture content and compaction levels. The sandy loam-organic matter mixtures were compacted at 3, 6, 9, 12, 15, 18 and 21% moisture contents and the clay loam and clay soil mixtures were compacted at 5, 10, 15, 20, 25, 30 and 35%. These moisture levels were chosen according to the consistency limits of the soils determined earlier (Ohu *et al*., 1989). Each of the soil-organic matter mixtures at each of the soil moisture contents was compacted in three layers using 0, 5 and 10 blows from a standard Proctor hammer in cylindrical moulds of dimensions 103 mm in diameter and 203 mm height.

The liquid and plastic limits of the soil organic matter mixtures were determined using the Casagrande method as described by Bowles (1983). The shear strengths of the soils in the compaction moulds were measured at five different depths (27, 45, 72, 99, and 116 mm) from the top of the mould using the shear vane and the average shear strength of the soil column was used for analysis. These depths used represent the soil profile in the field when changes in deformation occur as discussed by Ohu *et al.* (1985).

For the determination of water retention characteristics of the soils, water was added to the air dried soil organic matter mixtures to bring their gravimetric moisture contents to 12% for the sandy loam and 20% for the clay loam and clay soils. These moisture levels were near optimum for compaction as determined by Ohu *et al*. (1989). Following the method of Bowles (1983), each of the three soil organic matter mixtures was compacted in compaction moulds using 0, 5 and 10 Proctor hammer blows as described earlier. Samples of compacted soils were taken in cores of 53.6 mm diameter by 10 mm height. These compacted soils were saturated over a period of 5 days before conducting the water retention characteristics tests. Pressures of 33, 100, 500, 1000 and 1500 kPa were applied to the samples in the Pressure Plate Apparatus and their water retention values were obtained following the method described by Richards (1965). The water content at each suction step was calculated from the final water content when equilibrium was attained at 1500 kPa and from the mass of the oven dried samples. These water contents were converted to volumetric basis, since the amounts of water remaining in the soil at any equilibrium state is a function of the size and volume of water filled pores. The experiments were set up in a laboratory experiment using a completely randomized block design. Each test was replicated four times. The mean values of the results were analyzed using SPSS Version 10.

RESULTS AND DISCUSSION

All results are gathered in Tables 1-5 and Figs 1-5. Table 1 presents the granulometric composition of the original soils. The organic matter content for these soils were 0.1 ± 0.2, 0.1 ± 0.1, and 1.5 ± 0.3, respectively. The results of the liquid and plastic limits of the three soils incorporated with groundnut haulms, cow dung and chicken dung at two levels each (2 and 4%) are presented in Table 2. The plastic limit of the sandy loam soil could not be determined. This was attributed to high sand (77%) and low clay (17%) content of the soil. Also, the addition of organic materials might have decreased the cohesiveness of the sandy loam soil. This phenomenon was also reported by Ohu (1985) and Ahmed (1989). An increase in organic matter level increased the consistency limits of the three soils. Soils incorporated with chicken dung had the highest consistency limits followed by cow dung and groundnut haulms. This may be due to smaller particles and larger surface areas of the chic- ken dung compared with cow dung and groundnut haulms. Analysis of variance showed that changes in consistency limits of clay loam and clay soils were significant at the 5% level.

T a b l e 1. Granulometric composition of soils (% mass)

Sample location	Sand	Silt	Clay
Farm	77.0 ± 0.2	6.0± 0.1	17.0 ± 0.3
Biu	24.1± 0.2	32.1± 0.5	43.7 ± 0.4
Ngala	5.0± 0.3	35.0± 0.1	60.0 ± 0.2

All values are means of 4 replicates; ± standard deviation.

Figures 1, 2 and 3 show the plots of the shear strength for the University research farm sandy loam soil, Biu town clay loam and Ngala town clay, respectively. For all soil moisture content and organic matter levels, shear strength increased with increase in compaction level. Shear strength decreased with increase in organic matter level. For all compaction and organic matter levels, shear strength increased with increase in soil moisture content up to a point and thereafter decreased with further increases in soil moisture content. There were no values of shear strength at zero level of compaction for all soils. The moisture contents after the peaks could be regarded as been in excess of the pore volumes. Ohu *et al*. (1989) and Ekwue and Stone (1995) reported that water in excess of pore volume could decrease the cohesion of soil particles and consequently the shear strength of the soil. Soils incorporated with groundnut haulms had the least shear strength followed by cow dung and chicken dung. Analysis of variance for shear strength showed that the single term effects of organic matter type, organic matter and compaction levels as well as their first and second order interactions for the three soils were all significant at the 5% level.

