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Soil strength of some Central Eastern Nigeria soils and effect of potassium and sodium on their dispersion

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A b s t r a c t. Five soils with variable clay contents were studied with the objective of describing their physical properties and the influence of NaCl and KCl on their dispersion. The soils were analyzed for particle size distribution, Atterberg limits, chemical properties, coefficient of linear extensibility (COLE) and clay dispersion under different levels of treatments with NaCl and KCl. COLE ranged from 0.03-0.09 with all soils occurring within moderate to severe shrink-swell hazard rating. COLE significantly correlated positively with liquid and plastic limits ($r = 0.90^*$). Introduction of NaCl or KCl increases clay yield over that treated only with deionized water. Although there was significant difference in mean clay of the KCl treatment levels, there was no significant difference on the mean treatment levels of NaCl. The results will guide farmers in selection of optimal fertilizer and irrigation water rates, as wrong use may increase clay dispersion.

K e y w o r d s: Atterberg limits, coefficient of linear extensibility, clay dispersion, Nigeria

INTRODUCTION

Among the soil fertility components, agronomists most often overlook the physical composition of a soil in preference to its chemistry and the yield potential aspect. Soil physical properties play very significant roles in ensuring better crop growth and soil quality. The soil physical conditions are estimated on the basis of the density of soil, particle size distribution, macroaggregate size distribution and structural porosity (Medvedev, 1988). Dexter (1997) observed that soil phenomena and problems usually require more than one of these components for adequate evaluation. He noted that strength and stability are necessary if the soil is to retain its structure against imposed stress which may be in the form of raindrop impact, or may be anthropogenic in the form of agricultural traffic. These properties, according to Shein and Mizury (1998), affect the yield of cultivated plants. Munkholm and Kay (2002) showed that tensile failure is the desired mode of failure during seedbed preparation as large clods are fragmented without disturbing soil microstructure, indicating that soil strength is influenced by management and soil properties (Blanco-Canqui *et al*., 2005).

Sodium and potassium including Ca^{2+} are among the univalent cations which affect the dispersion of soils adversely. Ward and Carter (2004) showed that application of saline solutions to soils led to increased dispersion of the soil. Although sodium chloride application in soil may lead to dispersion, however, this depended heavily on the texture and some other factors. According to Prior *et al*. (1992), heavier soils with higher clay contents dispersed more than those with lower clay contents. This also is dependent on the nature and type of clay mineralogy. When a soil is dispersed, it leads to other detrimental outcomes. Le Bissonnais and Arrouays (1997) indicated that soil aggregate breakdown due to dispersion results in pore collapse which reduced infiltration rate, leading to runoff and erosion and, finally, soil degradation. Levy *et al*. (2003) remarked that increased exchangeable sodium prcentage (ESP) in soil increased aggregate slaking but only for soils with clay content <25%. The use of saline water for irrigation decreased aggregate slaking at ESP <5%, and for inherently stable soils with clay content >35% aggregate slaking decreased upon use of saline water only when ESP >15%. Although the studied soils are not currently saline, there is an increasing use of contaminated water from sewage and industrial bye-product for irrigation. The objective of this study was to describe the physical properties associated with strength of some soils, the relationship between strength with some measured soil properties, and to discuss the influence of sodium and potassium ions in the clay dispersion of these soils.

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MATERIALS AND METHODS

Location and field study

The studied area is between latitudes 5° 10’ and 6° 00’ N and longitudes 7°30’ and 8°00’ E. with tropical wet and dry season prevailing in the area. The mean annual rainfall is approximately 1500-1600 mm with most of the rains falling between April and October at very high intensity. The rainy season is followed by the dry season which occurs between November and March. The maximum temperature for this location is between 26-28°C which coincides with the rainy/ dry seasons. The geology of the location is mainly shale, often mixed with sandstone. The soil samples used for the study were collected from the 0-20 cm depth from 5 locations representing five different soils that are presently not under saline influence. NaCl and KCl suspensions at different concentration were used to leach the samples before the particle sizes determination, to determine the effect of Na^+ and K^+ ions on the dispersion. The soil analysis was carried out using the procedures described below, after sieving air dry soil samples using a 2 mm sieve.

Laboratory analysis

Particle size distribution of the less than 2 mm fine earth fractions was measured by the hydrometer method as described by Gee and Bauder (1986), in triplicate. The clay content from particle size analysis with chemical dispersion (calgon) is regarded as total clay (TC), while the content of clay obtained after particle size analysis using deionised water only is the water-dispersible clay (WDC).

