Soil Physical Conditions in Nigerian Savannas and Biomass Production

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The Savannas of Nigeria and Agricultural Production

Nigeria is located in the tropical zone (between latitude 4° and 14°N, and longitude 2°E), with a vast area having savanna vegetation (Figure 1). This is a region that is itself diverse, necessitating a classification into derived savanna, southern Guinea savanna and northern Guinea savanna. These classifications reflect environmental characteristics such as length of growing period, which for instance is 151-180 days for the northern Guinea savanna, 181-210 days for the southern Guinea savanna and 211-270 days for the derived savanna/coastal savanna (Jagtap, 1995). The major soils found in the various agroecological zones have coarse-textured surface soil, and are low in organic matter and chemical fertility (Tables 1-3). Although, yields can be improved by addition of inorganic and organic fertilizer, this can only be sustained and assured with high soil physical qualities. Soil physical qualities can be sustained at a high level with conservation tillage and soil conservation measures

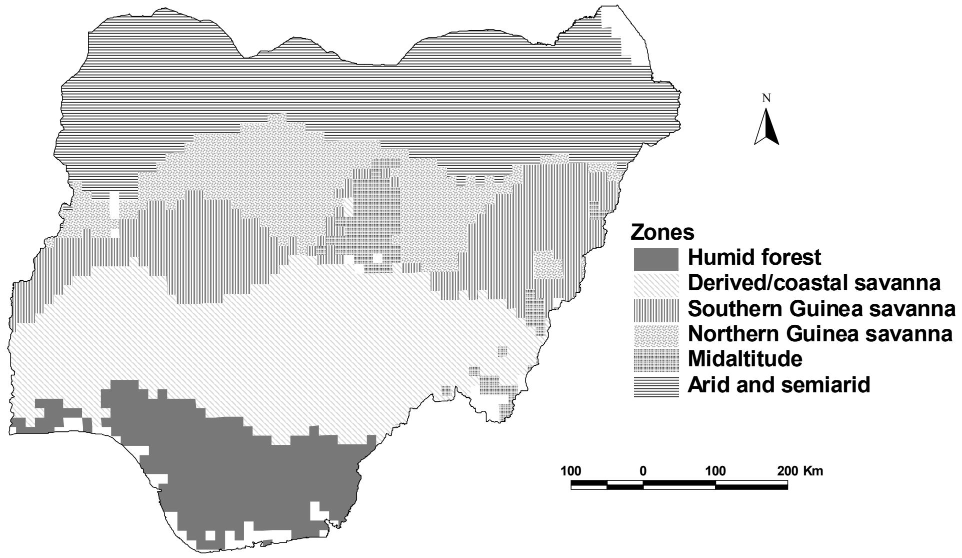

Fig. 1: Agroecological zones of Nigeria (Source: IITA GIS Unit, Ibadan, Nigeria)

Table 1. Some characteristics of agroecological zones of Nigeria (Source: Crop Modeling Unit, IITA, Ibadan, Nigeria).

Agroecological zone	Major soils (FAO classification)
Humid forest	Ferralsols, Nitosols and Gleysols
Derived/Coastal savanna (Moist savanna)	Ferrasols, Luvisols, Nitosols, Arenosols, Acrisols, Lithosols
Southern Guinea savanna (Moist savanna)	Luvisols, Acrisols, Ferralsols and Lithosols
Northern Guinea savanna (Moist savanna)	Luvisols
Mildaltitude savanna	Ferralsols, Nitosols

Table 2. Soil characteristics of soil in various agroecological zones of Nigeria Northern Guinea Savanna: Samaru, Zaria, Nigeria (Source: Oikeh et al., 1998)

	Soil depth (cm)			
Soil characteristics	0-17	17-31	31-82	>82
pH (H$_2$0)	5.2	4.9	5.4	5.3
Bulk density (Mg·m^{-3})	1.39	1.47	1.45	1.67
Water retention at -0.01 MPa (g·kg^{-1})	310	359	343	344
Water retention at –1.5 MPa (g·kg^{-1})	61	147	206	253
Sand (g·kg^{-1})	44	36	29	36
Clay (g·kg^{-1})	15	28	38	35

