FOR SOIL TO OIL THE NATION: ADVANCING THE FRONTIERS OF CONSERVATION AGRICULTURE IN NIGERIA

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All Non-Teaching Staff,
Members of my Family and Friends,
Special Guests,
Gentlemen of the Press,
Distinguished Ladies and Gentlemen,
Great FUNAABITES

1.0 EXORDIUM

I give God the glory for making it possible for me to deliver my Inaugural Lecture today. This is the second Inaugural Lecture to be delivered from the Department of Soil Science and Land Management, which I was privileged to head from February 2001 to January 2006, and January-March, 2008. **It is the first to be delivered in the sub-discipline of Soil Physics/Soil Conservation** while it is the ninth from the College of Plant Science and Crop Production. God must always be glorified because when I thought it was worthy to be a Professor, and only a Professor, I was just a boy in the Apostolic Church Grammar School, Orishigun Village (between Ketu and Mile 12), Lagos, without even an understanding of what it would take, and in which discipline; Humanities or Science? I only admired the few men and very few women in Nigeria then who were Professors.

I became a Soil Scientist because the University of Nigeria, Nsukka *assigned* me to the Department of Soil Science as a fresh student, who was admitted into the Faculty of Agriculture in 1978. I applied to study Agriculture and did not even know Soil Science was an option under the programme. By virtue of hindsight, the University did not make a mistake. Not at all, because this must have been a divinely guided assignment.

As a Soil Scientist, let me quickly posit that soil is not dirt; it is a natural resource, like crude oil. From biblical records, man was made from dust before *God breathed life into him* (Genesis 2: 7). Therefore, soil has been relevant to the existence of life from creation. To quote White (2006),"there is little merit in attempting to give a rigorous definition of soil because of the complexity of its make-up, and of the physical, chemical and biological forces that act on it."

Nonetheless, let me adopt the following definitions of soil by Brady and Weil (2002) for this lecture:

I. A dynamic **natural body** composed of mineral and organic solids, gases, liquids and living organisms which can serve as a medium for plant growth
II. The collection of natural bodies occupying parts of the Earth's surface that is capable of supporting plant growth and that has properties resulting from the integrated effects of climate and living organisms acting upon parent material, conditioned by topography, over periods of time.

Thus, Brady and Weil (2002) states that the soil functions as (i) medium of plant growth, (ii) regulator of water supplies, (iii) recycler of raw materials, (iv) habitat for soil organisms, (v) an engineering medium, and (vi) an interface for various components of the environment.

The emphasis on plant growth is a reflection of the strong link Soil Science has with Plant/Crop Science. It must, however be stated that although Soil Science evolved as an agricultural science, it has a life of its own as a Science that is linked to both agriculture and environment (Ellis and Mellor, 1995; Brady and Weil, 2002; Sparks, 2003; White, 2006; Salako, 2010a). The pedosphere or the soil environment is strongly linked to the atmosphere, biosphere and the hydrosphere, all of which define the totality of the environment. The soil holds the key to mitigation or even eradication of hunger, poverty, environmental pollution and adverse effects of climate change.

For Nigeria, out of a total land area of 923,768 km^2, only 36% was cultivated by 2005 (http://en.wikipedia.org/wiki/Land_use_statistics_by_country). Furthermore, Nigeria has 13000 km^2 of its total land area occupied by water, and just about 31% of it as arable land (CIA Factbook: http://www.factbook.org/factbook/ni.shtml) . Marginal lands are being cultivated in Nigeria, perhaps due to population pressure but more importantly due to nonchalant attitude to soil information. Some facts are quite incontrovertible for anyone with a good knowledge of Nigerian history:

- Agriculture was the mainstay of Nigerian economy before and after independence up to the period of oil boom (1971

-1983) (www.onlinenigeria.com/economics)

- Since the oil boom came into being, agriculture became a venture practiced more at subsistence level, with exports for food dwindling while imports of certain crop commodities like rice (which Nigeria can produce abundantly) increased
- There is the paradox of oil boom and oil gloom; a matter of the more money accruing from crude oil, the more miserable majority of Nigerians become. The more you look, the less you see.

Another fact that experts agree on is that the problem of unemployment in Nigeria or anywhere in the world can be solved with a virile investment in commercial, large-scale agriculture and agro-allied industries. This, unfortunately, cannot be achieved without a virile investment in natural resource conservation.

When God gave man the charge to have dominion over all things He created, He gave a directive (Genesis 1: 28): "*And God blessed them, and said unto them, Be fruitful, and multiply,* ***and replenish the earth****, and subdue it: and have dominion over the fish of the sea, and over the fowl of the air, and over every living thing that moveth upon the earth*". Ladies and Gentlemen, I understand "r**eplenish the earth**" as God's (divine) command to man to conserve natural resources for his own good. *Is man not failing*

God in this respect?

My area of specialization in Soil Science is Soil Physics/ Soil Conservation. Soil Conservation has traditionally been considered as Applied Soil Physics, being focused mainly on soil erosion, tillage and irrigation studies. It has, however, expanded beyond these limits in recent times with environmental issues such as soil pollution and remediation, carbon sequestration and climate change coming to the fore as parts of the responsibilities of the Soil Conservationist or Soil Physicist .

It has, therefore, been my responsibility over the last three decades to study soil as a natural resource that must be conserved both for sustainable production of crops and improved quality of the environment under different land uses. Let me also state that I took peculiar interest in going deeper than the topsoil (usually 0-20 cm depth at undisturbed sites) in some of my studies because I believed that this approach separated Soil Scientists from many other scientists who use soil as a mere object of their studies. Afterall, a Soil Scientist must know that the upper limit of soil is the boundary between soil and air, while the lower limit is arbitrarily set at 200 cm depth ((USDA/NRCS, 1999). I concur with the statement of Dobrovol'skii (2006) that "specialization in different branches of soil science (soil chemistry, soil physics, soil biology, soil geography, and soil cartography) should be based on solid background of comprehensive natural and humanitarian education"

2.0 MY CONTRIBUTIONS TO KNOWLEDGE: A CONCATENATION OF CATENAE

A catena is "a sequence of soils of about the same age, derived from similar parent materials and occurring under similar conditions, but having different characteristics because of variations in relief and drainage" (Brady and Weil, 2002). In this section, I wish to synthesize the various works which were carried out on different landscapes and in different agro-ecological zones of Nigeria; the savannas, the humid forest, and the semi-arid/arid zones. The inter-connections or inter-dependence of the various landscapes in terms of soil management are enunciated under the broad umbrella of "the tropics" or "tropical environment". This, of course, excludes my one-year stint, of research work, on soil water flux using (digital) tensiometers and an isotopic technique in Venice, Italy in 2007.

I worked largely in what today can be encapsulated as **Conservation Agriculture and Environmental Soil Science.** I studied soil erosion in relation to climate and vegetation, as well as quality of runoff water. Included in this respect were studies related to soil water balance. Conservation agriculture entails maximizing crop yields with minimum inputs or resources while sustaining soil productivity and protecting the environment (ISSS, 1996).

My works were specifically in the following areas:

i. Rainfall Characteristics and Erosivity
ii. Soil Erodibility and Aggregate Stability
iii. Soil Erosion, Soil Productivity Loss and Rehabilitation of Degraded Soils
iv. Fallow Management, Agroforestry, Soil Properties and Biomass Production
v. Soil Physical Characterization, Geostatistics and Fractal Analysis
vi. Soil Productivity under different Soil Management Options

The specific topics under these broad topics have contributed to various review papers by Salako (2002a; 2010a), Salako and Bachman (2002) and Salako and Tian (2004a).

2.1 Homage to the Forerunners

The foundation for my research works was laid in 1983 by the late **Professor (then Dr.) Joe Sonne Chinyere Mbagwu** (who passed on to eternity in 2008) in the Department of Soil Science, University of Nigeria, Nsukka (UNN). I was among the first set of students he supervised for B.Agric. projects in 1982/83 session. He did not only open up his personal library for me, he took me through research work and writing, such that I could lay claim to having a research paper published as early as 1985 (Mbagwu and Salako, 1985). He made me participate in writing this paper from my B.Agric. Project (Salako, 1983) by recalling me during my National Youth Service at Ahmadu Bello University, Samaru, Zaria to come to his home at Nsukka, for me to be part of writing the publication. **It was a very great inspiration and lesson for me to have a teacher who treated me as a son. May the soul of Prof. J. S. C. Mbagwu continue to rest in peace. My first visit for a training programme at Abdus Salam International Centre for Theoretical Physics (ICTP) Trieste, Italy in 1993 was facilitated by Prof. Mbagwu. The Centre subsequently provided great support for further researches when I joined FUNAAB, particularly between 2000 and 2009.**

In spite of not being assigned to be my Supervisor, **the late Prof. Mbagwu linked me with the International Institute of Tropical Agriculture (IITA), Ibadan for an appointment as a Research Scholar under Dr. Rattan Lal to carry out my M.Sc. research,** which I registered for in the Department of Soil Science UNN. I actually returned to Nsukka for the M.Sc. (1984-1986) because of him but we had no option than to accept the position of the Department on the assignment of another great Soil Physicist, Professor M. E. Obi.

Prof. Rattan Lal, now of Ohio State University, Ohio, USA is unarguably one of the foremost Soil Physicist in the World, and a voice on issues related to Soil Erosion and Conservation, (Conservation) Tillage, Carbon Sequestration, and Climate Change and its Mitigation. **Prof. Mbagwu, again mentored me to see the link between my B. Agric. project (Salako, 1983) and a part of my M.Sc. thesis (Salako, 1986) for me to develop my second research paper as a single author, that is, Salako (1988)**.

There were other teachers who I cannot just allow to be *subsumed* as co-authors in presenting this Inaugural Lecture: These were late Prof. OlaOlu Babalola, former Soil Physicist, Department of Agronomy, University of Ibadan, Ibadan who supervised my PhD thesis (1992-1997); late Dr. B. T. Kang, formerly Soil Fertility Specialist and Agro-Forester, IITA, Ibadan who was my main Supervisor as an IITA Research Associate between 1989 and 2000 and who encouraged me to carry out independent researches in the area of Soil Physics; Dr. Stefan Hauser, Soil Scientist, IITA who provided additional grant for my PhD thesis between 1992 and 1997; Dr. Guanglong Tian and Dr. Gunnar Kirchhof , both former Soil Scientists at IITA, who encouraged me further to carry out independent researches. It was virtually impracticable for a Research Associate to enjoy the grace of God that I had to carry out independent researches, then at IITA.

Still talking about mentorship and training, I worked as a Consulting Soil Scientist for TCI Consulting Associated in Ibadan but mainly in collaboration with Prof. A. G. Ojanuga (then of the University of Agriculture, Makurdi) between 1987 and 1989. We surveyed over 30000 ha of agricultural lands in old Bauchi (including current Gombe State) and Sokoto (including current Kebbi State) States for the various jobs done on Soil Survey and Land Evaluation for Irrigation Agriculture in northern Nigeria. It was the "apprenticeship" under Prof. A. G. Ojanuga that exposed me to practical (field) experience in Soil Survey and Pedology. I cannot, but say this formed the basis of my philosophy today that **a true Soil Scientist must dig deeper than the topsoil**.

My point: Although the afore-mentioned were co-authors in my various publications, they were more than that. They were the people that God, in His infinite mercy, placed at strategic junctions of my life to make me a Soil Scientist. Suffice to say here that "My Contributions to Knowledge" is not about me alone but also about the various Scientists I worked with, who are reflected as co-authors in both my published and unpublished data.

2.2. Rainfall Characteristics and Erosivity in Nigeria

2.2.1. Rainfall types and Duration

A rainfall event may either be equal to daily amount or not.

An event is a rainfall that falls continuously or intermittently without being separated from another event by a period up to 6 hours or more. My various studies have shown that a rainfall event can be taken as the daily rainfall amount in Nigeria or indeed the tropics, because virtually all the rain data collected showed that rains would either stop falling completely until another day, rather than being separated for a period up to 6 hours or more (Salako, 1986; 2006a; Salako *et al*., 1995a). **That is, rains that fall intermittently do not often have a separation period of 6 hours in a day**.

Rainfall can be characterized by types of storms, depending on when it reaches its peak intensity or intensities. According to Schwab *et al*. (1993), the classes of rainstorms are (a) Advanced, (b) Composite (c) Intermediate, and (d) Delayed. The proportions of these storm types (Figures 1-5; Tables 1 and 2) have been computed for rains in southern Nigeria (Salako, 1986; Obi and Salako, 1995; Salako *et al*. 1995a).

The practical significance of the classification of storms is the fact that **all storm types complement each other, to complicate the process of soil erosion**. Furthermore, all storm types occur any time during the rainy season (Table 1). In southern Nigeria, rainfall events between 100 and 200 mm were observed, and this could last up to 22 hours (Obi and Salako, 1995: Salako *et al*. 1995a; Salako, 2006a).