In order to generate model equations for estimating maximum shear strength and the moisture contents at which they occurred, the 0, 5 and 10 Proctor compaction blows used

T a b l e 2. Liquid and plastic limits of the three soil textures incorporated with three different organic materials at two different levels

Sample location and texture	Organic matter type and level (%)	Liquid limit (LL)	Plastic limit (PL)	Plasticity index (PI)
Farm (sandy loam)	2% GNH	24.73	-	-
	4% GNH	33.85	-	-
	2% CWD	26.41	-	-
	4% CWD	35.48	-	-
	2% CHD	27.60	-	-
	4% CHD	36.85	-	-
Biu (clay loam)	2% GNH	35.24	19.17	16.07
	4% GNH	44.10	21.34	22.76
	2% CWD	37.10	20.63	16.47
	4% CWD	46.32	23.41	22.91
	2% CHD	39.48	22.35	17.13
	4% CHD	48.71	25.11	23.60
Ngala (clay)	2% GNH	73.21	43.55	29.66
	4% GNH	82.05	49.11	32.94
	2% CWD	74.51	44.23	30.28
	4% CWD	83.74	49.93	33.81
	2% CHD	76.81	46.05	30.76
	4% CHD	85.30	50.67	34.63

All values are means of 4 replicates; GNH – groundnut haulms, CWD – cow dung, CHD – chicken dung.

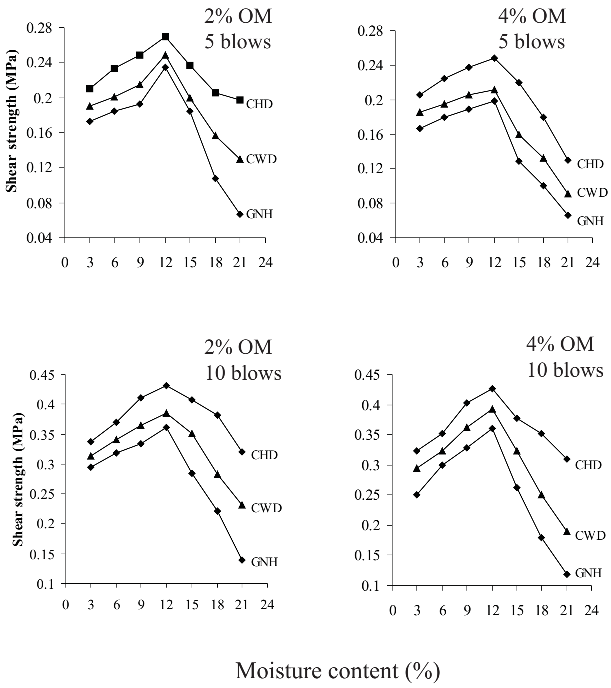

Fig. 1. Shear strength for sandy loam soil (Farm).

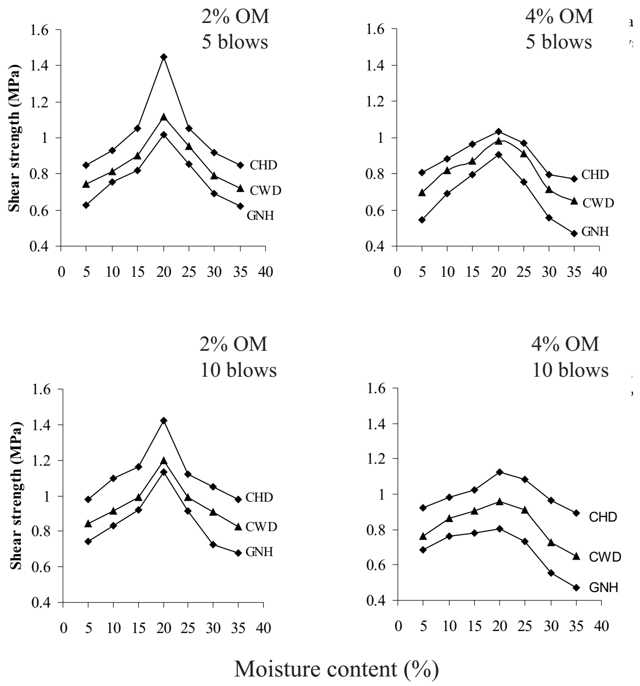

Fig. 3. Shear strength for clay soil (Ngala).