Derived savanna: Nsukka, southeastern Nigeria (Source: Igwe et al., 1995)

Soil characteristics	Soil depth (cm)			
	0-18	18-35	35-77	77-122
pH (H$_2$0)	5.77	5.02	5.35	5.01
Bulk density (Mg·m^{-3})	1.54	1.56	1.34	1.50
Sand (g·kg^{-1})	760	740	800	580
Clay (g·kg^{-1})	220	240	180	380

Table 3. Particle and gravel distribution (g·kg^{-1}) in the forest/savanna transition zone: Ibadan, southwestern Nigeria (Source: Salako et al., 1999).

Soil depth (cm)	Sand	Silt	Clay	Air-dried soil gravel content
0-15	834	94	72	124
15-30	745	95	160	120
30-45	706	105	190	128
45-60	658	97	245	172
60-90	646	83	271	232
90-120	616	109	275	125
120-150	618	128	254	156
150-200	644	175	181	144

Concepts of soil quality, degradation and sustainability

In one of the plethora of definitions, soil quality is defined as the capacity of a specific soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Brady and Weil, 1999). Thus, soil quality assessment reflects biological, chemical and physical properties, processes, and their interactions within each resource unit (Karlen et al., 2001). Lal (2001) stated that soil supports terrestrial life through five processes: (biomass production, (2) restoration and resilience of ecosystems, (3) purification of water, (4) detoxification of pollutants and (5) cycling of C, B, P, S and H_20. Soil quality is depleted as the soil is degraded through individual or combined processes of soil degradation which in the savanna region is mainly by soil erosion and compaction. When a soil is degraded, its capacity to produce biomass is reduced. Recovery of the soil through efforts to rehabilitate it depends on the inherent capacity of the soil and the level of degradation reached before rehabilitation efforts; soil resilience.

The soils of the savanna region are physically fragile (Tables 1-3) because the topsoil contains a large proportion of sand, causing weak aggregation given the low level of organic matter in this layer. The physical constraints are further compounded in gravelly soils (Table 3) or soils with shallow depth overlying plinthic or hardpan layers (Adeoye and Mohammed-Saleem, 1990; Salako et al., 2002).

The erosion of the 0-15 cm of the soil in Table 3 will lead to exposure of more gravel which will make working of the soil difficult. Also, the particle size distribution indicates that water retention is low while infiltration rate will be high. It is therefore imperative that appropriate soil management options for sustainable crop production and improved soil and environmental quality be found for the tropics.

Tillage, soil physical properties and crop production

Tillage is physical manipulation of the soil. Thus, the most profound effect of tillage is in relation to soil physical properties. For socio-economic and cultural reasons, manual tillage is still widely practiced in Africa as farming is largely at subsistence level. However, there are now a number of commercial farms especially for cash crop production in many parts of Africa. Many of these are located in locations which were hitherto reserved as forest and a need for sustainable production in pertinent to maintain ecological balance.

Soil physical properties which are altered by tillage are bulk density, water content, penetration resistance, soil temperature and aggregate stability. Tilled plots are more susceptible to soil erosion as soil aggregates will be loosened which leads to alteration of soil texture (Table 4; Lal, 1997a). Since the surface of the soil was low in clay content, silt was more eroded causing increase in sand content of tilled compared with no tillage plots as cultivation progressed from 1982 to 1986. Available water content and water infiltration were highest under no tillage and both were particularly low for ridge-tilled plots. Less erosion of particles enhanced water retention in the no till while the high infiltration rates were due to high macroporosity.

Mound tillage was also found to improve soil bulk density significantly compared to flat tillage in compacted soil ameliorated with planted fallows in southwestern Nigeria (Table 5). Such improvements in bulk density encourage root growth either for cereals, tuber crops or root crops in ridge tillage, mound tillage and deep tillage in different agroecological zones (Adeoye and Mohamed-Saleem, 1990; Salako *et al*., 2001). Rapid drying and increase in soil temperature on ridges and mounds occur if they are not mulched. Lal (1997b) advocated management of gravelly Alfsols in southwestern Nigeria with no tillage on short slopes (less than 100 m length) as the rate of increase in bulk density was higher for conventionally tilled plots compared with no tillage.