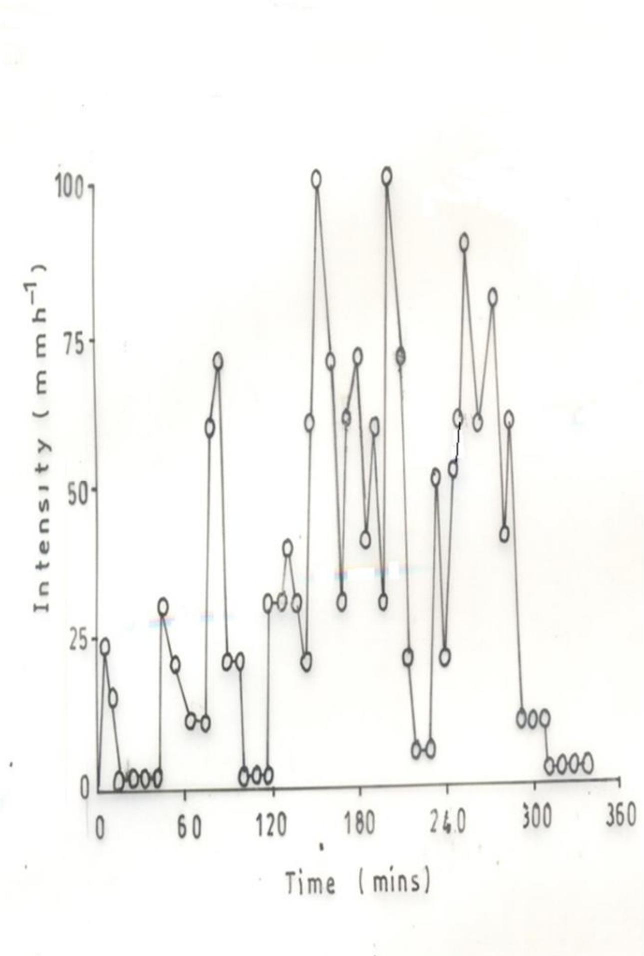


Figure 1: An Exceptional Storm with multiple peak intensities (also an Intermediate Storm Type) on July 15, 1978 at Umudike, southeastern Nigeria (Source: Salako, 1986)

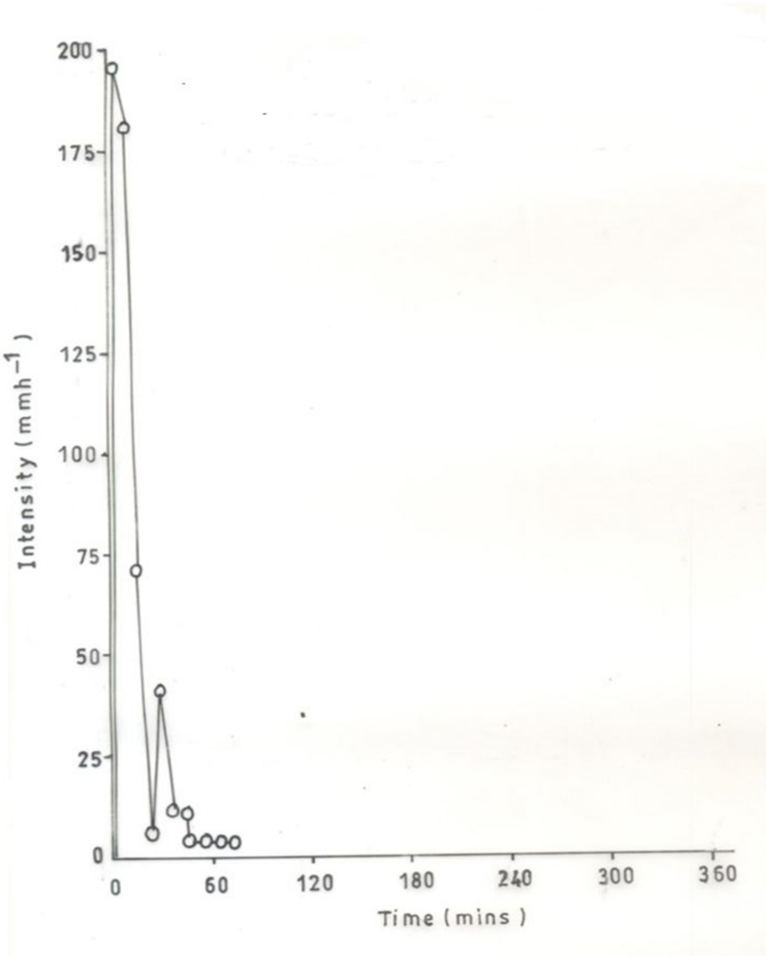


Figure 2: An Advanced Storm with early peak intensity on November 14, 1980 at Owerri, southeastern Nigeria (Source: Salako, 1986)

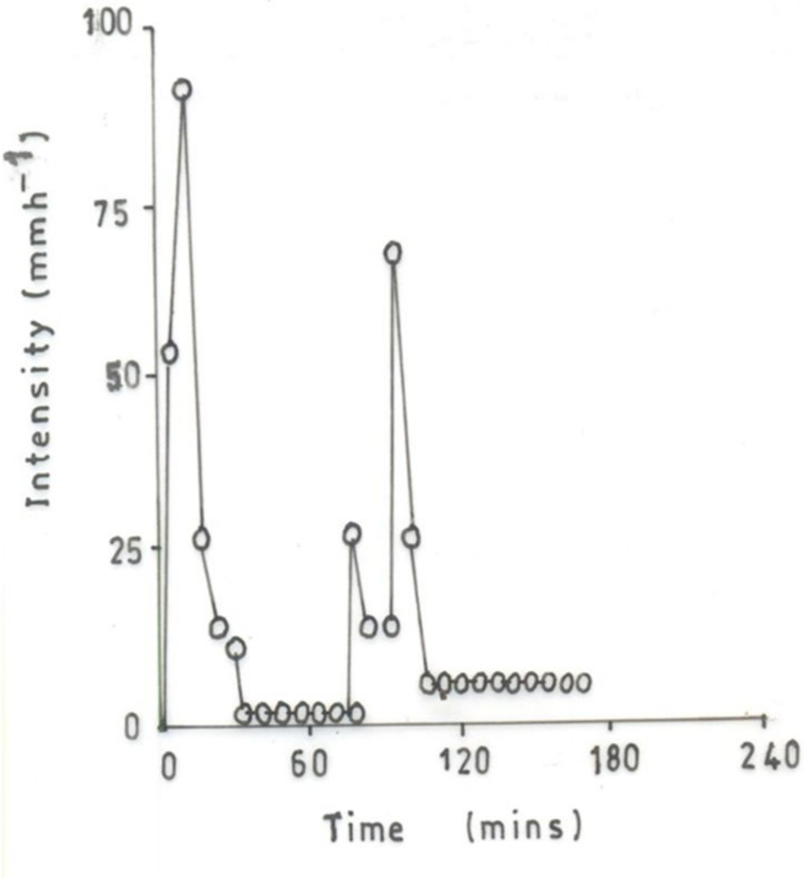


Figure 3: A Composite Storm with two distinct peak intensities on September 24, 1971 at Owerri, southeastern Nigeria
(Source: Salako, 1986)

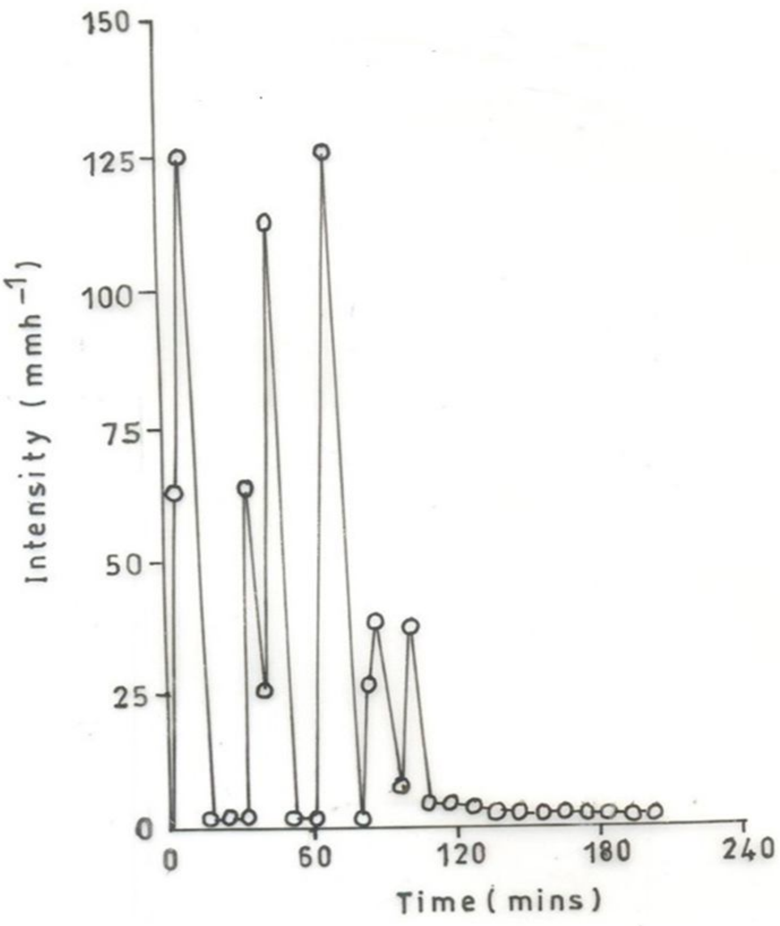


Figure 4: An Intermediate Storm with multiple peak intensities on May 13, 1978 at Nsukka, southeastern Nigeria
(Source: Salako, 1986)

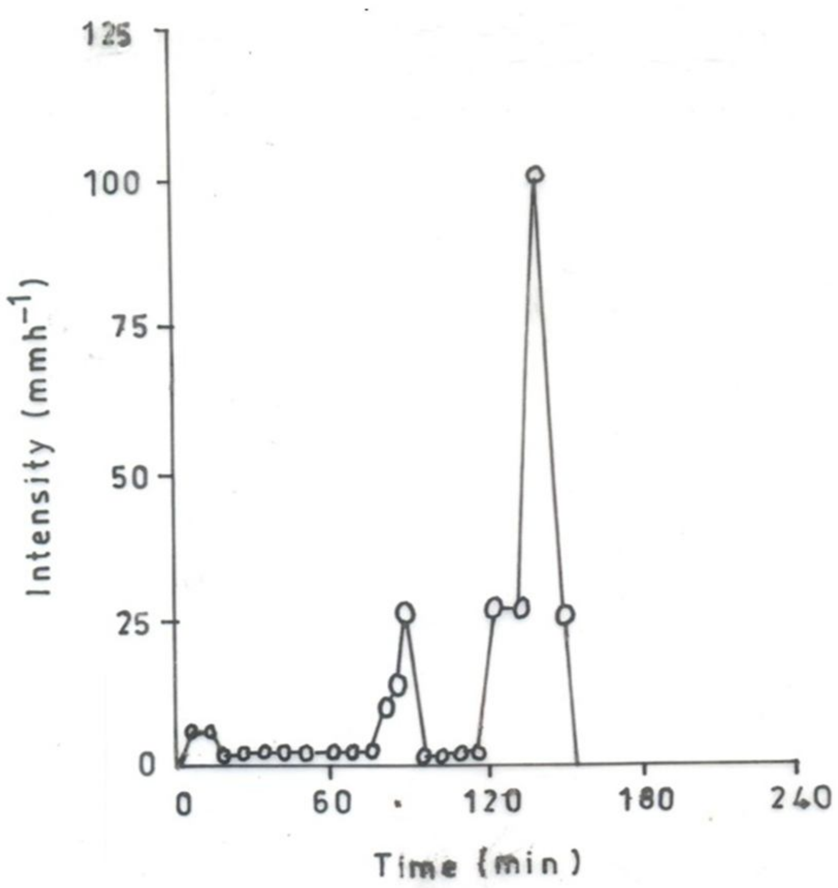


Figure 5: A Delayed Storm with delayed peak intensity on September 22, 1975 at Port-Harcourt, southeastern Nigeria (Source: Salako, 1986)

Table 1: Rainfall (storm) types in different agroecological zones of southeastern Nigeria

Location	Zone	Study period	Storm type (%)		
			Advanced	Composite/ Intermediate	Delayed
Nsukka	Southern Guinea Savanna	1976-1983	57	36	7
Umudike	Forest	1974-1985	51	31	18
Owerri	Forest	1973-1982	51	39	10
Port-Harcourt	Forest/ Coastal	1973-1981	46	42	12

(Source: Salako 1986; Obi and Salako, 1995)

Table 2. Rainfall (storm) types in different periods of the year in southeastern Nigeria

Period	Location	Storm type (%)	
		Advanced	Others
January-April	Nsukka	8.1	3.2
	Umudike	16.8	6.3
	Owerri	10.9	6.4
	Port Harcourt	11.6	8.1
May-August	Nsukka	25.4	25.4
	Umudike	22.5	29.5
	Owerri	23.5	25.2
	Port Harcourt	19.0	27.8
September-December	Nsukka	23.3	14.6
	Umudike	11.3	13.6
	Owerri	17.2	16.8
	Port Harcourt	15.8	18.3

(Source: Obi and Salako, 1995)

Therefore, a gentle rain (low intensities) can be a precursor of flooding and enormous erosion by first wetting the soil to saturation before a high-intensity long-duration rain. According to these authors, average rain duration is 1.0 to 4 hours during the average rain-days of 75-137 per annum in southern Nigeria.

2.2.2. Diurnal variation of rainfall

My co-authors and I were among the very few people who have taken time to analyse diurnal variation of rainfall, that is, frequency of rainfall within day and night time in the tropics, and perhaps, the first in Nigeria (Salako *et al*. 1995a; Salako, 2008a). This is relevant to evaporation of soil water during the daytime (Jackson, 1989), and perhaps hydraulic conductivity and infiltration of water in relation to thermal condition of surface soil. At Okomu, near Benin city, 61% of rain occurred during daytime (06.00 to 18.00 h), 29% during the night (18.00 to 6.00 h) whereas 10% did not conform to the categorization (Salako *et al*., 1995a).

At Ibadan, 48% of rain fell during daytime whereas at Port-Harcourt, 69% of rains were observed in daytime (Figure 6; Salako 2008a). When considering agroecological zones, major differences can occur in diurnal variation, as observed between 9 .00 and 21.00 h for Ibadan and Port-Harcourt (Onne) (Figure 6).

2.2.3. Rainfall and throughfall drop sizes and distribution

Rains fall in drops. There are various techniques to measure the drop sizes and distribution; the flour-pellet method was used at Nsukka and Okomu (Obi and Salako, 1995; Akinnifesi and Salako, 1997). Throughfall is rain that passes through a plant canopy. The bigger the sizes, the more erosive the raindrops. Raindrop sizes at Nsukka ranged from 0.6 to 3.9 mm with the dominant size exceeding 2 mm (Obi and Salako, 1995), At Okomu, near Benin City, the maximum raindrop size measured was 5.1 mm with a median drop size of 3.1 mm (Salako *et al*., 1995a).

