Implication of Soil Physical Properties for Agriculture and Environmental Sustainability: A Case Study of an Arable Land in The Guinea Savanna Area of Nigeria

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Abstract

Soil physical properties aids in understanding how soils function in an ecosystem and how they can be managed for optimum crop yields while conserving the soil environment. The objective of this study is to examine soil physical properties in the study area in relation to crop production, soil genesis and environmental sustainability. Soil study was undertaken using stratified random sampling approach. To examine soil physical properties in the area, a total of ten soil profile pits were dug and fifty two soil samples obtained from genetic horizons. Soil physical properties studied included particle size distribution, density, moisture characteristics; compaction and drainage characteristics. Particle size analysis showed a high degree of textural differentiation with the subsurface soils having higher clay content. Mean contents of dispersion ratios in the area were high (>0.71) indicating a high vulnerability of the soils to erosion. The available water holding capacity of the soils were low (range: 3.5-12.14%; mean: 6.3%) with the sub soils exhibiting a high level of compaction. The continuous use of these soils for crop production without appropriate management practices could lead to unacceptable low yields, increased soil erosion and pollution of nearby reservoirs.

Keywords: *soil, physical properties, agriculture, environment*

Introduction

Soil physical properties profoundly influence how soils function in an ecosystem and how they can best be managed for optimum crop yields while conserving the soil environment. Physical properties that influence soil quality include its particle size distribution, density, hydraulic conductivity and available water holding capacity just to mention a few (Brady and Weil, 1999). Research carried out by Malgwi et al (2000) on soil physical properties raised serious questions about the sustainability of continued crop production on a landscape at the Ahmadu Bello University farm, Zaria. This prompted a probe into examining the soil characteristics of a similar landscape.

The study area is located at the Institute for Agricultural Research Farm, Samaru, Zaria (110 11' N and 70 38'E). Samaru experiences a Tropical Continental climate with distinct seasonal regimes, oscillating between cool to hot dry and humid to wet (Iloeje, 2004). These two seasons reflect the influences of tropical continental and equatorial maritime air masses, which sweep over the entire country. The long-term mean annual rainfall is 1100 mm (monomodal) and the length of the season is about 130 to 190 days from late May to September/October (Yaro et. al., 1999). The Samaru area is underlain by a complex of igneous and metamorphic rocks of mainly Jurassic to Precambrian age (Wall, 1978). Soils over the Samaru area have also developed from fined grained loess material, deposited by winds from the Sahara and mixed over the years with the local soils, derived from Basement Complex rocks (Wall, 1978; Iloeje, 2004).

The objective of this study is to examine soil physical properties in the study area in relation to crop production, soil genesis and environmental sustainability.

Materials and Methods

The study area covers an area of about 400-ha with gentle slopes of about 2% in gradient stretching a distance of about 2 km. The slope was stratified using FAO (2006) guidelines into: highest, higher, intermediate, lower parts and bottom parts. Ten profile pits (ranging in depth from 115 to 170 cm) were dug to an impenetrable layer. The profiles pits were described and soil samples collected from genetic horizons using guidelines contained in the Soil Survey Manual (Soil Survey Division Staff, 1993). 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). Micro-aggregate stability indices were determined using dispersion ratios as described by Igwe (2005). Undisturbed soil samples obtained with a core sampler were used for bulk density determination by oven drying as described by Blake and Hartge (1986). Packing density (FAO, 2006) was estimated using this equation: $PD = Db + 0.009C$ (FAO, 2006). Where PD is packing density in Mg/m3, Db is the bulk density in Mg/m3, and C is the clay content (%, by weight). Available water holding capacity was determined using pressure plate method as described by Klute (1986) and, Brady and Weil (1999). Saturated hydraulic conductivity was estimated using the guidelines provided by the Soil Survey Manual (Soil Survey Division Staff, 1993) while soil porosity was estimated using the procedure outlined by Brady and Weil (1999). Weighted mean values of clay data in surface and subsurface soils were calculated to remove horizon bias. Surface soils in this study was regarded as either the Ap or combined Ap and AB horizons as the case may be. The Fishers test of significance was used to compare the variance of clay data among slope positions.