To simulate the effect of contaminated water for irrigation, the soils were also treated with KCl and NaCl suspensions, respectively at 20, 40, 70 and 100 S m^{-1} electrical conductivity. After the treatment excess salt was washed away through centrifugation and particle size distribution was determined by the method already described to obtain the clay content of soil in each treatment. Soil pH was measured in a 1:2.5 soil: 0.1 M KCl suspension. The soil organic carbon was determined by the Walkley and Black method described by Nelson and Sommers (1982). Exchangeable cations were determined by the method of Thomas (1982). The water-dispersible clay indices were calculated as follows:

Clay dispersion ratio (CDR) = WDC / Clay obtained from KCl or NaCl treatment. (1)

The WDC was used as reference because that was assumed to be the ‘best case scenario’ for irrigation purposes. The higher the CDR of the soil, the greater the ability of the soil to disperse. Atterberg limits were determined as described by Hillel (1980). The coefficient of linear extensibility (COLE) was calculated as described by Schafer and Singer (1976), thus:

$$\text{COLE} = (L_m - L_d)/L_d \quad (2)$$

where: L_m – length of moist soil, L_d – length of dry soil. Volumetric shrinkage (VS) was calculated from the COLE as:

$$VS = [(\text{COLE} + 1)^3 - 1]\ 100 \quad (3)$$

Schafer and Singer (1976) described the ratings and classification of COLE and VS under their corresponding shrink-swell hazard as follows:

COLE	VS	Shrink-swell hazard rating
0.00-0.03	0-10	Slight
0.03-0.06	10-20	Moderate
0.06-0.09	20-30	Severe
>0.09	>30	Very severe

Data analysis

Data analysis was performed by comparing the treatment means of clay dispersion ratio (CDR) within the different treatment levels using the SPSS.10 on Windows computer package. The significant levels of relationships are shown on a matrix.

RESULTS AND DISCUSSION

Particle size distribution and soil properties

The soils are mainly sandy clay loam, sandy clay and clay in their textural class. All soils contain ≥30% clay in their particle size distribution (Table 1). Relatively high silt contents were recorded for the soils. These values represent some significant increase in silt values over other soils formed on these degraded but highly weathered upland soils of the area. Akamigbo (1984) and Igwe *et al*. (1995) observed that typical soils from this agroecological zone have low silt contents which they attributed to high weathering processes in the soils. The silt content, however, significantly positively correlated with exchangeable Mg^{2+} and K^+ (r = 0.82*; 0.89*, respectively), but negatively correlated with exchangeable Na^+ (r = -0.90*). Apart from the Ugwuaku soil where the fine sand was more than the coarse sand, and Ezinnachi where the coarse sand was greater than the fine sand, the fine sand was either higher or equal to the coarse sand in the other soils (Table 1). Overall, the total sand content was not as high as in similar soils in the area. High total sand content was attributed to the nature of the underlying parent material which was derived from sedimentary materials (Akamigbo and Asadu, 1983).

The soils are basically acid with most pH range below 5.1 in deionized water and 4.2 in KCl solution. They are low in soil organic carbon (SOC) content (0.7-1.2 %), which is typical of the soils from this region. The exchangeable

T a b l e 1. Particle size distribution of the soils

Soil No.	Location	Particle size distribution (%, dia in mm)					TC*
		<0.002	0.002-0.02	0.02-0.2	0.2-2	0.02-2	
1	Ugwuaku	30	6	44	20	64	SCL
2	Ezinnachi	32	18	18	32	50	SCL
3	Isuochi	40	26	26	8	34	C
4	Agbogugu	42	26	16	16	32	C
5	Ihube	38	12	25	25	50	SC
	Mean	36	18	26	20	46	-
	CV %	14	50	44	45	28	-

*TC – textural class, SCL – sandy clay loam, C – clay, SC – sandy clay, CV – coefficient of variability.

cation including the cation exchange capacity (CEC) was low in the soils (Table 2). Very low nutrient contents including the CEC have been reported for these soils (Enwezor *et al.*, 1981). The cause of these low nutrient contents has been attributed to high leaching rate due to high rainfall, the nature and type of clay minerals, and high mineralization rate of the soil organic matter.