Although only 22% of raindrops were between 3 and 5 mm, this was very substantial for this range of large drops. These drops were erosive splashing between 24 and 1641 g m^{-2} of sand, which has the largest size among soil particles.

In what was then an emerging study area worldwide, Akinnifesi and Salako (1997) reported that canopies of 5-year old trees which were about 11 m tall transformed raindrops sizes to bigger, more erosive drops in plantations and a natural forest (Table 3). This showed that it was possible to have splash erosion under tree canopies if the floor was bare. Larger drops were formed with a mixed canopy of the natural forest. Structure of leaves (e.g., broad leaves in *Gmelina* versus pinnate leaves in *Senna*) also had influence on throughfall drop sizes. Lal (1998) also characterized raindrops in Ibadan, Nigeria.

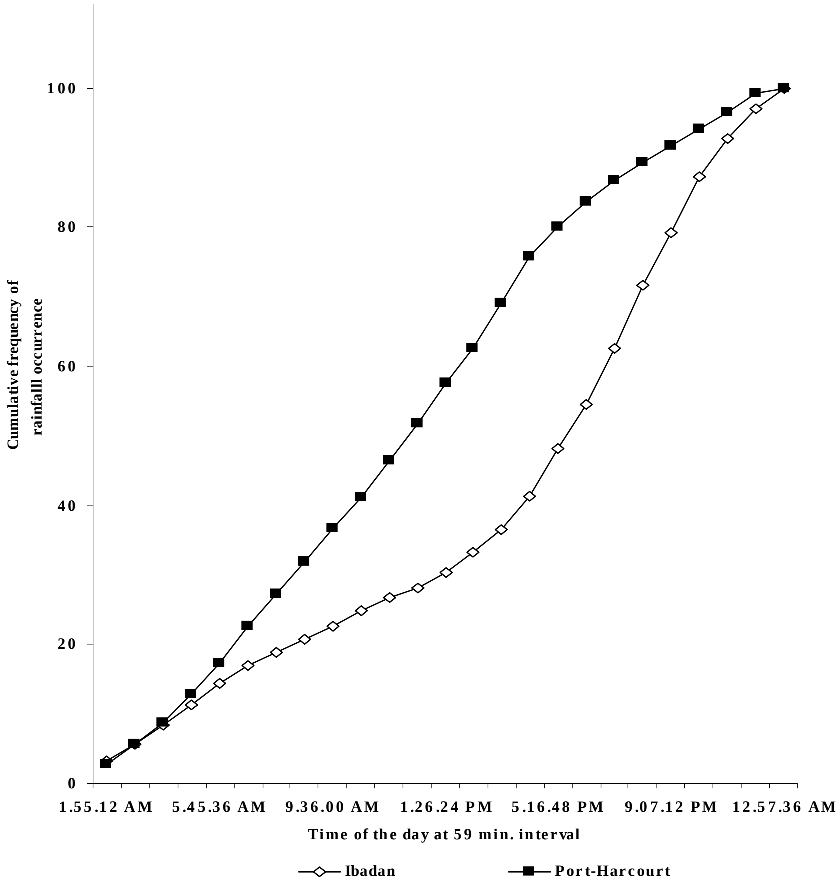


Figure 6: Diurnal variation of rainfall occurrence between the humid (Port-Harcourt) and sub-humid (Ibadan) zones of Nigeria (Source: Salako, 2008a)

2.2.4. Rainfall intensity

By the time we were carrying out studies on rainfall characterization in relation to soil erosion, automatic raingauges were very rare in Nigeria and in many developing nations. Yet the data of instantaneous recording of rainfall amount per time were needed to compute short-interval (mainly, 6-, 7.5- and 15-minute-) intensities for a very lucid understanding of rainfall erosivity. It was, therefore, a great opportunity for me to work with rainfall charts that spanned 1973-1985 for different locations in southeastern Nigeria (Table 1; Salako, 1986; Obi and Salako, 1995); 1986-1990 for Okomu, near Benin city (Salako *et al*., 1995a), and 1997-1999 for Ibadan and Onne, Port-Harcourt (Salako, 2006a; 2007; 2008a; 2009; 2010b).

The Ibadan and Port-Harcourt intensity-class distributions are adequate for the understanding of trend of rainfall intensity-class distribution in the tropics (Figures 7-9). The various studies have shown that 49-55% of rainfall would fall at erosive intensities, taken as those exceeding 25 mm h^{-1}, the threshold value Hudson (1965; 1995) reported for onset of erosion in the tropics. Furthermore, extreme intensities greater that 150 mm h^{-1} occurred from 5% of rainfall amount. **Worse still, the extreme intensities (75-150 mm h^{-1}) intensities**

occurred yearly, except for those greater than 150 mm h^{-1} (Table 4).

Table 3: Drop sizes and sand splashed by rain and throughfall in Okomu, near Benin city, Nigeria

Rainfall or Throughfall Location	Drop size (mm)		Splashed sand (g)	
	Median	Maximum	Fine sand	Medium sand
Cleared area	2.3	5.1	35 ± 7.9	28 ± 6.4
Gmelina arborea	3.6	5.3	33 ± 5.0	43 ± 7.0
Senna siamea	3.2	5.2	30 ± 5.6	37 ± 6.1
Natural forest	4.0	5.3	40 ± 9.2	46 ± 10.6

(Source: Akinnifesi and Salako, 1997)

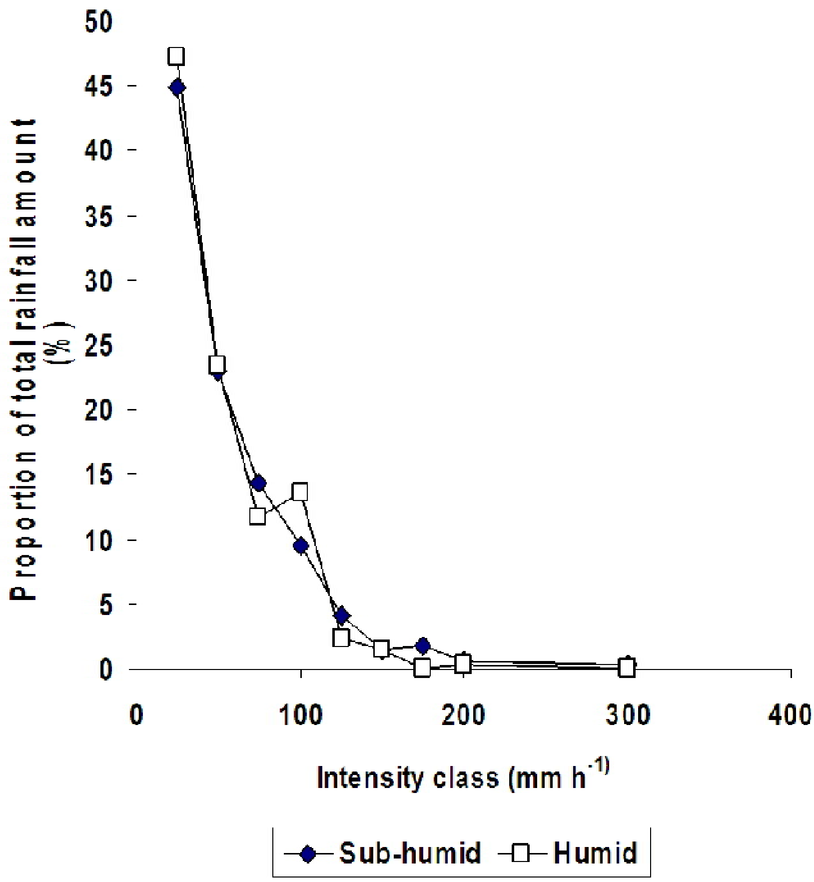


Figure 7: Proportion of rainfall contributing to different classes of intensity in Ibadan (sub-humid zone) and Port-Harcourt (Humid/ Coastal zone)
(Source: Salako, 2006a)

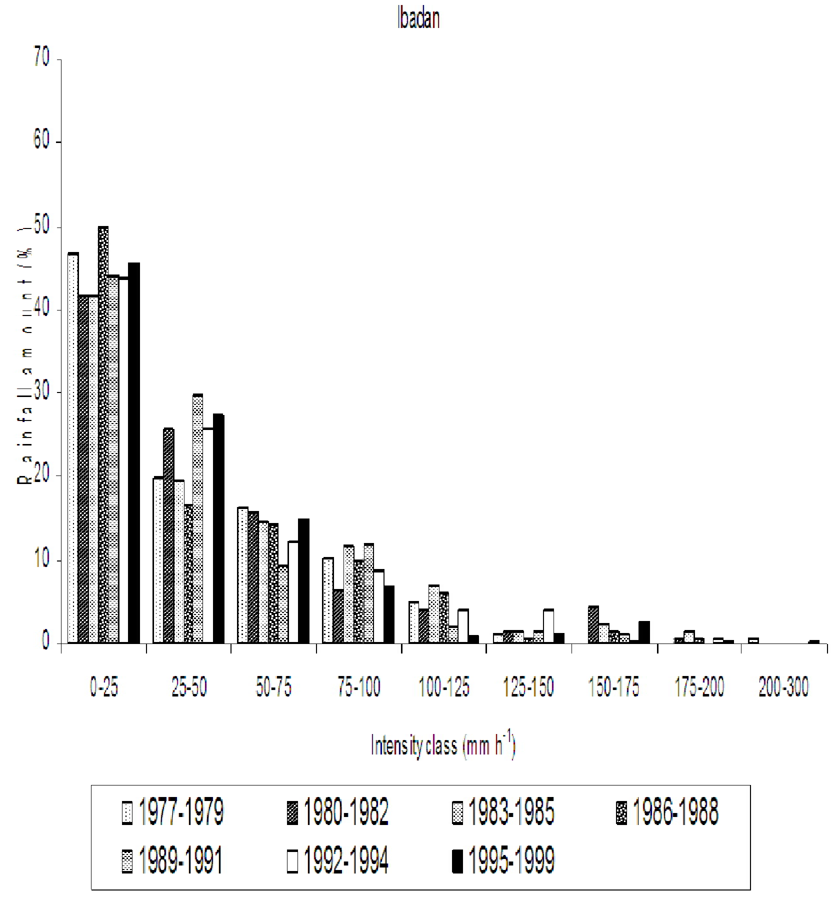


Figure 8. Rainfall amount-intensity class distribution at annual intervals at Ibadan, southwestern Nigeria (Source: Salako, 2008a)

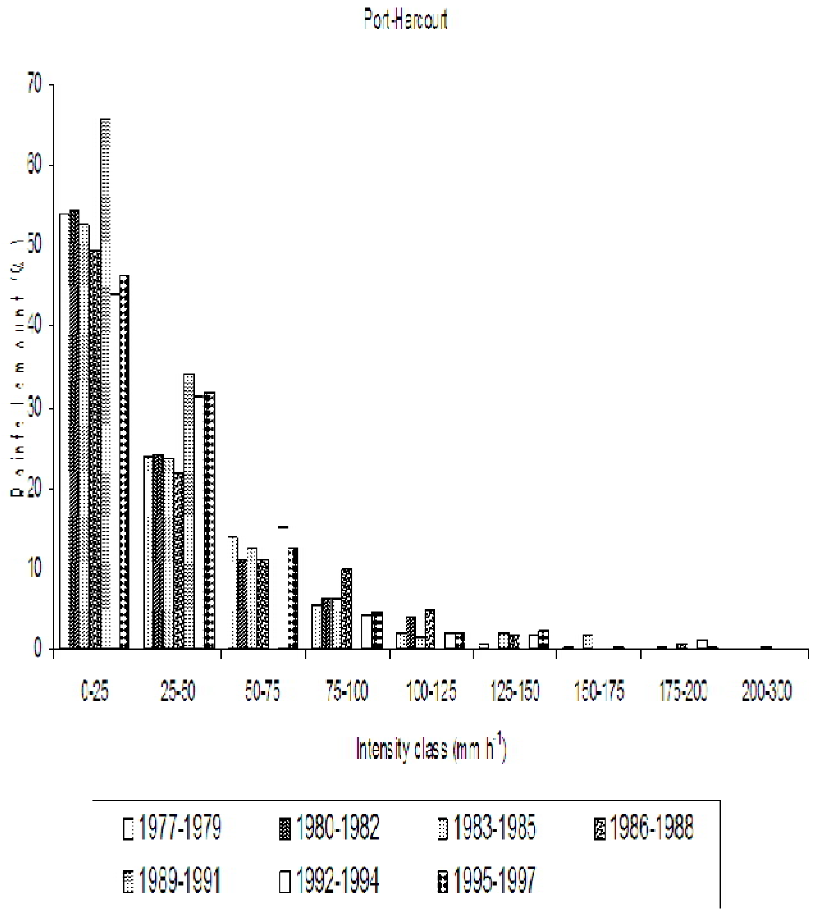


Figure 9. Rainfall amount-intensity class distribution at annual intervals at Port-Harcourt, southeastern Nigeria (Source: Salako, 2008a)

Table 4: Return periods of extreme rainfall intensities in southern Nigeria: Ibadan (sub-humid zone) and Port-Harcourt (Humid/Coastal zone)

Rainfall Zone	Rainfall intensity class (mm h^{-1})				
	100-150	150-180	180-200	200-250	>250
	Return period (years)				
Sub-humid	1	2	4	9	17
Humid forest	1	3	5	13	17

(Source: Salako, 2006a)

2.2.5. Rainfall intensity and climate change

With the opportunity of having up to 22-year data of automatic raingauge charts for Ibadan and Port-Harcourt (Onne), I worked on the trends in rainfall intensity, albeit rainfall erosivity with a view to understand climate change (Figures 8 and 9; Salako 2006a; 2008a). This was premised on the belief that short-interval, high intensity rains needed to be understood rather than monthly or annual rainfall alone, if soil erosion and flooding which were being attributed to climate change must be better explained.