Results and Discussion

Particle Size Distribution

Particle size distribution in profiles across slope positions is shown in Table 1. Analysis of variance revealed that clay contents in surface and subsurface soils were not significantly different ($P>0.05$) among slope positions. There was a similar trend in the distribution of total clay with depth among profiles at the highest to lower slope positions. The trend shows a typical bulge of the argillic or kandic horizon, which is an evidence of clay eluviation and illuviation processes. At the bottom slope position, there was an initial decrease and then an increase in clay content with depth. This dissimilarity in trend with those of other slope positions may be due to clay depositions on the surface soils in this area. Textures of the A-horizons from crest to lower slope positions were generally loams and are similar with that reported by Iloeje (2004) for soils of the area. In the bottom slope area soil textures ranged from sandy clay loam to clay and could be attributed to deposition of clay in this area by surface wash. Subsurface soils were finer in texture than surface soils and this may be partly due to eluviation-illuviation processes and partly to in situ clay formation.

Silt to Clay Ratios

Silt to clay ratios have been used to study the degree of pedogenic weathering in soils (Sombroek and Zonneveld, 1971). Generally low values (< 0.75) indicate old age of soils; values between 0.75 and 1.5 indicate moderate pedogenic weathering processes, while high values (> 1.5) indicate recent pedogenic processes (Sombroek and Zonneveld, 1971).

Silt to clay ratios among different soils of the landscape are shown in Table 1. These ratios (ranging from 1.52 to 2.71) indicate recent pedogenic processes in the A horizons of profiles at highest to lower slope position. This could be attributed to annual aeolian superficial deposition in the area. Iloeje (2004) noted the deposition of fine-grained loess soil materials by winds from the Sahara which had mixed over the years with the local soils derived from basement complex rocks in the Samaru area. In addition selective erosion of clay by surface wash leaving behind silts and sands could be responsible for the observed silt to clay ratios at highest to lower slope positions. Lower silt to clay ratios (ranging from 0.72 to 1.03) at bottom slope position could be attributed to relative accumulation of clay with respect to silt in the A- horizons as a result of surface wash (Paton, 1978). Silt to clay ratios in subsoil horizons were generally less than 0.75 and shows that more intensive weathering has taken place in subsoil compared to surface soils.

Table 1: *Particle size distribution in selected soil profiles*

Profile	Horizon	Depth	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Silt/ clay	Texture
				Highest				
1	Ap	0-17	19	29	52	0	1.58	loam
	BA	17-34	37	29	34	0	0.80	Clay loam
	Bt	34-65	45	25	30	0	0.57	clay
	Btc	65-95	31	19	50	31	0.63	Gravelly sandy clay loam
	Btv	95-150	23	15	62	0	0.68	Sandy clay loam
				Higher slope				
3	Ap	0-14	25	37	38	0	1.52	Loam
	BA	14-24	31	27	42	0	0.9	Clay loam
	Bt1	24-55	41	23	36	0	0.58	Clay
	Bt2	55-87	45	27	28	0	0.61	Clay loam
	Bt3	87-125	43	25	32	0	0.6	Clay
	Bt4	125-165	35	23	42	0	0.68	Clay loam
				Intermediate slope				
5	Ap	0-22	19	39	42	0	2.13	Loam
	BA	22-49	39	31	30	0	0.81	Clay loam
	Bt1	49-110	45	25	30	0	0.57	Clay
	Bt2	110-140	37	25	38	0	0.69	Clay loam
	Btv3	140-170	37	27	36	0	0.75	Clay loam
				Lower slope				
7	Ap1	0-22	15	39	46	0	2.71	Loam
	Ap2	22-44	25	39	36	0	1.60	Loam
	Bt1	44-84	47	31	22	0	0.67	Clay
	Bt2	84-112	45	27	28	0	0.61	Clay
	Btv3	112-170	39	27	34	0	0.71	Clay loam
				Bottom slope				
9	Ap	0-8	27	27	46	2	1.03	Sandy clay loam
	AB	8-32.5	17	27	56	6	1.66	Sandy loam