Coefficient of linear extensibility (COLE), volumetric shrinkage (VS) and Atterberg limits

The values of coefficient of linear extensibility (COLE) for the five soils are presented in Table 3. The major clay mineral of these soils is kaolinite, though smectite and illite occur in various proportions. They ranged between 0.03 and 0.09, with a mean of 0.06 and coefficient of variation (CV)

T a b l e 2. Chemical properties of the soils

Soil No.	Location	pH		SOC (%)	Na^+	K^+	Ca^{2+}	Mg^{2+}	CEC
		H_2O	KCl		(cmolc kg^{-1})				
1	Ugwuaku	5.0	4.1	0.70	0.052	0.003	1.0	0.17	17.60
2	Ezinnachi	5.1	4.1	0.77	0.047	0.005	1.2	1.38	14.40
3	Isuochi	5.1	4.1	1.20	0.042	0.005	2.1	1.55	13.60
4	Agbogugu	5.0	4.2	1.12	0.042	0.005	1.2	0.53	20.80
5	Ihube	5.0	4.0	0.93	0.068	0.003	1.4	0.34	8.80
	Mean	5.0	4.1	0.94	0.05	0.004	1.38	0.79	15.04
	CV %	1	2	23	20	33	31	79	30

T a b l e 3. Coefficient of linear extensibility (COLE) and Atterberg limits for the soils

Soil No.	Location	COLE	VS	LL	PL	PI
1	Ugwuaku	0.03	9.27	27	15	12
2	Ezinnachi	0.04	12.49	31	20	11
3	Isuochi	0.07	22.50	36	23	13
4	Agbogugu	0.06	19.10	38	27	11
5	Ihube	0.09	29.50	41	28	13
	Mean	0.06	18.57	34.6	22.6	12
	CV %	41	43	16	24	8

VS – volumetric shrinkage, LL – liquid limits, PL – plastic limits, PI – plasticity index.

of 41%. From the ratings of Schaffer and Singer (1976) it was observed that the soils fall within the groups of moderate to severe shrink-swell hazard rating. Lewis (1979) remarked that soils which have COLE ≥ 0.09 may be used as a criterion for the allocation to vertic subgroup of soil classification. This subgroup has the potential of cracking when dry and expanding extensively when wet because of the levels of 2:1 clay minerals contained in them and thus posing serious problems in workability of the soils. Again the volumetric shrinkage of the soils (VS), also given in Table 3, followed the trend of COLE. Barzegar *et al*. (1995) remarked that these properties (COLE and VS) measure the shrink-swell potentials or soil shrinkage hazard levels of the soil and that they were related to amount and types of clay mineral present in the soil. The Ihube soil, which had the highest VS, was not the soil with the highest clay content. Therefore, clay content per se may not be the only factor responsible for the high VS but the amount and type of clay mineralogy and combination of these clays. Igwe (2003) found a direct relationship between COLE and clay content, smectite, total MgO and total Al_2O_3 in floodplain soils. The soils studied are not on the floodplain but are hydromorphic in nature and similar in some characteristics with flooded soils. Mbagwu and Abeh (1998) indicated that in some Nigerian soils VS was influenced more by the dominant clay minerals than by the texture or soil order. According to them soils containing either low or trace concentrations of smectite or vermiculites (2:1 minerals) acted like expansive soils in spite of the dominance of the 1:1 minerals. Some previous studies on the clay mineralogy of these soils (Igwe *et al*., 2005; Jungerius and Levelt, 1964; Unamba-Oparah, 1985) showed that some quantities of 2:1 clay minerals were observed in the soil in spite of the dominance of kaolinite and of Fe_2O_3 and Al_2O_3.

The Atterberg limits are presented in Table 3. The Atterberg limit measures the soil consistency through the plastic limit, liquid limit and the plasticity index. The liquid limits (LL) in our soils ranged from 27 to 41% and followed closely the trend in the VS and COLE. LL positively correlated significantly with the VS (r= 0.90*). The mean was 34.6 while CV of LL was 16%, indicating very close range of the LL values of the soils. This LL of the Atterberg limits is very crucial in the management of soils, especially those used for irrigation agriculture or where soil erosion by water is common due to the high rainfall intensity. This is because at very high moisture content, the soil disperses easily and may tend to flow, thus constituting environmental hazard. In the study area soil erosion by water is very rampant and often poses a great environmental problem for agricultural soils and silting of streams and lakes. Plastic limit (PL) or the upper limit of soil friability was from 15-28% and also along the line of VS and COLE. Just as in LL, PL had positive significant correlation with VS (r = 0.91*). Although the PL did not correlate significantly with contents of clay and soil organic matter, the coefficients were high enough and positive, thus indicating that increase in these properties will result in increased PL. The coefficient of variation was 24%. According to Utomo and Dexter (1981), at low to moderate PL in most soils friability is at its maximum. The plasticity index (PI) is very narrow and ranged from 11-13. The trend did not follow the pattern of the VS, PL or LL (Table 3). However, it correlated negatively with the cation exchange capacity of the soil (r= -0.79*).