Temporal variations (Figures 8 and 9) in rainfall intensity classes suggest an increasing trend of intensities between 25 and 50 mm h^{-1} in southern Nigeria. Furthermore, intensity class of 150-300 mm h^{-1} was more pronounced in the sub-humid than humid zone. The results showed that event or daily analyses of rainfall amount and duration removed the obscurity of information when data were analysed on annual basis. **While there was a decreasing trend in annual rainfall amount, there was an increasing trend in erosive rainfall intensities observed on a 7.5-15-minute time-scale**. Let me re-emphasize that the detection of these erosive intensities would not have even been possible if we had computed intensity as "daily" rainfall amount divided by 24 h (a day), as many analysts do, erroneously or out of convenience. **It was made possible with the analyses of rainfall amount within short intervals, and can be better done these days with automatic weather stations, which use digital recordings which may be configured to read at smaller durations even less than 5 minutes.**

2.2.6. Rainfall erosivity indices

Apart from short-term rainfall intensity, rainfall erosivity indices included kinetic energy (*E*, in MJ ha^{-1}) of rainfall (Hudson, 1965; 1995; Kowal and Kassam, 1976; Wischmeier and Smith, 1978; Renard *et al*. 1997), product of event or daily rainfall amount (*A*) and maximum short-term intensity (I_m), (AI_m in $cm^2 h^{-1}$; Lal, 1976), product of kinetic energy E, and maximum 30-minute intensity, I_{30} (EI_{30} in MJ. mm ha^{-1}. h^{-1}; Wischmeier and Smith, 1978; Renard *et al*. 1997).

The most popular among these indices is the EI_{30}, which is used to calculate rainfall erosivity factor, *R*, in the Universal or Revised Universal Soil Loss Equation, USLE (Wischmeier and Smith, 1978; Renard *et al*. 1997). Two other indices were developed for tropical countries so that the *R* factor could be computed from monthly and annual rainfall amounts (Arnoldus, 1977; Roose, 1977).

Values of all these popular indices were computed for different agro-ecological zones in Nigeria (Salako, 1983; 1986; 1988; 2006a; 2007; 2008a; 2010b; 2010c; Salako *et al*., 1995a; Mbagwu and Salako, 1985; Obi and Salako, 1995). Some variants of these popular indices found suitable for our environment were proposed by us. These studies also revealed that annual rainfall amount might be decreasing but rainfall erosivity was increasing, particularly at smaller-time scale. For instance, the fact that annual rainfall amount in the savanna was relatively low compared to the humid zone, this did not imply that rainfall erosivity there, on a daily basis, was low. It was actually increasing because the reduced annual rains fell within shorter intervals.

The climax of my studies on rainfall erosivity since 1983 came with studies published between 2006 and 2010 (Salako 2006a; 2007; 2008a; 2010b; 2010c) when I published parameters to compute short-term rainfall intensity and kinetic energy from daily or event rainfall, and consequently providing tools for computing erosivity indices on daily, monthly, seasonal and annual bases (Tables 5-7). The equation is of the type, aA^b, with the parameters, a and b, varying for agroecological zones. Variants of the erosivity indices such as EI_{15}, which is a product of E and maximum 15-minute intensities, I_{15} were also computed purposely for the tropical environment. The importance of these equations or model parameters (Tables 5-7) lies in the fact that a Soil Conservationist can compute soil losses for any given time-scale (daily, seasonally or annually) using the Revised Universal Soil Loss Equation (RUSLE).

Table 5: Regression parameters of the model, $R = aA^b$, for the prediction of rainfall erosivity index (dependent variable) from rainfall amount (mm) (independent variable) in southern Nigeria. Dependent variable, R is EI_{30} index (MJ mm ha^{-1}h^{-1}); $P < 0.001$

	Constants		r^2	N
Rainfall zone	Intercept, *a*	Slope, *b*		
Daily erosivity index (R) versus daily rainfall amount (A)				
Sub-humid	0.66	1.74	0.86	1511 days
Humid	0.27	1.94	0.96	2106 days
Annual erosivity index (R) versus annual rainfall amount (A)				
Sub-humid	1.08	1.32	0.55	22 years
Humid	2.17	1.19	0.69	12 years

r^2 = Coefficient of determination

n = number of observations (days or years)

(Source: Salako, 2006a)

Table 6a: Daily parameters of erosivity index relationship, $L = aA^b$, with independent variable being daily rainfall, A (in mm); $P < 0.001$, number of observations > 1500 days

Dependent variable, daily L	Intercept, a	Slope, b	Coefficient of determination, r^2
	Ibadan		
I_{30} (mm h^{-1})	3.71	0.698	0.65
I_m or I_{15} (mm h^{-1})	4.42	0.77	0.64
AI_m (cm^2 h^{-1})	0.04	1.76	0.90
	Port-Harcourt		
I_{30} (mm h^{-1})	1.80	0.82	0.87
I_m or I_{15} (mm h^{-1})	2.91	0.77	0.73
AI_m (cm^2 h^{-1})	0.03	1.77	0.93

Table 6b: Annual parameters of erosivity indices with independent variable being annual rainfall, A (in mm); $P < 0.01$, number of observations, 15 years for Ibadan, 12 years for Port-Harcourt

Dependent variable, annual L	Intercept, a	Slope, b	Coefficient of determination, r^2
	Ibadan		
I_{30} (mm h^{-1})	8.62	0.76	0.46
I_m or I_{15} (mm h^{-1})	26.34	0.67	0.56
AI_m (cm^2 h^{-1})	0.40	1.07	0.66
	Port-Harcourt		
I_{30} (mm h^{-1})	2.29	0.90	0.74
I_m or I_{15} (mm h^{-1})	12.96	0.72	0.49
AI_m (cm^2 h^{-1})	0.01	1.44	0.89

(Source: Salako, 2007)

Table 7a: Regression parameters of the model, $R = aA^b$, for the prediction of daily erosivity (dependent variable) from daily rainfall amount (mm) (independent variable) in southern Nigeria (P < 0.001)

Rainfall erosivity index	Intercept, *a*	Slope, *b*	Coefficient of determination, r^2
	Ibadan (n = 1511 days)		
E (MJ ha^{-1})	0.126	1.180	0.97
EI_{30}-BF (MJ mm ha^{-1} h^{-1})	0.492	1.864	0.89
EI_{15}-BF (MJ mm ha^{-1} h^{-1})	0.579	1.940	0.86
	Port-Harcourt (n = 2106 days)		
E (MJ ha^{-1})	0.113	1.205	0.98
EI_{30}-BF (MJ mm ha^{-1} h^{-1})	0.223	2.057	0.97
EI_{15}-BF (MJ mm ha^{-1} h^{-1})	0.355	2.005	0.92

Table 7b: Regression parameters of the model, $R = aA^b$, for the prediction of annual erosivity (dependent variable) from annual rainfall amount (mm) (independent variable) in southern Nigeria (P < 0.001)

Rainfall erosivity index	Intercept, *a*	Slope, *b*	Coefficient of determination, r^2
	Ibadan (n = 22 years)		
E (MJ ha^{-1})	0.273	0.969	0.90
EI_{30}-BF (MJ mm ha^{-1} h^{-1})	9.814	0.998	0.44
EI_{15}-BF (MJ mm ha^{-1} h^{-1})	7.114	1.108	0.59
	Port-Harcourt (n = 18 years)		
E (MJ ha^{-1})	0.130	1.070	0.98
EI_{30}-BF (MJ mm ha^{-1} h^{-1})	0.302	1.462	0.78
EI_{15}-BF (MJ mm ha^{-1} h^{-1})	1.023	1.335	0.82

(Source: Salako, 2008a)

While EI_{30} is the recommended index for USLE or RUSLE, EI_{15} can be used for tropical environment to prevent underestimation of *R* factor.

2.2.7. Development of isoerodent maps for Nigeria

Ladies and Gentlemen, if providing tools for computing rainfall erosivity indices at a given time-scale was a climax, the development of isoerodent maps for Nigeria gave me a better satisfaction that I could elevate the foundation laid by the late Prof. Joe Sonne Chinyere Mbagwu at Nsukka to a superstructure at the national level. I have developed various isoerodent maps for Nigeria (Salako, 2010b) for the purpose of Land Evaluation, and Soil Conservation Planning (Figures 10-13).

The annual or monthly *R* factor value can be obtained straight from the isoerodent maps, and if it must be re-computed for different time-scales starting from daily to annual, the model parameters (Tables 5-7) can be applied. Although, Salako (2010c) drew annual iso-erodent maps with modified Fournier index in which it was found that annual values close to annual EI_{30} values of the maps in Salako (2010b) were obtained, the smaller time-scale used in Salako (2010b) makes me feel convinced to recommend it over the modified Fournier index, which with my experience has often been miscalculated by neophytes who did not pay attention to units of measurements of the original USLE and its conversion to *SI* units in relation to Fournier index.

Soil conservationists, agronomists, hydrologists, environmentalists and engineers can use the models and maps (Tables 5-7; Figures 10-13; Salako 2006a; 2007; 2008a; 2010b) in soil erosion and flood control studies. These tools have removed the difficulties of finding appropriate erosivity index value for different locations in Nigeria, and indeed the tropics.

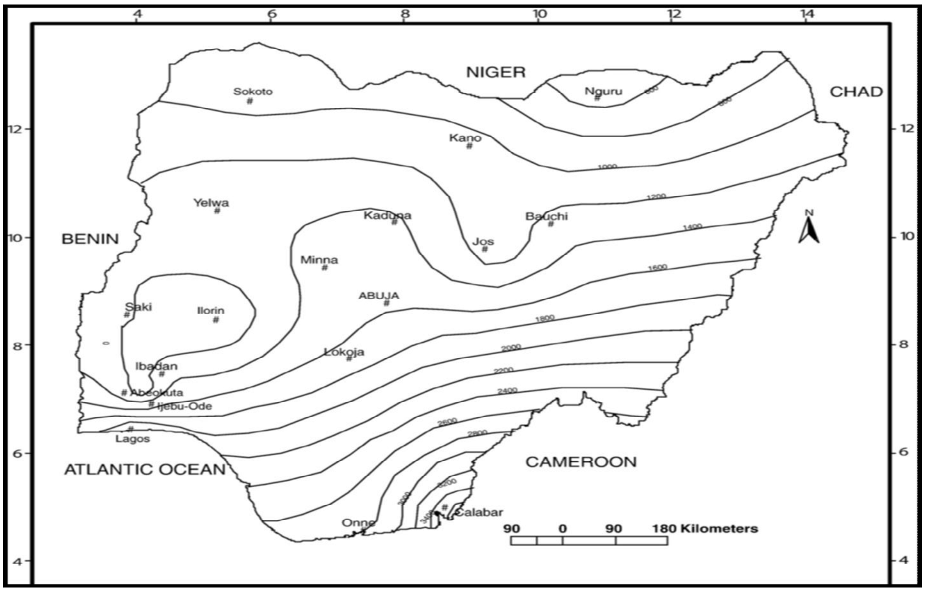


Figure 10: Isoerodent map of Nigeria with mean monthly values of EI_{30} (MJ mm ha^{-1} h^{-1}) index during the rainy season, May–October (Source: Salako, 2010b)

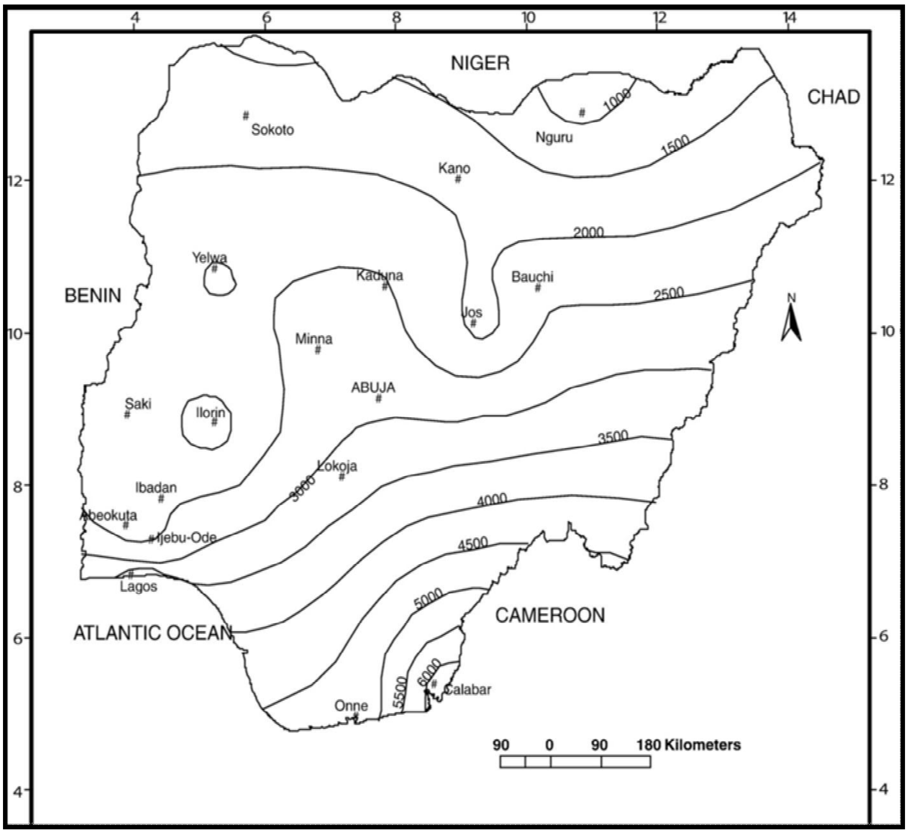


Figure 11: Isoerodent map of Nigeria with mean monthly values of EI_{15} (MJ mm ha^{-1} h^{-1}) index during the rainy season, May–October (Source: Salako, 2010b)