Bt1	32-65	25	31	44	8	1.28	Loam
Bt2	65-85	33	19	48	25	0.59	Gravelly sandy clay loam
Bcg	85-152	37	21	42	42	0.58	Very gravelly clay loam

Dispersion Ratio

Mean contents of dispersion ratios for soil across the landscape were generally high (> 0.71) indicating the high vulnerability of the soil to erosion. Igwe (2005) observed that the higher the dispersion ratio the greater the ability of the soil to disperse. Mean contents of dispersion ratio were higher at the intermediate and lower parts of slope (Table 2) suggesting higher rates of soil erosion in those areas. Bergsma et al (1996) reported that most erosion takes place about three-quarter down straight or linear slopes. The role of vegetation in preventing soil erosion has been underscored by Brady and Weil (1999). The study area, as a result of the activities of man over the centuries, has been rid of much of its vegetation through bush burning, cultivation, grazing, firewood gathering and cutting for building purposes such that most of the land area is exposed to agents of soil erosion (Blair-Rains et al, 1977).

Density and Porosity

Bulk density values in selected profiles across slope positions are shown in Table 3. The values ranged from 1.36 to 1.69 Mg/m3 with a mean of 1.53 Mg/m3 and were similar to that reported by Young (1976) as typical of tropical soils. Weighted average of packing density values (Table 3) in subsurface soils of the selected profiles ranged from 1.83 to 2.01 Mg/m3 indicating high level of compaction. Jones et al (2003) reported that subsurface soils with a packing density greater than 1.75 Mg/m3 are have already undergone compaction.

Soil porosity data for selected profiles across the landscape is shown in Table 3. Soil porosity ranged from 36 to 45% (mean: 42%) in the various horizons. The values are close to that required for an ideal soil. Brady and Weil (1999) had noted that for an ideal medium textured, well granulated surface soil in good condition for plant growth; approximately 50% of the soil volume would consist of pore space.

Table 2: *Drainage status of profiles across slope position*

		Dispersion ratio	
Slope unit	Drainage class	Range	Mean
Highest	Well drained	0.63 – 0.78	0.71
Higher	Well drained to moderately well drained	0.70 – 0.74	0.72
Intermediate	Well drained to moderately well drained	0.77 – 0.85	0.81
Lower slope	Moderately well drained to imperfectly drained	0.76 – 0.89	0.83
Bottom slope	Poorly drained	0.66 – 0.77	0.72

Moisture Characteristics

Water movement in soil is controlled by two factors: 1) the resistance of the soil matrix to water flow and 2) the forces acting on each unit of soil water (Brady and Weil, 1999). The rate of water movement through the soil is limited by the soil horizon with the lowest hydraulic conductivity. The hydraulic conductivity class of selected soil profiles across the landscape is shown in Table 3. The table shows that low hydraulic conductivity is usually encountered around the interface between the surface and subsurface soils. This condition could lead to high rates of runoff and consequently, soil erosion.

Available water holding capacities (AWHC) in selected profiles across slope positions are shown in Table 3. AWHC ranged from 3.5 to 12.14 % with a mean of 6.3 %. The AWHC values of the soils were relatively low and may be attributed to the generally low organic matter contents and poor structural development of the soils (Brady and Weil, 1999). Poor soil structural development and low levels of organic matter have been reported in these soils by Owonubi (2008). As a result, relatively higher irrigation frequencies might be needed to sustain crop growth if irrigated agriculture is being contemplated in the area.