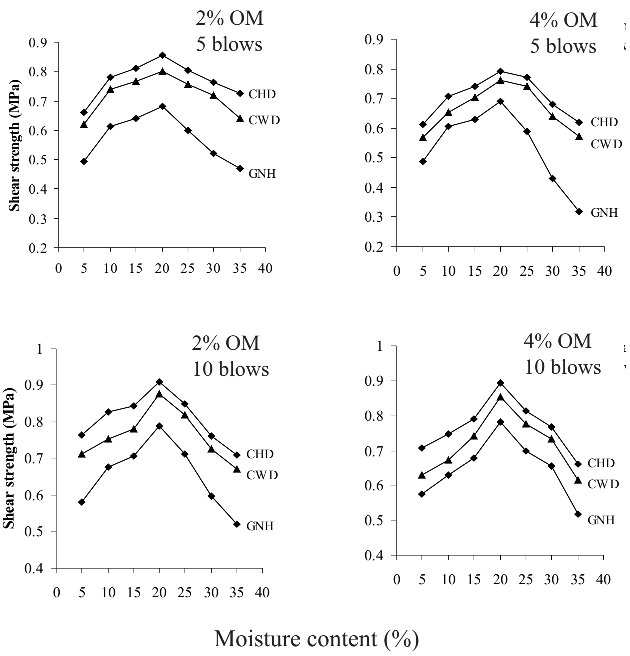

Fig. 2. Shear strength for clay loam soil (Biu).

in the study were converted to 66.7, 177.2 and 287.7 kPa static equivalent pressures using the equation derived by Raghavan and Ohu (1985). Using the clay content, organic matter level, the dry density of the organic materials and compaction level as independent variables, statistical equations were generated for all the three soils used. The multiple regression equations generated were as follows:

$$\tau_{max} = -0.58 - 0.047\ OM + 0.0036\ CP + 0.12\ C + \\ +0.43\ DM \quad (n = 54,\ r^2 = 0.72) \qquad (1)$$

$$\theta_{max} = -10.79 + 0.18\ OM + 0.089\ CP + 0.13\ C + \\ +10.28\ DM \quad (n = 54,\ r^2 = 0.73) \qquad (2)$$

where: τ_{max} – maximum shear strength (MPa), θ_{max} – moisture content at which the maximum shear strength occurred (%), OM – organic matter content (%), CP – compaction (kPa), CT – clay content (%), DM – dry density of the organic material (Mg m^{-3}), r^2 – multiple regression coefficient which is significant at 5% level. Equations (1) and (2) are similar to those reported by Stone and Ekwue (1993) and Ekwue and Stone (1995) for predicting the maximum shear strength and their corresponding moisture contents.

T a b l e 3. Water retention characteristics of the soils studied

Organic matter type and level	Pressure (kPa)	Compaction (Proctor blows)								
		Sandy loam			Clay loam			Clay		
		0	5	10	0	5	10	0	5	10
2% GNH	33	20.98	31.81	33.13	23.98	34.14	35.74	38.91	48.38	52.57
	100	13.35	22.17	28.20	18.81	28.52	33.87	28.14	37.90	43.60
	500	3.98	20.25	21.48	13.68	25.84	30.99	26.25	37.75	43.48
	1000	3.15	17.09	21.32	9.18	23.71	27.54	26.10	37.00	42.53
	1500	3.00	15.93	18.02	7.00	22.66	25.12	25.90	36.90	41.81
4% GNH	33	23.29	34.94	36.12	28.21	39.51	41.57	35.21	45.71	50.08
	100	16.83	24.82	31.42	21.14	30.15	35.48	26.81	37.11	41.87
	500	7.19	22.93	23.85	17.12	27.29	32.08	24.80	36.44	41.20
	1000	6.00	19.48	23.00	14.23	25.81	30.01	24.72	35.31	41.10
	1500	4.15	17.00	20.38	10.44	24.94	28.12	23.93	34.53	39.00
2% CWD	33	23.55	32.24	33.30	26.20	35.47	38.58	39.54	50.01	54.12
	100	18.72	26.23	28.41	22.43	31.84	34.72	29.07	41.24	46.12
	500	8.42	24.80	25.10	15.46	27.32	31.00	28.14	40.10	45.70
	1000	6.21	22.72	22.48	12.20	25.81	30.32	27.22	40.00	45.20
	1500	5.95	17.21	18.35	9.31	25.47	29.51	27.15	39.70	44.90
4% CWD	33	27.02	36.00	37.76	29.54	40.12	43.01	36.20	47.72	51.50
	100	20.81	28.34	33.91	22.32	34.41	38.24	27.53	39.84	43.72
	500	10.32	25.91	27.21	19.00	33.24	38.15	25.83	37.32	42.70
	1000	9.00	23.73	26.42	16.64	31.95	35.81	25.16	37.11	41.82
	1500	8.15	18.22	22.50	12.12	29.82	33.43	25.00	37.03	41.51
2% CHD	33	25.20	33.41	36.41	29.12	39.81	43.32	41.73	53.00	57.00
	100	20.12	28.32	30.20	23.41	35.48	40.00	32.52	44.73	48.81
	500	9.98	25.68	27.51	19.42	33.71	35.67	31.48	43.48	48.47
	1000	9.00	23.82	22.80	15.33	31.15	35.00	30.53	43.31	47.86
	1500	7.87	18.47	22.11	12.48	30.87	34.50	29.92	42.85	46.12
4% CHD	33	28.03	41.33	43.24	31.31	46.81	48.62	38.21	50.47	53.62
	100	22.18	34.42	36.26	24.82	41.33	42.31	30.52	42.91	47.45
	500	12.49	31.20	31.57	22.00	38.73	39.98	29.88	41.87	46.12
	1000	11.72	24.00	29.08	18.10	37.44	39.75	28.41	41.00	46.25
	1500	9.25	22.71	28.24	14.42	37.41	39.52	27.51	40.50	45.00