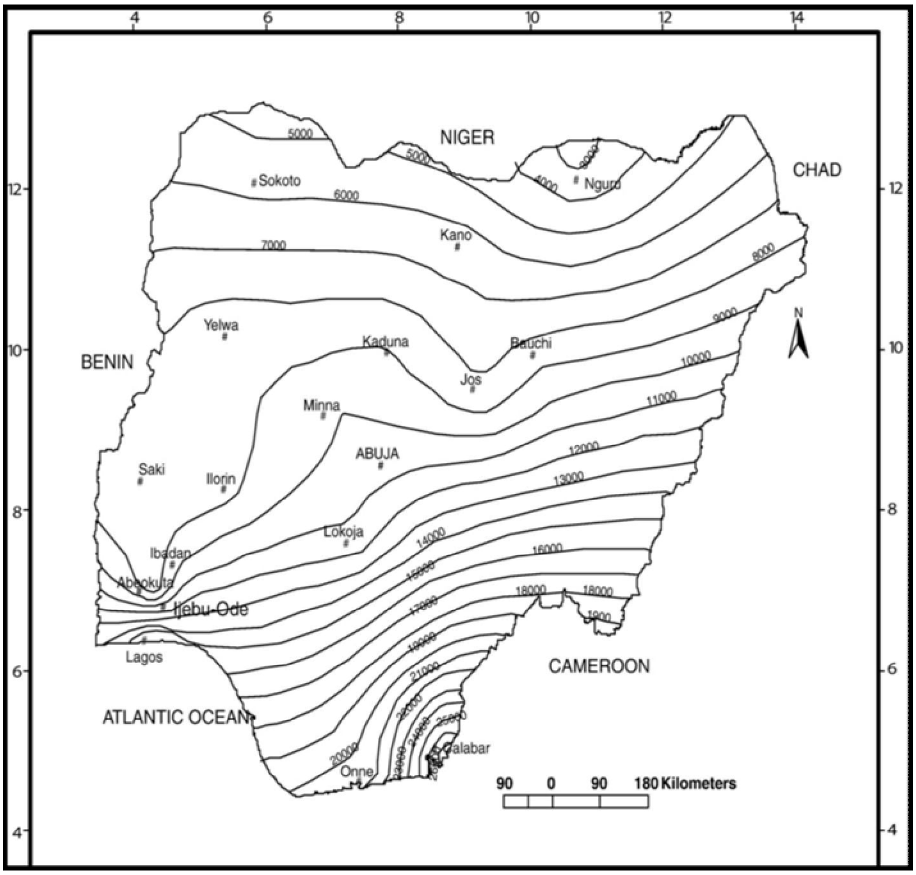


Figure 12: Isoerodent map of Nigeria with annual values of EI_{30} (MJ mm ha^{-1} h^{-1}) index
(Source: Salako, 2010b)

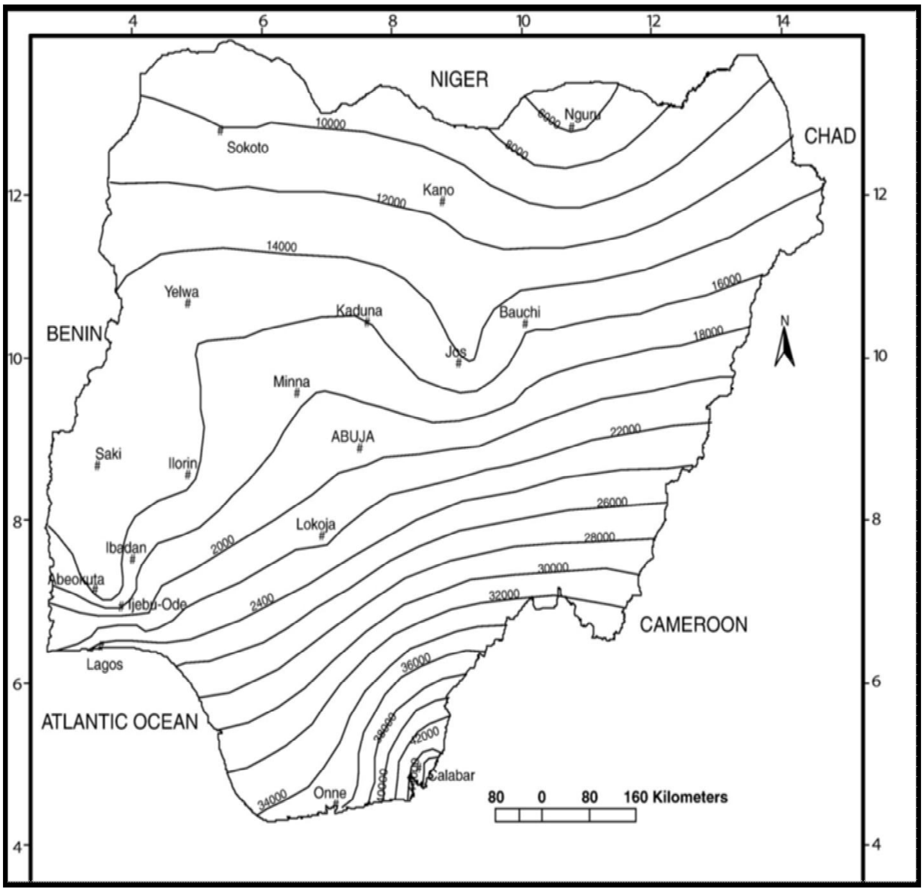


Figure 13: Isoerodent map of Nigeria with annual values of EI_{15} (MJ mm ha^{-1} h^{-1}) index
(Source: Salako, 2010b)

2.3. Soil Erodibility and Aggregate Stability

Soil erodibility is the susceptibility of soil to erosion, whereas soil aggregate stability is the resistance of soil aggregates to disruptive forces. These disruptive forces are usually from rainfall or wind, both agents of soil erosion. Soil aggregates are formed when flocculated (colloidal) soil particles are cemented together by agents such as organic matter, iron and aluminum hydroxides. Thus, soil erodibility and aggregate stability are two sides of the same coin because the stability of soil aggregates are often measured by their resistance to disruptive forces.

Soil erodibility can be measured directly using what is called soil erosion or runoff plots but can rapidly be assessed using some soil properties (Wischmeier and Smith, 1978; Renard *et al*., 1997; Hudson, 1995; Lal and Shukla, 2004). It can also be measured using a rainfall simulator. Soil aggregate stability can be measured using wet-sieving method to simulate resistance to rainfall disruptive force or dry sieving method to simulate resistance to wind disruptive force. Furthermore, it can also be assessed using soil properties.

In Southeastern Nigeria, Obi *et al.* (1989) assessed soil erodibility of soils from different parent materials using four methods: wet-sieving technique, the Wischmeier *et al*. (1978) nomograph, portable rainfall simulator and runoff plot measurements. The wet-sieving technique indicated that soil aggregate stability was high, ranging from 70–92 percent for five most stable soils. Estimated values of soil erodibility ranged from 0.002 to 0.058 Mg h MJ^{-1} mm^{-1} using the nomograph and from 0.006 to 0.09 Mg h MJ^{-1} mm^{-1} for dry runs and 0.002 to 0.07 Mg h MJ^{-1} mm^{-1} for wet runs, using the rainfall simulator. Furthermore, actual measurement of erodibility from runoff plots of a sandy loam soil at Nsukka, typifying the dominant soils of the region, gave erodibility value of 0.007 Mg h MJ^{-1} mm^{-1} compared to values of 0.012 and 0.03 Mg h MJ^{-1} mm^{-1} using the nomograph and the rainfall simulator techniques. Thus, the nomograph approach was not really suitable for measuring soil erodibility in southeastern Nigeria in spite of its high popularity due to its being a component of the (R) USLE. In spite of this finding, I recommend its use with the rainfall erosivity factor values in Salako (2010b) for decisions on soil conservation planning using RUSLE, with a conscious effort to compensate for the error margin.

Soil aggregate stability has also been evaluated under different fallow management systems in southwestern Nigeria (Salako, 1997; Salako *et al*., 1999; 2001; Salako and Hauser, 2001). Apart from the conventional mean-weight diameter (MWD) and geometric mean diameter (GMD) used for evaluating aggregate stability, Salako *et al*. (1999) also used fractal analysis for its evaluation of aggregate stability in southwestern Nigeria and extended the use of fractal analysis to describe particle size distribution for soils found in Nigerian savannas in some other studies (Salako, 2006b; 2006c). Mean-weight diameter and GMD are actually indices of macroaggregate (> 250 µm) stability (Salako and Hauser, 2001). Indices of microaggregate stability (< 250 µm) include dispersibility of clay in water relative to a standard dispersant (Salako, 2001; Salako *et al*., 2006a)

Aggregate stability was greatly influenced by type of fallow, slope position and seasonal variations (Salako, 2003; 2004; Salako *et al*., 1999). It was imperative to consider fallow management based on intensity of cultivation of soils (Kirchhof and Salako, 1998; 2000). Significant effects of the interactions of cropping intensity and fallow systems were mainly observed with soil samples taken at 0-5 cm depth (Table 8) but generally not with samples taken at 5-10 and 10-15 cm depth. Organic carbon of the 0-5 cm depth did not exceed 35 g kg^{-1} at 0-5 and generally < 20 g kg^{-1} for 5-10 cm and 10-15 cm. **Organic matter is low in this soil, and must be preserved at land clearing stage and by management practices that can build it up, as it enhances soil quality and productivity.** Conventional tillage and poor or no ground cover had been shown **to have long-lasting negative effects** even after fallowing such lands for 6 years or more (Kirchhof and Salako, 1998; 2000; Salako *et al*. 2006b; 2006c; 2007a).

Aggregates are weakened during the wet season, demanding concerted conservation efforts during this period. **Overall, planted fallows such as *Pueraria phaseoloides* and *Leucaena leucocephala* ordinarily appeared not to have comparative advantage over natural or bush fallow but a closer check on the interactions of cropping intensity and fallow system showed that advantages over each other would depend on these interactions (Table 8).**

Another important issue settled with the study was the necessity or otherwise of sieving soils for 30 minutes as prescribed by Yoder (1936) for the wet-sieving method. **Salako and Hauser (2001) reported that there is nothing sacrosanct about this 30-minute wet-sieving period, and it was not really necessary for the sandy soils of southern Nigeria (Table 9).** Wet-sieving for 30 minutes after pre-sieving soaking of 5-10 minutes imposes a lot of stress on aggregates which are inherently weak, and could obscure fine details of treatment effect. In effect, Salako and Hauser (2001) recommended that wet-sieving analysis should be carried out within 10 minutes: 5-minute wetting by immersion and 5-minute wet sieving. Properties of soil which played significant roles in the aggregation of soils of southern Nigeria included Ca, Mg and Clay contents.

Microaggregate stability measured using water-dispersible clay and dispersion ratio on the Alfisol with the different fallow management (Table 8), showed that although water dispersible clay was less than 60 g kg^{-1} in the 0-15 cm soil depth because it was inherently low in clay content, the soil dispersion ratio was generally above 50% (Salako, 1997; 2001). **Thus, the upland soil was highly vulnerable to dispersion, hence erosion. The implication of this was that soils of southern Nigeria require proper management to avoid erosion.**

Clay dispersion ratio tended to increase with soil depth (Table 10; Salako *et al*., 2006a). The particle size distribution (Tables 10 and 11) showed that sand was the dominant soil particle in the upland soil of southwestern Nigeria. This did not only lead to poor aggregation but also poor soil fertility, particularly if organic matter content was low. The higher clay content and presence of gravel in the subsoil (Tables 10 and 11) would impede water flow and restrict root growth.

Table 8: Soil surface (0-5 cm) aggregate stability as indicated by mean-weight diameter of different fallow systems since 1989 in Ibadan, southwestern Nigeria

Fallow system	Cropping Intensity				Mean
	Continuous cropping	1-y crop/1-y fallow	1-y crop/2-y fallow	1-y crop/3-y fallow	
January 1994					
Bush fallow	4.2	6.0	6.4	6.3	5.7
Pueraria	4.4	5.6	5.2	6.3	5.4
Leucaena	4.6	4.4	5.0	6.4	5.1
Mean	4.4	5.3	5.5	6.3	
March 1995					
Bush fallow	3.7	5.8	5.6	3.5	4.7
Pueraria	5.1	5.2	4.8	3.7	4.7
Leucaena	4.6	5.3	5.3	5.1	5.1
Mean	4.5	5.4	5.2	4.1	
November 1995					
Bush fallow	3.2	3.6	4.1	4.0	3.7
Pueraria	3.9	3.5	3.1	3.9	3.6
Leucaena	3.5	3.5	2.4	4.1	3.4
Mean	3.5	3.5	3.2	4.0	
		$LSD_{0.05}$			
	January 1994	March 1995	November 1995		
Fallow systems	NS	NS	NS		
Cropping intensity	1.18	0.85	0.65		
Cropping intensity x same system	2.01	1.69	1.12		
Cropping intensity x different system	1.88	1.97	1.03		

NS: Not significant

100% cropping intensity: Continuous cropping, 1989-1995, 50%: 1-year cropping/I-year fallow. 33%: 1-year cropping/2-year fallow, 25%: 1-year cropping/3-year fallow, all since 1989.