An interesting observation by Kirchhoff and Salako (2000) showed that after fallowing a degraded Alfisol caused by tillage and soil erosion in southwestern Nigeria for 6 years, the previously tilled plots under bare fallow (tilled up and down slope without crop cover) and conventional tillage still recorded more soil losses (1.78-2.83 t/ha) than the previous no tillage plots (1.34 t/ha). These results indicate that soil degradation caused by tillage cannot be easily obliterated. A land user should carefully weigh the options for tillage and no tillage before embarking on tillage. Conventional tillage should be avoided while conservation tillage should be practiced when tillage is adopted.

Table 4. Changes in soil particle size distribution of the 0-10 cm soil depth due to tillage between 1982 and 1986 on a Luvisol (Alfisol) in Ibadan, southwestern Nigeria (Lal, 1997b)

	Particle size distribution (g/kg)			AWC (%)	Equilibrium infiltration rate (cm/h)
Tillage treatment#	Sand	Silt	Clay	4.8	40
No till + mulch	738	86	177	4.3	30
No till + chisel	759	83	159	4.4	22
Ploughing	758	78	164	4.7	25
Disking	746	80	174	4.8	32
No till-mulch	748	82	168	5.4	24
Dry season ploughing	757	78	165	3.7	27
Ploughing + mulch	778	71	151	3.8	16
Ridge till	780	62	158	4.5	27
LSD (0.05)	23	12	NS	1.8	20

No till + mulch = no till + crop residue mulch, No till + chisel = no till + crop residue mulch and chiseling in the row to about 50 cm depth once a year, Ploughing = Mouldboard ploughing and two harrowings, Disking = Disc ploughing and rotovation, No till – mulch = No till – crop residue, Dry season ploughing = Mouldboard ploughing in the dry season and two harrowings just before seeding, Ploughing + mulch = Mouldboard ploughing and two harrowings + mulch, Ridging = Moldboard ploughing and two harrowings with contour ridging

Table 5. Improvement of soil bulk density by tillage after fallowing a compacted/hardsetting soil in southwestern Nigeria in 1995 (Salako et al., 2001)

	Tillage	
Fallow species	Level tillage	Mound tillage
P. phaseoloides	1.44	1.22
L. leucocephala	1.39	1.15
Natural fallow	1.35	1.17
Continuous cropping	1.45	1.35
Effect	P < 0.0001	

Soils which were naturally hardened or which had been compacted by machinery will probably need to be tilled to restore their productivity (Tables 6 and 7). Furthermore, Table 7 shows that there is an enhancement of fertilizer usage by tillage.

Table 6. Effect of deep tillage on maize grain and *Stylosanthes hamata* yields in Kurmin Biri grazing reserve, sub-humid northern Nigeria (Adeoye and Mohammed-Saleem, 1990)

Tillage system	Tillage depth or height of ridge (cm)	Maize grain (t/ha)	Dry matter of 'Stylo' (t/ha)
Disc harrowing	10- 15	4.00	5.48
Disc harrowing + subsoiling	40	4.93	6.87
Disc harrowing + ridging	25-30	4.21	5.04
LSD ($P < 0.05$)		0.84	0.84

Table 7. Tillage effects on yield of intercropped maize and cassava in southwestern Nigeria (Salako and Tian, 2003)

7a. Maize yield as affected by tillage and fertilization after 2 years of cultivating a degraded Alfisol

	Stover yield			Grain yield		
Nitrogen level (kg ha^{-1})	Mound	Level	Mean	Mound	Level	Mean
0 N	2.11	0.68	1.39	0.75	0.2	0.49
30 N	1.33	0.91	1.12	0.83	0.63	0.73
60 N	3.01	2.12	2.57	1.60	1.11	1.36
Continuous cropping	0.62	0.09	1.69	0.24	0.06	0.15
Mean	1.77	0.95		0.86	0.51	
Treatment means	LSD	*P*		LSD	*P*	
N level	1.042	0.0127		0.625	0.0091	
Manual tillage	0.817	0.0065		0.348	0.0343	
Tillage x N level	1.199	0.0379		0.69	0.0358	