Table 3: *Density and moisture characteristics in selected profiles across slope positions*

Horizon	Depth[a]	Bd (Mg/m^3)	PD (Mg/m^3)	Ksat Class	Porosity (%)	AWHC (cm)	AWHC (%)
P1							
A	0-17	1.50	1.67	ML	43	2.08	7.23
BA	17-34	1.54	1.87	L	42	1.56	5.96
Bt	34-65	1.57	1.98	L	41	2.53	5.19
Btc	65-95	1.69	1.97	ML	36	2.44	4.82
Btv	95-150	1.46	1.67	MH	45	2.8	3.5
P3							
A	0-14	1.51	1.74	ML	43	1.57	7.43
BA	14-24	1.59	1.87	L	40	0.61	3.85
Bt1	24-55	1.58	1.95	L	40	3.16	6.45
Bt2	55-87	1.57	1.98	L	41	3.91	7.79
Bt3	87-125	1.57	1.96	L	41	3.1	5.19
Bt4	125-167	nd	nd	nd	nd	nd	nd
P5							
A	0-22	1.45	1.62	MH	45	2.24	7.04
BA	22-49	1.49	1.84	ML	44	3.03	7.53
Bt1	49-110	nd	nd	nd	nd	nd	nd
Bt2	110-140	1.46	1.79	ML	45	2.44	5.59
Btv3	140-170	1.36	1.69	ML	49	3.06	7.46
P7							
A1	0-22	1.43	1.57	MH	46	3.81	12.14
A2	22-44	1.44	1.67	MH	46	1.57	4.96
Bt1	44-84	1.67	2.09	L	37	3.67	5.49
Bt2	84-112	1.59	2.00	L	40	2.85	6.41
Btv3	112-170	1.60	1.95	L	40	5.32	5.73
P9							
A	0-8	1.40	1.64	MH	47	0.81	7.3
AB	8-32.5	1.48	1.63	H	44	2.5	6.9
Bt1	32.5-65	1.56	1.79	ML	41	3.64	7.19
Bt2	65-85	1.58	1.88	MH	40	1.43	4.52
Bcg3	85-152	1.66	1.99	L	37	6.14	5.52

a units in cm; Bd = bulk density; FC = field capacity; PD = packing density; AWHC = available water holding capacity; nd = not determined; PWP = permanent wilting point; L = Low (0.001 – 0.1µm/s); ML = Moderately low (0.1 – 1.0 µm/s); MH = Moderately high (1.0 – 10.0 µm/s); H = High (10 – 100 µm/s); Ksat = saturated hydraulic conductivity

On the basis of observation made on mottling and soil color, the All Indian Soil and Land Use Survey Organization (I.A.R.I., 1971) guidelines were used to place each of the parts of slope in drainage classes (Table 2). In summary, the highest part of slope was well drained, the higher to intermediate part of slope was well drained to moderately well drained, the lower part of slope was moderately well drained to imperfectly drained, while the bottom part of slope was poorly drained. The poor drainage conditions at the bottom part of slope is likely to cause some micronutrient toxicity; and nitrogen deficiency because anaerobic bacteria which convert nitrates to ammonia multiply under these conditions (Cleveland and Soleri, 1991).

Conclusion

This study was carried out to examine soil physical properties in relation to crop production, soil genesis and environmental sustainability in the study area. The study revealed that the texture of surface soils in the study area are generally loams which should normally provide the right conditions for plant growth. However, the soils have undergone a great deal of sub soil compaction and reduction in available water holding capacity most likely due to continuous mechanized farming over the years. The high dispersion ratios of the soils and the low saturated hydraulic conductivity encountered below the surface soil implies high runoff rates and subsequent soil erosion. The erosional processes if not checked are likely to impoverish the soils while soil particles carried away in runoff water are likely to pollute and reduce storage capacity of nearby water reservoirs overtime. It is therefore recommended that conservation tillage systems be employed on a long term basis in place of the conventional tillage system being practiced in the area.

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