(Source: Salako *et al*., 1999)

Table 9: Variation of aggregate stability with time spent on sieving using mean-weight diameter (MWD) and geometric mean diameter (GMD) indices for an Alfisol in Ibadan and an Ultisol in Okomu, south-central Nigeria at 0-15 cm depth

Wet sieving period (min)	Aggregate Stability Index (mm)			
	Alfisol		Ultisol	
	MWD	GMD	MWD	GMD
5	2.64	1.08	3.55	1.09
10	2.47	1.08	3.80	1.11
15	2.48	1.06	4.11	1.23
20	2.43	1.06	3.81	1.11
25	2.57	1.09	3.08	1.05
30	2.28	1.04	2.34	1.08
35	2.18	1.01	3.11	1.04

(Source: Salako and Hauser, 2001)

Table 10: Soil particle size, bulk density and clay dispersion in relation to average depths of horizons at Ibadan, southwestern Nigeria

	Particles size class# (g kg^{-1})										
Average soil horizon depth (cm)	Total sand	Silt	Clay	Gravel	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Bulk density (g cm^{-3})	Dispersed clay ratio
0-10	813	133	54	45	118	258	184	206	47	1.35	0.000
10-30	806	117	77	151	129	238	195	198	46	1.43	0.124
30-58	678	128	194	315	160	216	145	125	32	1.49	0.239
58-102	589	102	309	321	171	201	102	86	29	1.51	0.353
102-142	541	121	338	201	128	169	104	107	33	1.50	0.176
142-200	502	142	356	218	125	152	91	94	40	1.50	0.070
LSD ($P < 0.05$)	136	NS	115	270	NS	105	79	73	16	0.14	0.229

LSD ($P < 0.05$) = Least significant difference less than 5% level of probability
NS = No significant differences
# Very coarse sand (1-2 mm), coarse sand (0.5-1 mm), medium sand (0.25-0.50), fine sand (0.1-0.25 mm) and very fine sand (0.05-0.10 mm)

(Source: Salako *et al*., 2006a)

Table 11: Soil particle size and bulk density in relation to average depths of horizons at Alabata, southwestern Nigeria

Average soil horizon depth (cm)	Particles size class ($g\ kg^{-1}$)									
	Total sand	Silt	Clay	Gravel	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Bulk density ($g\ cm^{-3}$)
0-20	824	113	63	73	109	225	211	234	45	1.38
20-40	794	112	94	208	132	216	199	205	42	1.48
40-77	692	106	202	263	154	194	155	156	33	1.58
77-125	607	114	279	238	130	171	131	145	30	1.57
125-200	635	135	230	164	109	166	151	179	30	1.64
LSD ($P < 0.05$)	102	21	77	135	44	44	44	60	9	0.09

Very coarse sand (1-2 mm), coarse sand (0.5-1 mm), medium sand (0.25-0.50), fine sand (0.1-0.25 mm) and very fine sand (0.05-0.10 mm)

(Source: Salako *et al*., 2006a)

2.4. Soil Erosion, Soil Productivity Loss and Rehabilitation of Degraded Soils

Studies carried out under this section were to quantify soil loss and runoff under different soil management practices as well as to understand how to reverse the negative consequences of poor soil management. **They included understanding the mechanism of soil loss from mounds used for cultivation of yams, which was very significant in tropical environment where mounds are generally used to cultivate root and tuber crops**.

2.4.1. Soil loss

The standard method of measuring soil erosion by water is with the use of runoff or soil erosion plots under natural rain (Hudson, 1965; 1993; 1995; Wischmeier and Smith, 1978; Renard *et al*., 1997)). Other methods include the use of simulated rainfall either in the field or laboratory, erosion pin method to monitor soil loss or accretion on a field, use of splash cups to measure splash erosion, and aggregate stability measurements.

Kang *et al*. (1998) reporting on soil loss and runoff of 9-year old alley-cropped plots with or without tillage found that tillage between 1990 and 1992 caused 4.3 t ha^{-1} of mean annual soil loss whereas no-tillage resulted in 1.1 t ha^{-1}. Mean runoff was 32.4 mm for tilled plots and 11.0 mm for no-tillage. Alley cropping with *Gliricidia sepium* and *Leucaena leucocephala* resulted in mean annual soil loss of less than 1 t ha^{-1}. Salako *et al*. (2006c) measured soil loss under mound tillage on a previously eroded soil that had been fallowed for 6 years (Figures 14 and 15). For this soil, the tolerable soil loss limit is about 2 t ha^{-1} y^{-1}, yet soil loss exceeded this value in spite of legume residue management, and became more pronounced by the third year of cropping the land. Also, measured was relative loss of mound heights or soil detachment from mounds (Table 12; Salako *et al*., 2006c). Original mound heights ranged from 20-26 cm, with a 47.5 cm base diameter. **The study on soil erosion under mound tillage was very important given the wide adoption of mound tillage in tropical agriculture, particularly for root and tuber crop production. Besides, measuring soil loss under mound tillage as well as using a digital profile-meter for such was (probably) not yet recorded as at the time of this study**.

A similar (manual) approach using soil erosion pins was adopted to monitor soil erosion on farmers' fields in Abeokuta, southwestern Nigeria (Sotona *et al*., 2014). **This study re-affirmed that not all the eroded sediments detached and eroded from the upland reaches the downslope (Figure 16). This applies to runoff plots, where erosion is meas-**

ured at a given slope length. The increase or decrease in mound heights reported by Salako *et al*. (2006c) was basically due to accretion or removal of soil from the base of the mounds, within the furrow. This accretion or removal of soil forms part of the process of soil erosion in the field and has relevance to variability of soil properties on eroded sites. Gravel pavement becomes more obvious on the surface as erosion becomes more severe (Table 13; Salako *et al*., 2006b).

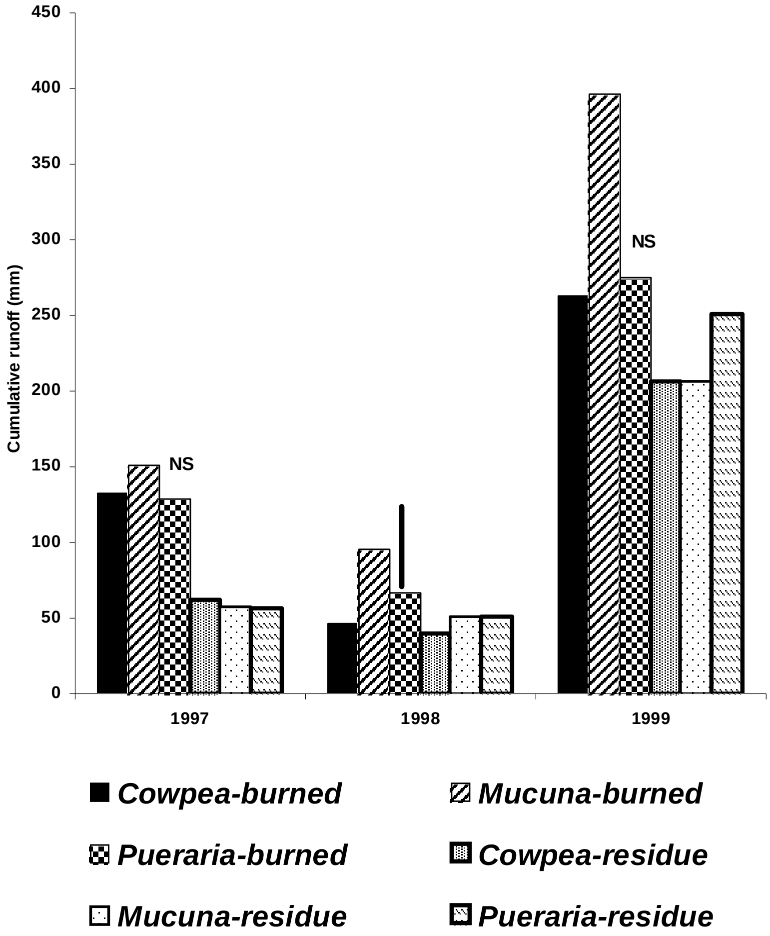


Figure 14: Cumulative runoff from previously eroded plots rehabilitated with fallow and managed with leguminous cover crops to cultivate maize and yam under mound tillage
(Source: Salako *et al*., 2006c)

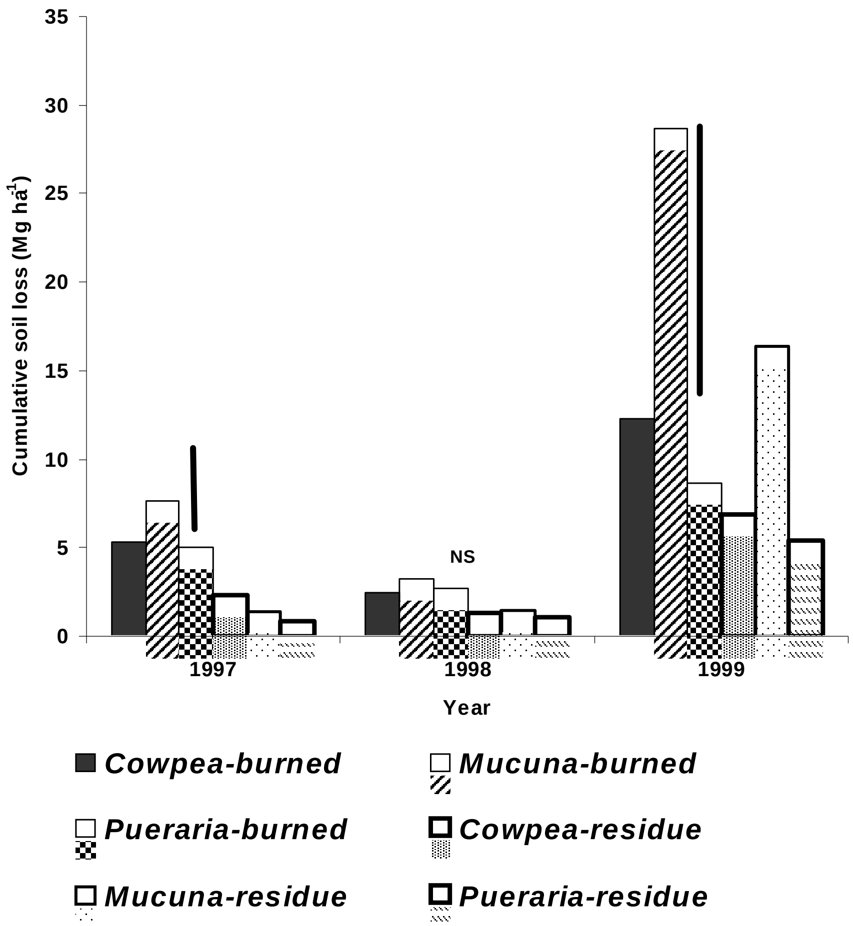


Figure 15: Cumulative soil loss from previously eroded plots rehabilitated with fallow and managed with leguminous cover crops to cultivate maize and yam under mound tillage
(Source: Salako *et al*., 2006c)

Table 12. Relative changes† in mound height to the initial height (22-26 cm) by the end of the cropping seasons in 1997, 1998 and 1999

		Relative mound height (%)		
Legume	Residue management	1997#	1998	1999
Cowpea	Burned	6	14	29
Mucuna		-1	18	26
Pueraria		12	22	37
Cowpea	Mulched	-6	21	53
Mucuna		12	10	40
Pueraria		9	17	38
	LSD (0.05)	18	11	27

† Negative sign implies that there was a net increase in mound height, caused by erosion of furrows.

Cumulative rainfall at the time of measurement was 525 mm in 1997; 355 mm in 1998 and 1299 mm in 1999.

(Source: Salako *et al*. 2006c)

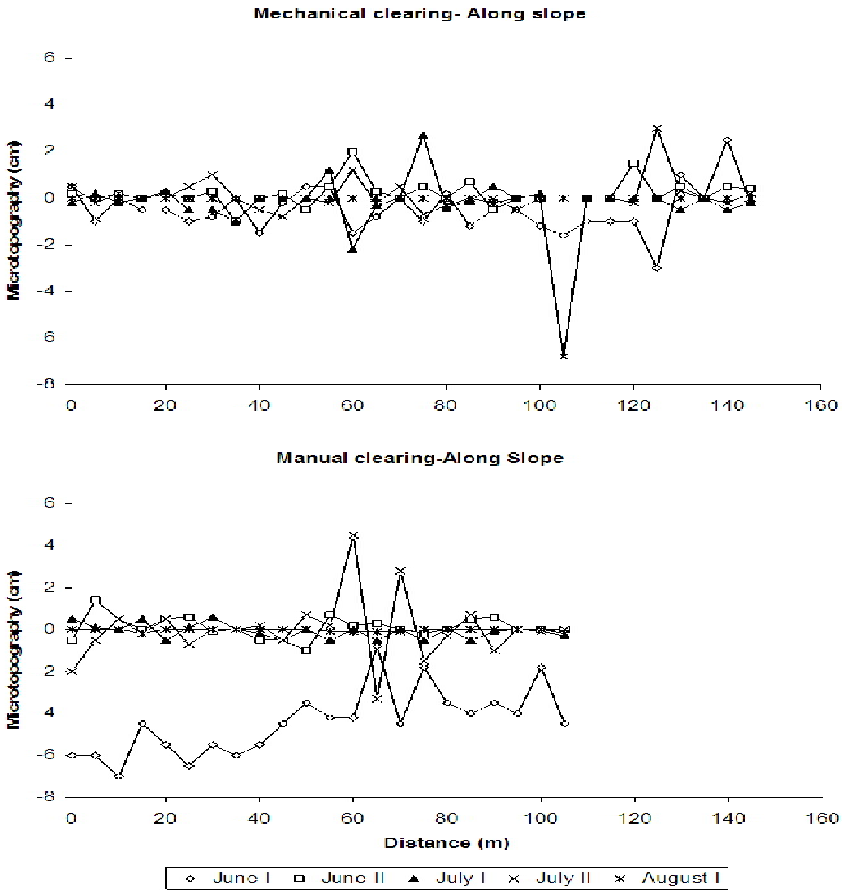


Figure 16: Microtopographic changes due to soil erosion on mechanically and manually cleared maize farmlands on toposequences of the Federal University of Agriculture, Abeokuta in 2007 as measured with erosion pins along (vertical) slopes (Source: Sotona *et al*., 2014).