Table 7b. Effects of tillage and different levels of N on intercropped cassava yields (t·ha^{-1}) on the degraded Alfisol in southwestern Nigeria in 1995/1996 crop year

	Cassava root yield		
Nitrogen level (kg ha^{-1})	Mound	Level	Mean
0 N	19.9	15.7	17.8
30 N	17.1	15.2	16.2
60 N	19.8	16.3	18.1
Continuous cropping	13.7	9.0	11.4
Mean	17.6	14.1	
Treatment means	LSD	P	
N level	6.4	0.0002	
Manual tillage	3.55	0.0034	
Tillage x N level	4.54	0.0432	

Fallow management, physical properties and crop production

Soils with coarse texture are not often sensitive to some physical parameters while some physical parameters are more relevant in a given study than others. Sustainable crop production researches in the tropics have focused on the role of planted fallows and their spatial arrangement (e.g., as in alley cropping) for many decades.

In some studies carried out in Nigeria, physical properties measured were water content by gravimetric and volumetric methods, bulk density by core method, aggregate stability by wet-sieving and drop method, penetrometer resistance, water retention characteristics using tension table and pressure-plate apparatus. Water infiltration rates were measured using double-ring infiltrometer. These methods are discussed by various authors in Klute (1986) and Carter (1993). There have been advances in many these methods but experiences are limited by availability of equipment. One of such is the use of less cumbersome equipment such as tension infiltrometers to measure saturated and unsaturated flow in the field (Topp et al., 1992) and the improvements in penetrometers which make dynamic measurements with soil depth possible. These equipments are often equipped with dataloggers that facilitate data management.

The effects of fallow management systems on soil physical properties and intercropped maize (*Zea mays* L.) grain were studied in Ibadan, southwestern Nigeria between 1994 and 1995 (Table 8). The A-horizon of the Alfisol at the site had a coarse texture which was rapidly degraded by continuous cropping. Soil physical properties improved with decrease in cropping intensities but the trend shown by aggregate stability under impact of water drops was not as discernible as other characteristics when compared to crop yield. Also, soil water retention was generally similar. The effects of fallow were obscured by the coarse-textured surface soil, and might not be noticed at all if the topmost layer (0-5 cm) of soil was not sampled. Thus, it is often difficult to detect changes in soil physical properties in coarse textured soils.

Table 8. Effects of various cropping intensities on soil physical properties and maize yield in Ibadan, southwestern Nigeria.

	Cropping intensities (%)				
Parameters	25	33	50	100	LSD (0.05)
Bulk density (0-10 cm depth)(g·cm^{-3})	1.18	1.21	1.25	1.31	0.05
Soil resistance within *Leucaena* hedgerow (kPa)	51	58	62	66	13
Soil resistance in *Leucaena* alley (kPa)	52	66	73	74	15
Number of water drops (0-5 cm depth)	108	117	109	86	22
Number of water drops (5-10 cm depth)	102	75	81	63	23
Grain yield in 1994 (t/ha)	3.11	-	-	1.19	0.36
Grain yield in 1995 (t/ha)	-	1.85	1.47	0.86	0.24

Experiences with advanced equipment

Disc permeameter: In-situ techniques of measuring soil hydraulic properties constitute one of the major advances in soil physics in the last three decades (Topp et al., 1992). Prior to the development of such techniques, unsaturated water flow had in particular been determined largely with models or inferred from other soil physical properties such as texture. However, the advent of tension infiltrometers or disk permeameters had made it possible to evaluate such flows directly on the field (White et al., 1992).

Water transmission characteristics under different fallow management systems shown in Figure 2 were measured with the CSIRO disc permeameter in southwestern Nigeria in 1996. The equipment can be used to generate data on cumulative infiltration, infiltration rate, sorptivity, steady-state flow rate, hydraulic conductivity, macroscopic capillary length and mean pore size (CSIRO, 1988). These parameters are calculated from infiltration theories, particularly those proposed by Philip (1957). Sorptivity, which is water uptake by the soil when there is no gravitational effect (Philip, 1957), is a good index of how these fallow management systems have influenced soil structure. It provides information on the soil's absorption rate and varies with initial water content and structural stability (Hamblin, 1985).