Explanations as in Table 2.

T a b l e 4. Water retention parameters of sandy loam, clay loam and clay soils incorporated with different organic materials compacted at three levels

Soil type, organic matter type and level	Compaction level								
	0 blows (66.7 kPa)			5 blows (177.2 kPa)			10 blows (287.7 kPa)		
	a	n	r^2 (%)	a	n	r^2 (%)	a	n	r^2 (%)
				Sandy loam soil					
2% GNH	150.03	0.553	97	52.59	0.163	93	55.89	0.149	97
4% GNH	119.20	0.447	98	58.65	0.163	92	60.68	0.146	99
2% CWD	100.28	0.393	98	50.26	0.128	82	53.92	0.135	91
4% CWD	88.79	0.332	99	58.76	0.144	87	59.64	0.126	96
2% CHD	80.39	0.320	98	52.29	0.126	86	55.61	0.125	96
4% CHD	78.78	0.287	98	63.52	0.125	94	61.75	0.108	99
				Clay loam soil					
2% GNH	74.32	0.303	94	47.23	0.100	97	49.65	0.086	91
4% GNH	62.81	0.227	93	54.48	0.110	91	56.66	0.094	98
2% CWD	69.43	0.258	95	48.17	0.089	99	53.16	0.061	98
4% CWD	58.33	0.176	91	55.51	0.056	93	55.79	0.050	85
2% CHD	60.42	0.202	94	48.96	0.064	96	53.16	0.061	98
4% CHD	58.33	0.176	91	55.51	0.057	93	55.79	0.050	85
				Clay soil					
2% GNH	42.58	0.073	81	50.90	0.047	70	55.31	0.040	77
4% GNH	51.27	0.110	78	58.14	0.074	76	61.26	0.062	74
2% CWD	42.90	0.066	80	52.87	0.042	76	55.47	0.030	75
4% CWD	51.42	0.106	77	60.01	0.071	79	62.66	0.060	76
2% CHD	44.64	0.056	86	55.59	0.037	80	58.52	0.031	82
4% CHD	52.82	0.092	79	61.59	0.060	77	64.68	0.052	75

Explanations as in Table 2.

The water retention characteristics of the three soils studied is presented in Table 3. For all organic matter types and levels, pressure levels and soil types, water retention increased with increase in compaction level. For all soil types, compaction level, organic matter types and levels, water retention decreased with increases in pressure. For sandy loam and clay loam soils, and all organic matter types, water retention increased with increases in organic matter level while that of clay soil decreased with increase in organic matter level. Water retention was highest at the least pressure for all organic matter types and levels, soil type and compaction levels. For all the three soils, chicken dung incorporation gave the highest volumetric moisture content followed by cow dung and groundnut haulms, respectively. Chicken dung has high binding effect on the three soils studied (Ohu *et al*., 2001) and therefore did not allow water to be released easily. Groundnut haulms was reported to have low binding effect on the soils because of its fibrous nature (Ohu *et al*., 2001) and therefore water was easily released. Although cow dung was also reported to be fibrous (Ohu *et al*., 2001), its effect on volumetric moisture content was less than that of groundnut haulms. Mappa (1986) reported that compaction of soils with high clay content decreased the amount of water retained at any given level. However, in this study, the compaction of the clay soil increased its capacity to retain more water at any given pressure. Ohu *et al*. (1985) attributed this phenomenon to the addition of organic materials to the soils before compaction. The addition of the organic materials might have increased their pore spaces which lead to increase in water retained in the soil after application. Analysis of variance of the mean values of the volumetric moisture contents showed that the single term effects of organic matter type, organic matter and compaction levels as well as their first and second order interactions were all significant at 5% level.