Table 13: Gravel size distribution (0-15 cm soil depth) on the surface soil of an eroded area in Federal University of Agriculture, Abeokuta, southwestern Nigeria

Gravel size (mm)	Gravel concentration ($g\ kg^{-1}$) Fairly Degraded	Moderately degraded	Severely degraded	LSD ($P < 0.05$)
> 19	0	56	193	137
8-19	17	107	131	90
4-8	102	179	167	65
2-4	211	245	227	NS

(Source: Salako et al., 2006b)

2.4.2. Soil productivity loss

Eroded sediments and runoff carry along soil nutrients (Table 14; Salako 2008b). There was no range of soil particles, including gravel that could not be eroded. Furthermore, the loss of nutrients implied the loss of soil fertility. Besides, soil particles could seal or clog soil pores, impairing the hydraulic properties of soils. **When physical and chemical properties of the soil are impaired, soil productivity is lost.**

Salako *et al*. (2007b) simulated soil erosion in Abeokuta by desurfacing both upland and lowland soils to measure loss in productivity, and the extent of restoration with different amendments. **According to the authors, for the two years of study, high grain yields were sustained with poultry manure/no topsoil removal (1784-3571 kg ha^{-1}) and NPK + urea/no topsoil removal (2371-2600 kg ha^{-1}) at the lower slope (Table 15). However, the soil at the upper slope was more resistant to degradation as 16-67% loss in yield was observed compared to 65-75% for lower slope when no nutrients were applied. Nonetheless, both the upper and lower slope positions were productive with the application of poultry manure irrespective of topsoil removal, compared to NPK + urea which were only effective without topsoil removal.**

This study showed that it was better not to allow soil erosion on the Alfisols. At worst, erosion should only be within a tolerable limit of about 2 t ha^{-1} y^{-1}. Furthermore, the study cautions about indiscriminate use of inorganic fertilizers; they do not boost yields when soils are severely degraded. Policy makers who are not Soil Scientists must bear it in mind that the productivity of the soil is a multi-dimensional issue encompassing physical, chemical and biological properties. Chemical fertilizers may not even solve soil chemical problems if used indiscriminately. In fact, every soil amendment, including or-

ganic manure, just like drugs, must be used with expert advice. Sustainability is a critical issue that must be considered in choosing soil ameliorants or amendments

Table 14a: Properties of sediments eroded under different legume treatments and maize cultivation in 1996 at Ibadan, southwestern Nigeria

Legume	Particle size distribution (g kg^{-1}) Total	Silt	Clay	Gravel (g kg^{-1})	Exchangeable Ca and acidity (cmol kg^{-1}) Ca	Acidity
Cowpea	756	170	74	69	5.44	0.500
Mucuna	653	234	113	61	8.07	0.683
Pueraria	696	213	91	59	9.00	0.712
No legume	643	269	88	32	11.45	0.300
LSD ($P < 0.05$)	42	56	25	36	3.562	0.412

Table 14b: Properties of sediments eroded under different legume treatments and yam cultivation in 1997 at Ibadan, southwestern Nigeria

Residue Management	Total sand	Very coarse	Coarse sand	Medium sand	Fine sand	Very fine	Silt	Clay
Burned	736	194	233	155	109	45	212	52
Mulched	684	156	194	146	130	58	242	74
No legume	750	211	224	146	118	52	215	35
LSD ($P < 0.05$)	66	55	39	NS	21	13	29	23

(Source: Salako, 2008b).

Table 15: Maize grain yields (kg ha^{-1}) in 2003 and 2004 on soils of a toposequence after artificial desurfacing to different depths in Federal University of Agriculture, Abeokuta, Nigeria

Slope position	Nutrient amendment	Topsoil depth removed (cm)	2003	2004
Upper slope	No amendment	0	937.4	19.5
		15	513.4	283.4
		25	301.3	14.3
	NPK + Urea	0	3113.6	317.6
		15	1874.8	43.4
		25	145.1	19.0
	Poultry manure	0	3126.9	521.1
		15	1439.6	646.7
		25	3660.3	1003.7
Lower slope	No amendment	0	1149.5	309.8
		15	312.4	196.0
		25	89.3	266.4
	NPK + Urea	0	2600.2	2370.9
		15	1506.6	89.8
		25	160.7	126.1
	Poultry manure	0	3571.1	1783.6
		15	2287.8	1044.1
		25	1428.5	813.3
LSD ($P < 0.05$)				
Slope position (A)			NS	459.0
Nutrient amendment (B)			1016.3	312.9
Topsoil removed (C)			1094.0	503.2
A x B x C			1339.2	529.9

(Source: Salako *et al*., 2007b)

2.4.3. Rehabilitation of degraded soils

In studies conducted under this sub-section, Salako *et al*. (2007b) focused on the rehabilitation of artificially degraded soils whereas Kang *et al*. (1997) and Salako *et al*. (2006b; 2006c) focused on soils degraded under rainfed agriculture, with or without mechanized land clearing. Kang *et al*. (1997) studied an Alfisol degraded during mechanized clearing and by water erosion, which was then rehabilitated with 4-year old planted tree and herbaceous fallows (Tables16-18).

More than 66% of the tree nutrients were contained in stems and main branches intended for firewood and were not burned on the field. This represented a large loss of nutrients from fallow. Furthermore, the burned biomass on the field only gave an advantage in terms of crop yield, only in the first year of cropping. The second-year crops did not reflect the increased nutrients observed after burning biomass. Crop yields were also low for the two years of cropping, though cassava yield was fair on some treatments (Table 18). **The study suggested that sustainable crop production could not be achieved with four-year planted fallows and biomass burning on a severely (physically) degraded Alfisol.**

By the design of the experiment, it was possible to determine the effects of the fallow and its management after 6 years

(Salako and Tian, 2003a). Fallowing for 6-years improved crop yields to expected levels, and the yields were further increased by mound tillage and nitrogen application (Tables 19-21). The encouraging yields did not last more than one year of cropping, raising posers about the fragility of the soils and the need to prevent soil erosion or degradation right from the point of land clearing. It also became clear that minimum tillage (i.e., mound tillage in this case) and the use of soil amendments could be inevitable for sustainable production of crops after fallowing for 6 years, a severely eroded or degraded soil. A need for intermittent fallows and cropping could be deduced (Salako et al., 1999; Tian et al., 2005).

Talking about managing soil productivity right from the land clearing stage, Salako *et al* (1995b) working on an Ultisol cleared of a primary forest (about 150 years according to Salako and Hauser, 2001 citing Jones (1955)) in Okomu, near Benin City, found that a windrow where forest biomass was packed and burned yielded 12.9 t ha^{-1} a^{-1} of fresh fruit bunches of oil palm (*Elaeis guineensis*) compared to 8.5 t ha^{-1} a^{-1} from non-windrows, about five years after establishment. For interplanted cocoyam (*Xanthosoma sagittifolium*), cormel yield was 11.3 t ha^{-1} a^{-1} on windrow and 7.5 t ha^{-1} a^{-1} on non-windrows. It appears that the large natural forest burned on windrows sustained crop production longer than when it was not

concentrated in windrows. **Therefore, burning effects could be attributed to age of fallow, amount of biomass burned, and soil type or condition.** Fallow length of six years with proper soil management (appropriate tillage and fertilization) was necessary to boost the productivity of a physically and chemically degraded Alfisol in southwestern Nigeria.

Salako (2008c) found that the application of poultry manure or presence of *Mucuna pruriens* as a cover crop on a physically degraded soil in Abeokuta, southwest Nigeria enhanced maize grain yield, which ranged from 2.2-3.2 t ha^{-1} in the first year of cropping. All the studies on the rehabilitation of degraded soils point to one fact: never allow the soil to be severely degraded because the process of rehabilitation is very complex. Soils in the tropics are inherently heterogeneous within a short distance; they become more heterogeneous with soil erosion or any other form of degradation. As indicated, even the Alfisols of southwestern Nigeria required location- or situation-specific management to put them back to one-year cropping after severe degradation. Cultivation of a previously degraded Alfisol in southwestern Nigeria would require a minimum of six-year fallow, minimum tillage (ridges or mounds) and the use of both organic and inorganic amendments. If trees are planted as

fallows, it would require burning a large amount of the biomass either in windrows or non-windrows to sustain crop production for more than one year.

Table 16: Selected characteristics of 4-year old planted fallow species in Ibadan, southwestern Nigeria

Fallow species	Population (no/ha)	Height (m)	BHC (cm)	Biomass (t/ha)	Above-ground nutrient yield (kg/ha) N	P	K	Ca	Mg	Total
Pueraria phase-oloides	-	-	-	12**	223	5.5	80	171	29	509
Psophocarpus palustris	-	-	-	14**	245	7.4	67	176	29	524
Senna siamea	4479	9.2	28.5	127	1009	45.6	983	824	206	3064
Leucaena leucocephala	6537	7.0	18.5	59	390	23.3	361	499	103	1376
Acacia leptocarpa	3855	7.5	30.3	110	945	30.4	335	1182	98	2591
Acacia auriculiformis	3131	4.7	20.5	58	611	21.4	312	640	78	1662
Natural growth	-	-	-	12***	136	4.6	56	159	30	386
SE	389	0.48	0.8	1.64	83	6.0	108	163	33	
LSD (0.05)	1246	1.5	2.6	33	253	17.8	321	487	98	

*BHC: Breast Height Circumference
- Not measured
** Included dead litter
*** Mainly *Chromolaena odorata*
(Source: Kang *et al*., 1997)

Table 17: Surface (0-15 cm) soil chemical characteristics before (BB) and after burning (AB) cleared 4-year old biomass of planted fallows on a degraded Alfisol in Ibadan

							Exchangeable cations (cmol kg^{-1})					
	pH-H_2O		Organic C (g/kg)		Extractable P (mg/kg)		K		Ca		Mg	
Fallow species	BB	AB	BB	AB	BB	AB	BB	AB	BB	AB	BB	AB
Pueraria phaseoloides	5.2	6.5	9	17	4.4	23.2	0.2	0.4	2.3	5.6	0.6	1.4
Psophocarpus Palustris	5.3	7.0	13	21	3.0	25.3	0.2	1.0	4.2	8.9	0.7	2.0
Senna siamea	5.5	7.4	11	23	5.7	26.6	0.3	1.7	4.5	18.7	0.8	2.3
Leucaena leucocephala	5.5	7.7	11	17	2.6	29.4	0.3	2.6	3.0	9.7	1.0	2.6
Acacia leptocarpa	5.1	7.0	13	22	4.0	20.2	0.1	0.7	3.4	9.7	0.8	2.1
Acacia auriculiformis	5.2	7.5	9	22	3.3	45.5	0.1	1.3	2.6	14.1	0.6	2.3
Natural growth	5.5	7.5	10	15	2.7	35.7	0.2	1.8	2.3	16.9	0.8	2.4
Continuous cropping*	5.5	5.7	8	10	2.1	11.9	0.1	0.1	2.6	2.9	0.6	0.7
SE	0.2	0.2	1.5	2.7	1.18	8.4	0.05	0.44	0.78	3.3	0.15	0.3
LSD (0.05)	NS	0.7	4.4	8.0	3.47	24.8	0.14	1.30	2.29	9.8	0.44	0.7

* Cassava residue burned
BB: Before Burning Cleared Biomass
AB: After Burning Cleared Biomass

(Source: Kang *et al*., 1997)

Table 18: Intercropped maize grain and fresh cassava root yields after cropping the degraded Alfisol which had been under 4 years of planted fallow

	Maize grain yield ($t\ ha^{-1}$)		Fresh cassava root ($t\ ha^{-1}$)	
Fallow species	1993	1994	1993/1994	1994/1995
Pueraria phaseoloides	0.73	0.69	16.0	11.8
Psophocarpus palustris	1.17	1.19	14.0	12.4
Senna siamea	0.73	0.99	11,0	7.3
Leucaena leucocephala	0.98	0.82	9.0	8.9
Acacia leptocarpa	0.65	0.82	10.0	10.0
Acacia auriculiformis	0.90	0.50	8.0	6.3
Natural growth	0.88	1.02	13.0	12.3
Continuous cropping	0.43	0.36	6.0	9.3
SE	0.13	0.20	1.6	2.0
LSD (0.05)	0.37	0.59	5.0	NS

SE = Standard error, LSD (0.05) = Least significant difference at 5% probability level, NS = Not significant

(Source: Kang *et al*, 1997)

Table 19: Intercropped maize yields ($t\ ha^{-1}$) in 1995 as affected by a 6-year fallow period and tillage on the degraded Alfisol in southwestern Nigeria

	Stover			Grain		
Fallow species	Mound	Level	Mean	Mound	Level	Mean
P. phaseoloides	3.53	2.74	3.14	2.03	1.51	1.77
S. siamea	3.09	1.60	2.35	2.20	1.73	1.97
L. leucocephala	3.14	2.29	2.72	2.41	1.98	2.19
A. leptocarpa	3.88	3.03	3.46	2.67	2.30	2.48
A. auriculiformis	2.82	1.66	2.24	2.29	1.25	1.77
Natural fallow	3.72	2.24	2.98	1.93	1.41	1.67
Continuous cropping	1.99	1.07	1.53	0.74	0.40	0.57
Mean	3.17	2.09		2.04	1.51	
Treatment means		LSD	*P* level		LSD	*P* level
Fallow species means		1.11	0.0312		0.810	0.0398
Tillage means		1.08	0.0002		0.527	0.0135
Tillage x Fallow species means		1.43	0.0484		1.111	0.0457

LSD = least significant difference
P level = The probability level at which the least significant difference was obtained

(Source: Salako and Tian, 2003b)

Table 20: Intercropped maize yields (t ha^{-1}) in 1996 as affected by a 6-year fallow period and tillage on the degraded Alfisol in southwestern Nigeria

	Stover			Grain		
Fallow species	Mound	Level	Mean	Mound	Level	Mean
P. phaseoloides	1.71	0.85	1.28	0.91	0.45	0.68
S. siamea	1.80	1.18	1.49	0.95	0.75	0.85
L. leucocephala	1.25	0.82	1.04	0.77	0.42	0.60
A. leptocarpa	2.66	1.58	2.12	1.30	0.84	1.07
A. auriculiformis	1.87	1.03	1.45	0.93	0.45	0.69
Natural fallow	1.67	0.81	1.24	1.32	0.58	0.95
Continuous cropping	0.62	0.09	0.36	0.24	0.06	0.15
Mean	1.65	0.91		0.92	0.51	
Treatment means	LSD	*P* level		LSD	*P* level	
Fallow species means	0.631	0.0374		0.484	0.0375	
Tillage means	0.746	0.0001		0.411	0.0014	
Tillage x Fallow species means	0.851	0.0464		0.672	0.0405	

(Source: Salako and Tian, 2003b)

Table 21: The first crop year (1995/1996) intercropped cassava yields (t ha^{-1}) as affected by 6-year fallow and tillage on the degraded Alfisol in southwestern Nigeria