Using the CSIRO (1988) manual as guide, cumulative infiltration, infiltration rates and difference d between final (volumetric water content at measurement potential or θ_m) and initial soil water (θ_i) content ($m^3 \cdot m^{-3}$) were calculated from the data collected from fallow management plots at Ibadan southwestern Nigeria. Sorptivity s, steady-state flow rates, hydraulic conductivity K ($cm \cdot h^{-1}$), macroscopic capillary length λ_c (cm) and characteristic mean pore size λ_m (cm) were calculated.

Sorptivity s ($cm \cdot h^{-0.5}$) was obtained as the slope of the cumulative infiltration (cm) plotted against the square root of time ($t^{0.5}$ where t is in h). The steady state flow rate SF was found from the plot of cumulative infiltration as a function of time during the last part. The calculation of hydraulic conductivity at each water supply head was based on steady state flow rate and sorptivity:

$$K = SF - 4bs^2 \cdot (\pi r d)^{-1} \tag{1}$$

where r is the radius of the disc permeameter ring and b = 0.55 (shape factor).

Steady-state infiltration was actually assumed to occur during the last part of the saturated flow (at 10 mm water supply head) because flow was very rapid and water in the calibrated reservoir was usually exhausted in less than 6 minutes.

The macroscopic capillary length was calculated from

$$\lambda_c = bs^2 / dK \tag{2}$$

and the characteristic mean pore size λ_m was calculated from

$$\lambda_m = 7.4/ \lambda_c. \quad (3)$$

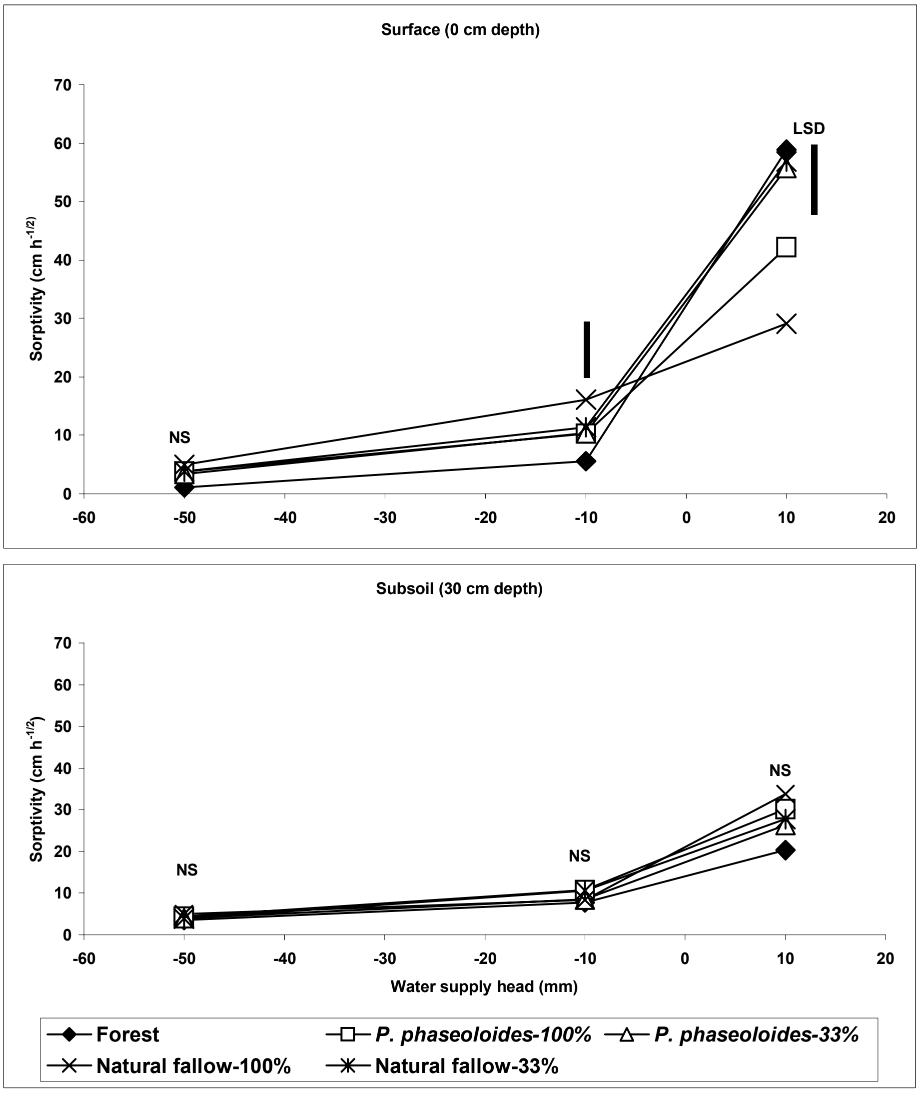

Figure 2. Water transmission characteristics under different fallow management systems measured with a disc permeameter in Ibadan, southwestern Nigeria

Although the sorptivity values appeared reasonable when compared with data obtained with the traditional double-ring infiltrometer for saturated flow, many negative values of hydraulic conductivity K were obtained. Positive values of K were obtained in all observations made on the soil surface (0 cm depth) at –10 mm water supply head. Also, the hydraulic conductivity for 0 cm depth at –50 mm water supply head was generally positive, and was left out because the observation implied the use of the shape factor. Thus, the negative values were usually under the following conditions: saturated water flow (+ 10 mm water supply head) irrespective of depth, and subsoil (30 cm soil depth) irrespective of water supply potential. Mean pore sizes could not be evaluated reasonably because of the various negative hydraulic conductivity values.