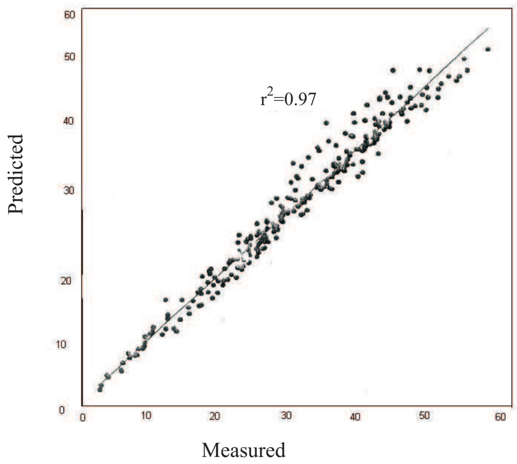

Fig. 4. Moisture content (% vol.) measured and predicted.

T a b l e 5. Saturated hydraulic conductivity (K) of sandy loam, clay loam and clay soils incorporated with three different organic materials at three different compaction levels

Organic matter type and level	Compaction (blows)	K 10^{-4} (mm s^{-1})		
		Sandy loam	Clay loam	Clay
2% GNH	0	18.12	2.50	1.04
	5	17.43	1.96	0.53
	10	12.41	1.85	0.42
4% GNH	0	19.14	2.96	1.19
	5	18.45	2.17	0.68
	10	14.39	2.11	0.61
2% CWD	0	17.29	2.40	0.99
	5	16.00	1.86	0.48
	10	11.57	1.75	0.37
4% CWD	0	18.25	2.59	1.14
	5	17.65	2.04	0.63
	10	12.65	1.96	0.57
2% CHD	0	16.35	2.31	0.99
	5	15.75	1.67	0.44
	10	10.71	1.46	0.32
4% CHD	0	17.43	2.69	1.19
	5	16.83	1.95	0.59
	10	11.82	1.85	0.52

Explanations as in Table 2.

The volumetric moisture content retained by the soils between 33 and 1500 kPa pressure can be adequately described using the power curve relationship developed by Ohu *et al*. (1987). This is of the form:

$$\Theta = a\psi^{-n} \tag{3}$$

where: Θ – volumetric moisture content (%), ψ – pressure (kPa), a and n are coefficient and exponent to be determined.

Using the equivalent static pressure of Proctor compaction blows, organic matter type and organic matter level, stepwise regression analysis was performed to estimate a and n in Eq. (3). The values of the coefficient a, and exponent n are given in Table 4 based on soil type, compaction level, organic matter type and level. The estimated a, and n values of each soil at different organic matter type and level and compaction level were used to calculate the water retained at different suctions. These values were calibrated with the measured values as shown in Fig. 4 and resulted in an r^2 value of 0.97. The model presented in Eq. (3) can therefore be used for quick estimation of the water retention characteristics of the soils after load application.

The result of the saturated hydraulic conductivity of the soil-organic matter mixtures is presented in Table 5. For all organic matter type and levels, and soil types, saturated hydraulic conductivity decreased with increase in compaction level. For all soil and organic matter types and compaction levels, saturated hydraulic conductivity increased with increase in organic matter level. At all compaction levels, and organic matter type and levels, saturate hydraulic conductivity was highest for sandy loam soil followed by clay loam and clay soils, respectively. For all treatments, groundnut haulms gave the highest hydraulic conductivity followed by cow dung and chicken dung, respectively. Generally, increase in the level of the organic materials decreased the effect of soil compaction and improved the saturated hydraulic conductivity. This is attributed to the addition of the organic materials which might have increased the proportion of larger pores even after compaction. Analysis of variance showed that the single term effects of compaction level, organic matter type and level, as well as their first and second order interactions were all significant at 5% level.

CONCLUSIONS

1. Incorporation of groundnut haulms, cow dung and chicken dung into soils would reduce soil strength.
2. Among the three organic materials used, groundnut haulms was more effective in reducing shear strength followed by cow dung and chicken dung.
3. Addition and increase in level of each of the three organic materials to each of the three soil textures increased water retention properties of the soils. The water retained in the soil with chicken dung incorporated was the highest followed by cow dung and chicken dung.
4. The high value of coefficient of determination (r^2=0.97) obtained when measured and calculated values of moisture content (% vol.) were calibrated indicates that Eq. (3) could be used for quick estimation of water retention curves of soils that are subjected to various amounts of pressures.

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