Effects of potassium and sodium chloride on the dispersion of the soils

The generated clay contents of the soils following the dispersion of the soil with deionized water and different conductivity levels of KCl and NaCl are shown in Table 4. The mean values indicated that deionized water had 12.4% clay content as against mean value of 17, 14.4, 14 and 14 produced by KCl at 20, 40, 70 and 100 S m^{-1} electrical conductivity (Ec), respectively, and a significant F-ratio of 3.94 (Table 4). This showed that the different concentrations of KCl had some significant influence on the dispersion of these soils, irrespective of the solution of high conductivity used.

In most cases there was higher clay content for the soils dispersed with NaCl over those dispersed by water (Table 4). Although there was no significant difference in the values of the dispersion concentration used in NaCl, yet soils dispersed with 70 S m^{-1} Ec NaCl had the highest mean values followed by those of 20 S m^{-1} Ec. It was not clear from this experiment why increased concentration of the salt solution failed to give corresponding higher values. However, Ward and Carter (2004) showed that dispersion depended on several soil properties, such as sodium adsorption ratio, electrical conductivity, clay type, organic matter contents, ratio of chloride ions to charge of sulfate ions in soil water and the ratio of charge of sodium ions to the sum of the charges of sodium and calcium ions in soil water. Also Guarnieri *et al*. (2005) remarked that different soils may have very different response to the treatment with these dispersants.

The clay dispersion ratio (CDR), relative to the clay dispersed in water and with salt solution, showed that for the soils treated with KCl the highest CDR was obtained from the soil treated with 70 S m^{-1} followed by those treated with 40 and 100 S m^{-1}, respectively. The least was the CDR for the soils dispersed with 20 S m^{-1} (Table 5). This showed that the dispersion problem posed by KCl ions was achieved at about 40 S m^{-1} Ec and higher values. The same also goes for the NaCl treatment, where the highest CDR was at 100 S m^{-1} followed by 40 S m^{-1}. Higher dispersion ratio was always achieved at the highest concentration. These results should be a guide to farmers in areas where these salts are always applied in irrigation water as sodium chloride and muriate of potash (potassium chloride). The later is also a major fertilizer source in the country.

T a b l e 4. Results of clay dispersion (%) with potassium and sodium chloride treatments (S m^{-1})

Soil No.	Deionized water	KCl treatments				NaCl treatments			
		20	40	70	100	20	40	70	100
1	11	20	13	14	14	19	15	25	15
2	9	16	19	14	13	15	14	13	13
3	19	16	14	14	15	19	15	29	15
4	13	16	13	13	14	14	15	13	14
5	11	16	13	13	13	14	14	13	13
Mean	12.4	17	14.4	14	14	16	14	19	14
CV %	41	11	28	4	61	16	6	42	7
F-Ratio					3.94*				1.23
LSD (0.05)					1.38				NS

*Significant at p≤ 0.05, NS – not significant.

T a b l e 5. Clay dispersion ratios of the clay relative to treatment (S m^{-1})

Soil No.	KCl treatments				NaCl treatments			
	20	40	70	100	20	40	70	100
1	0.55	0.84	0.79	0.79	0.58	0.73	0.44	0.73
2	0.56	0.47	0.64	0.69	0.60	0.64	0.69	0.69
3	1.20	1.40	1.40	1.30	-	1.30	0.66	1.30
4	0.81	1.00	-	0.92	0.92	0.87	-	0.92
5	0.69	0.85	0.85	0.85	0.79	0.85	0.85	0.85
Mean	0.76	0.91	0.92	0.91	0.72	0.87	0.66	0.90
CV %	35	37	36	21	22	29	26	27

CONCLUSIONS

From the results of the study we make the following conclusions:

1. The soils are sandy clay loam to clay with moderate silt and clay contents. They are stable even at very high tropical rainfall intensities common in the area.

2. They were moderate to severe in their shrink-swell potential hazard rating. Coefficient of linear extensibility (COLE) and volumetric shrinkage (VS) values were thought to be related to the varying amount of 2:1 clay minerals which occur alongside with kaolinite in the soils. The 2:1 minerals influenced COLE more than the 1:1 type.

3. The liquid and plastic limits were related closely to the volumetric shrinkage (VS).

4. Finally, the added KCl ions significantly affected the yield of clay where the values of KCl and NaCl increased along with increase in the clay dispersion ratio (CDR). The outcome of these results should serve as a guide to farmers in the application of irrigation water and fertilizer containing NaCl and muriate of potash which is KCl.

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