It was assumed that the observations of unrealistic negative values of hydraulic conductivity were due to soil heterogeneity and/or change in soil structure during measurements, i.e. collapse of macropores. Soil physical heterogeneity was accentuated at the site by the gravel interspersing soil particles. Thus, it appears the simplifying assumptions in calculating hydraulic parameters with the disc permeameter have to be modified for applicability in heterogeneous tropical soils.

Penetrometer: Penetrometers can be broadly classified as static or dynamic (Herrick and Jones, 2002). Most static penetrometers consist of a rigid, cone-tipped rod attached to a pressure-measuring device while dynamic penetrometers supply a known amount of kinetic energy to the penetrometer and are not subject to operators' variability. In the gravely soils of University of Agriculture, Abeokuta, Nigeria a cone penetrometer in the dynamic category called RIMIK CP20 penetrometer had been used to evaluate variability of soil strength with depth (Figure 3). This penetrometer uses an ultrasonic method for measuring depth (AGRIDRY RIMK PTY Ltd (1994). In Figure 3, changes in penetrometer resistance in the gravelly coarse-textured soils with depth in the dry season were affected by gravel concentration. The measurements were taken in a field which had a vegetation biomass of 32 t/ha for trees and 18 t/ha for grasses and herbaceous plants. Field water content within 0-50 cm depth was less than 20 g/kg. A maximum value of 5000 kPa was not actually recorded but assumed for the impenetrable depths of some points which were penetrated at others. Overall, penetrometer could only reach a depth of 325 mm at some points although it was configured to read up to 500 mm depth. The value of 5000 kPa is the maximum possible measurement by the cone penetrometer. A reading of 3628 kPa was recorded at the 0-25 mm soil depth, indicating that the gravel in the soil can constitute impediment to root growth. Soil water content was very low as these measurements of penetrometer resistance were carried out in February. The soil strength data indicated that roots can easily be deformed at this site in the bid to grow in soil interspersing gravel, since they cannot penetrate gravel. It was also indicated that impediment to root growth can be encountered from the surface as it was possible to record penetrometer resistance existing 3600 kPa. Roots may meet lesser resistance in the wet season when most crops are grown but this expectation may be dashed due to presence of the stones and gravel. Crop root growth may be drastically impeded at soil strength values exceeding 2500 kPa, depending on management practices.

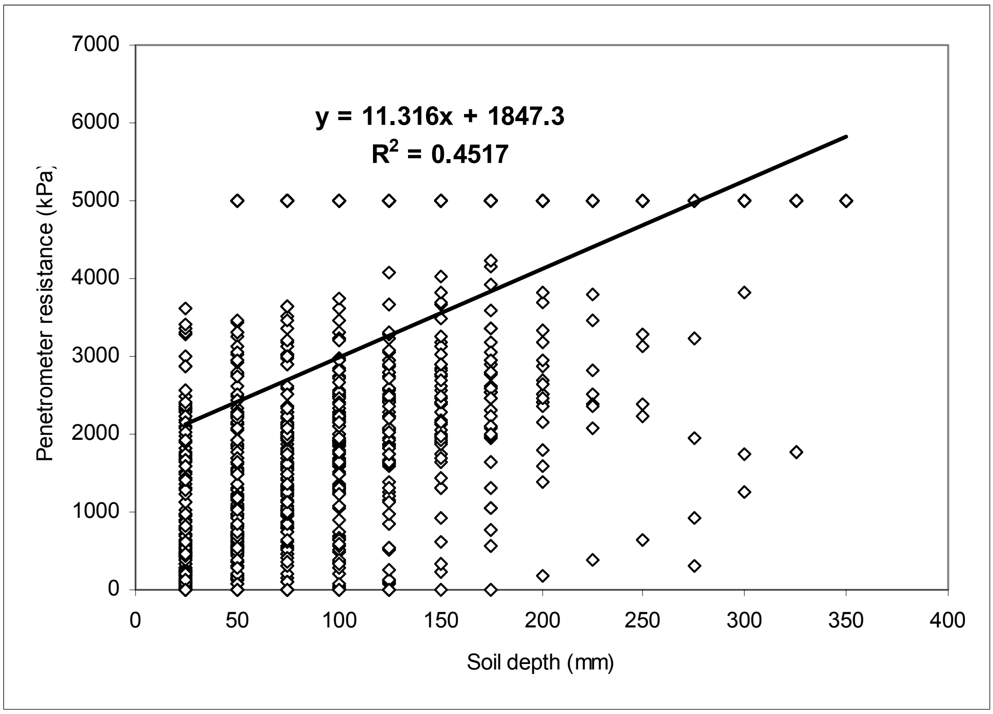

Figure 3. Penetrometer resistance (kPa) on a field under fallow at Abeokuta, southwestern Nigeria in February 2001. Gravel and stones constituted impediments to penetrometer as they would to plant roots even in topsoil (Salako F. K. unpublished).

Concluding remarks

Application of soil physics in the area of food production and environmental management still lags behind other sub-disciplines of soil science, particularly soil fertility in the tropics. A great challenge is posed by the vast area of upland soils which are made up of coarse-textured soils and in some cases gravel and stones. Aggregates of such soils are weak, they loose productivity fast and do not retain adequate water and nutrients for sustainable production. These characteristics imply that even with the best of soil fertility amendments, soil physical conditions must be managed to achieve sustainable crop production. Plant growth had to be encouraged in the soils, such that enough biomass is produced for food and soil management. Another area which requires attention in the tropics is with regard adaptability of equipment for accurate evaluation of soil physical properties. Most commercially available equipment in the field of soil physics needs to be modified to suit the tropical environment.

References

Adeoye, K. B., and Mohamed-Saleem, M. A. 1990. Comparison of effects of tillage methods on soil physical properties and yield of maize and stylo in a degraded ferruginous tropical soil. Soil & Tillage Research 18: 63-72

Brady, N.C. and Weil, R.R. 1999. The nature and properties of soil. 12th edition. Prentice Hall, New Jersey, USA. 881 pp.

Carter, M. R. (editor) 1993. Soil sampling and methods of analysis. Canadian Society of Soil Science/Lewis Publishers, Boca Raton, Florida, USA.

CSIRO, 1988. CSIRO disc permeameter instruction manual. CSIRO Center for Environmental Mathematics, Canberra, Australia.

Hamblin AP 1985. The influence of soil structure on water movement, crop root growth, and water uptake. Advances in Agronomy 38, 95-157.

Herrick, J. E. and Jones, T. L. 2002. A dynamic cone penetrometer for measuring soil penetration resistance. Soil Science Society of America Journal 66: 1320-1324.

Igwe, C. A., Akamigbo, F. O. R. and Mbagwu, J. S. C. 1995. Physical properties of soils of southeastern Nigeria and the role of some aggregating agents in their stability. Soil Science 160: 431-440.

Jagtap, S. S. 1995. Environmental characterization of the moist lowland savanna of Africa. In: Kang, B. T., Akobundu, I. O., Manyong, V. M., Carsky, R. J., Sanginga, N. and Kueneman, E. A. (editors), Moist savannas of Africa: Potentials and constraints for crop production. Proceedings of an IITA/FAO Workshop held from 19-23 September 1994, Cotonou, Republic of Benin, pp. 13-30.

Karlen, D. L., Andrews, S. S. and Doran J. W. 2001. Soil quality: Current concepts and applications. Advances in Agronomy 74: 1-40.

Klute, A. (editor). 1986. Methods of soil analysis. Part 1. Physical and mineralogical methods. 2nd edition. American Society of Agronomy-Soil Science Society of America, Madison, Wisconsin, USA.

Kirchhof, G. and Salako, F. K. 2000. Residual tillage and bush-fallow effects on soil properties and maize intercropped with legumes on a tropical Alfisol. *Soil Use and Management.* 16: 183-188.

Lal, R. 1997a Long-term tillage and maize monoculture effects on a tropical Alfisol in western Nigeria. I. Crop yield and soil physical properties. *Soil & Tillage* 42: 145-160.

Lal, R. 1997b. Soil degradative effects of slope length and tillage methods on Alfisols in western Nigeria. 3. Soil Physical properties. *Land Degradation and Development* 8: 325-342.

Lal, R. 2001. Managing world soils for food security and environmental quality. Advances in Agronomy 74: 155-192.

Oikeh, S. O., Chude, V. O., Carsky, R. J., Weber, G. K. and Horst, W. J. 1998. Legume rotation in the moist tropical savanna: Managing soil nitrogen dynamics and cereal yields in farmers' fields. Experimental Agriculture 34: 73-83.

Philip JR 1957. The theory of infiltration: Sorptivity and algebraic equations. Soil Science 84, 257-264.

Salako, F. K., Babalola, O., Hauser, S. and Kang, B. T. 1999. Soil macroaggregate stability under different fallow systems and cropping intensities in southwestern Nigeria. Geoderma 91: 103-123.

Salako, F. K., Hauser, S., Babalola, O. and Tian, G. 2001. Improvement of the physical fertility of a degraded Alfisol with planted and natural fallows under humid tropical conditions. *Soil Use and Management* 17: 41-47.

Salako, F. K., Tian, G. and Kang, B. T. 2002. Indices of root and canopy growth of leguminous cover crops in the savanna zone of Nigeria. *Tropical Grasslands* 36: 33-46.

Salako, F. K. and Tian, G. 2003. Management of a degraded Alfisol for crop production in southwestern Nigeria: Effects of fallow, mounding and nitrogen. *Journal of Sustainable Agriculture* (In press).

Topp, G. C., Reynolds, W. D. and Green, R. E. (editors) 1992. Advances in measurement of soil physical properties: Bringing theory into practice. Proceedings of a symposium sponsored by Division S-1 of the Soil Science Society of America in San Anthonio, Texas 21-26 Oct 1990. Soil Science Society of America Publication 30.

White, I., Sully, M. J. and Perroux, K. M. 1992. Measurement of surface-soil hydraulic properties: Disk permeameters, tension infiltrometers, and other techniques. In: Topp, G. C., Reynolds, W. D. and Green, R. E. (editors) 1992. Advances in measurement of soil physical properties: Bringing theory into practice. Proceedings of a symposium sponsored by Division S-1 of the Soil Science Society of America in San Antonio, Texas 21-26 Oct 1990. Soil Science Society of America Publication 30. pp. 69-103.