	Fresh above ground biomass			Fresh cassava root		
Fallow species	Mound	Level	Mean	Mound	Level	Mean
P. phaseoloides	22.8	18.3	20.6	23.5	18.3	20.9
S. siamea	20.2	14.6	17.4	19.4	11.7	15.6
L. leucocephala	24.6	18.3	21.5	17.2	12.6	14.9
A. leptocarpa	22.6	15.9	19.3	18.7	15.2	17.0
A. auriculiformis	23.2	13.6	18.4	18.2	11.8	15.0
Natural fallow	17.9	15.6	16.8	17.4	16.0	16.7
Continuous cropping	11.9	8.3	10.1	13.7	9.0	11.4
Mean	20.5	15.0		18.3	13.5	
Treatment means	LSD	*P* level		LSD	*P* level	
Fallow species means	3.816	0.0338		3.574	0.0341	
Tillage means	5.487	0.0001		4.779	0.0001	
Tillage x Fallow species means	5.218	0.0398		4.670	0.0493	

(Source: Salako and Tian, 2003b)

2.5. Fallow Management, Agroforestry, Soil Properties and Biomass Production

2.5.1. Above-ground characteristics of trees used in agroforestry

Fallow management or planted fallow studies were necessary if the long period (≥ 10 years) of fallowing under shifting cultivation had to be reduced due to limitation in land availability with increasing population and other compelling needs. Selected tree and herbaceous species were used as planted fallow, either on degraded soils or freshly cleared land (Tables 16-21; Kang *et al*., 1997; Salako *et al*., 1999; 2001; 2002; 2006c; Salako and Hauser, 2001; Salako and Tian, 2001; 2003a; 2003b; 2004a; 2005; Salako and Kirchhof, 2003; Tian *et al*., 1999; 2001a; 2005; 2007). Trees were selected to serve different purposes, such as provision of food (fruits and leaves), herbal medicine, firewood, etc., although, the primary aim was to replenish the soil under fallow. Besides, it was hypothesized that tree roots would grow deeper into the soil, thereby improving sub-soil properties for subsequent crop cultivation. It was, therefore considered imperative to study not just the soils but (fallow) plant characteristics.

The above-ground characteristics of some planted fallow species were presented earlier (Table 16). Akinnifesi and Salako (1997) also presented some above-ground charac-

teristics of *Gliricidia sepium* and *Senna siamea* with ages between 5 and 16 years. Salako and Tian (2001) measured above-ground characteristics of 3 to 8-year old planted fallows on a severely degraded Alfisol in Ibadan, south-west Nigeria (Tables 22a-22c)). Also, Kang *et al*. (1998) reported pruning biomass under alley cropping with *G. sepium* and *Leucaena* with different spacing (Table 22d).

The seasonal pattern for the mean total litterfall (kg ha^{-1} y^{-1}; Y variable) for each month (X variable; 1 - 12 months) can be predicted for the various fallow species (Salako and Tian, 2001):

Senna siamea: $Y = 436X^2 - 5441X + 2186$
$R^2 = 0.91$ (1)
Leucaena leucocephala: $Y = 160X^2 - 1801X + 13078$
$R^2 = 0.50$ (2)
Acacia leptocarpa: $Y = 338X^2 - 3952X + 17136$
$R^2 = 0.55$ (3)
Acacia auriculiformis $Y = 485X^2 - 5753X + 20752$
$R^2 = 0.73$ (4)
Natural fallow $Y = 321X^2 - 4252X + 20358$
$R^2 = 0.77$ (5)

Litterfall was also studied under a number of agroforestry tree species in Ibadan, southwestern Nigeria and Onne, southeastern Nigeria (Table 23; Salako and Tian, 2005). Leaf-fall constituted the bulk of litterfall (Tables 22 and 23). Maximum temperature and minimum relative humidity were major climatic variables that triggered litterfall (Salako and Tian, 2001).

The various studies under this sub-section have contributed to knowledge not just in providing data of above-ground characteristics of fallow species over a long-term period but also providing tools for predicting or calculating certain above-ground characteristics. This is particularly useful for trees (or perennial plant species) for which many years are required before meaningful data can be generated.

2.5.2. Below-ground characteristics of trees used in agroforestry: Root study

Roots of plants can be studied using various methods, which include core and profile pit methods (Böhm, 1979). Both the core and profile-pit methods were used in studies on roots. These were tedious methods, used for root studies in south-west and northern Nigeria (Salako *et al*., 2002; Salako and Tian, 2004b; Dada *et al*., 2012). Roots were sampled with cores, excavated and or mapped with transparent foil for further laboratory and computer analyses with appropriate software.

For instance, roots of 2-year old *Gliricidia sepium* and *Acacia leptocarpa* were characterized up to 300 cm depth in a farmer's field at Mokwa, northern Nigeria using Delta-T scanner to obtain the root length, volume and mass densities (Tables 24 and 25; Salako and Tian, 2004b). **The observation of deep rooting by the trees suggested that if left for long as fallow plants, they would influence soil productivity through the creation of biopores and addition to soil organic matter after decomposition.** Scanned roots of herbaceous legumes also indicated that they could spread up to 1 m depth but the presence of hard-pans or compact subsoil was a major limitation in both southwest and northern Nigeria (Figure 17).

Table 22a: Litterfall on a severely degraded Alfisol under 3 to 4-year planted fallows in Ibadan, southwest Nigeria

	Fallow species					Location	
Litterfall (kg ha^{-1} y^{-1})	*Senna siamea*	*Leucaena leucocephala*	*Acacia leptocarpa*	*Acacia auriculiformis*	Natural fallow	Hedgerow (n =608)	Centre n =912
Pod	83	1011	1141	155	553	617	570
Wood	578	1274	126	114	401	629	412
Leaf	7118	6499	63335	6650	6760	7004	6451
Leaf-fall (%)	91.5	74	83.3	96.1	87.6		

Table 22b: Litterfall on a severely degraded Alfisol under 7 to 8-year planted fallows in Ibadan, southwest Nigeria

	Fallow species					Location	
Litterfall (kg ha^{-1} y^{-1})	*Senna siamea*	*Leucaena leucocephala*	*Acacia leptocarpa*	*Acacia auriculiformis*	Natural fallow	Hedgerow (n = 176)	Centre (n =264)
Pod	546	511	58	888	122	524	359
Wood	1306	1154	934	693	2056	1213	1213
Leaf	8516	8384	9673	10526	11434	9583	9789
Leaf-fall (%)	82.1	83.4	90.7	86.9	84		

(Source: Salako and Tian, 2001)

Table 22c: Nutrient concentration (%) in leaves/twigs of 6-year old planted fallows on a severely degraded Alfisol in Ibadan, southwest Nigeria

	Fallow species						
Nutrient (%)	*Senna siamea*	*Leucaena leucocephala*	*Acacia leptocarpa*	*Acacia auriculiformis*	*Pueraria phaseoloides*	Natural fallow	LSD (5%)
N	2.06	2.46	1.75	2.04	1.87	2.18	0.31
P	0.06	0.07	0.05	0.04	0.06	0.10	0.02
K	1.14	1.57	0.92	1.40	1.92	1.77	NS
Ca	1.91	2.59	1.28	1.41	1.66	1.85	0.55
Mg	0.38	ND	0.33	0.40	0.56	0.58	NS

LSD: Least significant difference applicable to trees (leaves/twigs) alone
NS: Not significant
ND: Not determined

(Source: Salako and Tian, 2001)

Table 22d: Dry pruning biomass of hedgerows of *Leucaena leucocephala* and *Gliricidia sepium* as affected by inter-hedgerow spacing

	Biomass (t ha^{-1} y^{-1})					
	Prunings			Wood		
Treatment	1990	1991	Mean	1990	1991	Mean
2 m *Gliricidia*	6.88	5.16	6.02	3.41	3.21	3.31
4 m *Gliricidia*	4.77	2.95	3.86	2.00	1.92	1.96
2 m *Leucaena*	10.40	8.40	9.40	6.70	5.24	5.92
4 m *Leucaena*	6.72	6.96	6.84	4.30	3.90	4.10

(Source: Kang *et al*., 1998)

Dada *et al*. (2012) reported a root biomass production by maize grown on an artificially eroded Alfisol toposequence in Abeokuta to range from 0.08 (no amendment) to 0.40 t ha^{-1} (poultry manure). **Therefore, root growth was enhanced with the addition of organic and inorganic fertilizers, just as they did for above-ground biomass.**

It was implied from the various root studies that just as the variety of plants in an old natural forest have different heights (multi-strata), so also their roots would penetrate different depths. Depths penetrated would, of course, be impeded by hard pans, gravel and other adverse soil factors. The improvement of soil under natural fallow, compared to planted fallow probably lied in this advantage of natural fallow or forest having substantial biomass at different subsoil depths, particularly between 0 and 40 cm depths.

2.5.3. Decomposition of litter

Soil organic matter is very crucial to the productivity of the soil for crop production and its functionality as a medium for mitigation of environmental pollution. Therefore, the decomposition of litters is an important focus in understanding how soil properties can be enhanced by fallow or how deposited wastes would be transformed to soil organic matter.

Tian *et al*. (2007) indicated that the quality of litters influenced the decomposition rate. Therefore, it should not be expected that different fallow plants would contribute to soil organic matter at the same rate or the same way (Figures 18 and 19). The following equation was developed for predicting decomposition rate constant, k, of plant residues across agroecological zones in West Africa:

$$k = 0.122 - 0.000747*PRQI^2 - 0.0233*PRQI*CI + 0.00337*CI*PRQI^2 \quad (6)$$

where PRQI is the plant residue quality index and CI is climate index

Differences observed in surface soil chemical properties under 7-year old arboreta comprising various agroforestry plant species in Ibadan and Onne, southern Nigeria indicated that litter quality mattered in fallow plant contribution to soil productivity (Table 26; Salako and Tian, 2005).

Table 23. Leaf-fall under various 7-year old trees in Ibadan (derived savanna), southwest Nigeria and Onne (humid forest), southeastern Nigeria

Species	Mean annual litterfall ($t\ ha^{-1}\ y^{-1}$)				Leaf-fall at Ibadan only	
	Ibadan	Onne	Mean		Leaffall ($t\ ha^{-1}\ y^{-1}$)	% of litterfall
Alchornea cordifolia	7.3	8.6	7.9		6.4	91
Calliandra calothyrsus	-	-			7.2	88
Dactyladenia barteri	14.4	12.0	13.2		9.4	67
Dialium guineense	9.4	8.9	9.1		5.3	59
Grewia pubescens	6.3	6.9	6.6		5.0	83
Inga edulis	10.8	15.8	13.3		9.2	84
Irvingia gabonensis	5.7	11.7	8.7		5.7	95
Nauclea diderrichi	10.7	11.3	11.0		10.3	94
Pterocarpus	8.1	7.3	7.7		5.7	71
Treculia africana	12.0	9.9	11.0		7.6	63
Forest	14.6	20.3	17.4		14.0	93
Mean	9.8	11.3				
				LSD	3	
Species		2.9				
Species at Ibadan		4.3				
Species at Onne		4.4				
Species x different		4.2				

- Not included

(Source: Salako and Tian, 2005)

Table 24a: Root length density (mm ml^{-1}) of *Gliricidia sepium* and *Acacia leptocarpa* in relation to soil depth and lateral distance from main tree stem at 2 years of establishment in Mokwa, southern Guinea savanna zone of central Nigeria

		Trees	
Depth (cm)	*G. sepium*	*A. leptocarpa*	Mean
0-15	11.04	5.93	8.48
15-30	2.47	3.51	2.99
30-45	1.65	1.27	1.46
45-60	1.36	1.28	1.32
60-75	2.83	0.30	1.56
75-90	0.97	0.68	0.83
90-105	1.26	0.56	0.91
105-120	1.38	0.39	0.88
120-135	1.09	0.50	0.79
135-150	1.13	0.76	0.94
150-165	1.20	0.15	0.68
165-180	1.10	0.47	0.79
180-195	1.01	0.13	0.57
195-210	1.55	0.45	1.00
210-240	0.85	0.61	0.73
240-270	0.72	0.47	0.59
270-300	0.56	0.13	0.34
	1.89	1.03	
		LSD (P < 0.05)	
Trees		0.64	
Depth		1.73	
Trees x Depth		2.61	

24b: Root density in relation to lateral distance

	Trees		
Lateral Distance (cm)	*G. sepium*	*A. leptocarpa*	Mean
0	1.71	1.18	1.44
14	2.13	0.64	1.38
24	1.85	1.11	1.48
35	1.89	1.16	1.52
		LSD(P< 0.05)	
Lateral distance		NS	
Trees x LD		1.93	

Table 25: Volume and mass densities of *Gliricidia sepium* and *Acacia leptocarpa* at 2 years of establishment in relation to soil depth in Mokwa, southern Guinea savanna zone of central Nigeria

	Volume density# (%)		Mass density (mg cm^{-3})	
Soil depth (cm)	*G. sepium*	*A. leptocarpa*	*G. sepium*	*A. leptocarpa*
0-15	1.360	0.514	28.35	1.94
15-30	0.772	0.188	6.40	1.39
30-45	0.206	0.013	1.91	0.07
45-60	0.423	0.100	3.94	0.54
60-75	0.572	0.016	7.43	0.08
75-90	0.394	0.123	1.97	1.01
90-105	0.133	0.003	1.24	0.01
105-120	0.066	0.006	0.80	0.05
120-135	0.048	0.005	0.15	0.01
135-150	0.168	0.004	1.66	0.03
150-165	0.034	0.001	0.16	0.00
165-180	0.019	0.004	0.10	0.01
180-195	0.028	0.001	0.29	0.00
195-210	0.046	0.003	0.20	0.01
210-240	0.011	0.012	0.07	0.06
240-270	0.007	0.004	0.06	0.03
270-300	0.032	0.002	0.76	0.02
LSD(0.05)				
(Tree x Depth)	0.506		7.33	

- # Volume density was obtained as ml roots / ml soil before conversion to percentage
(Source: Salako and Tian, 2004b)

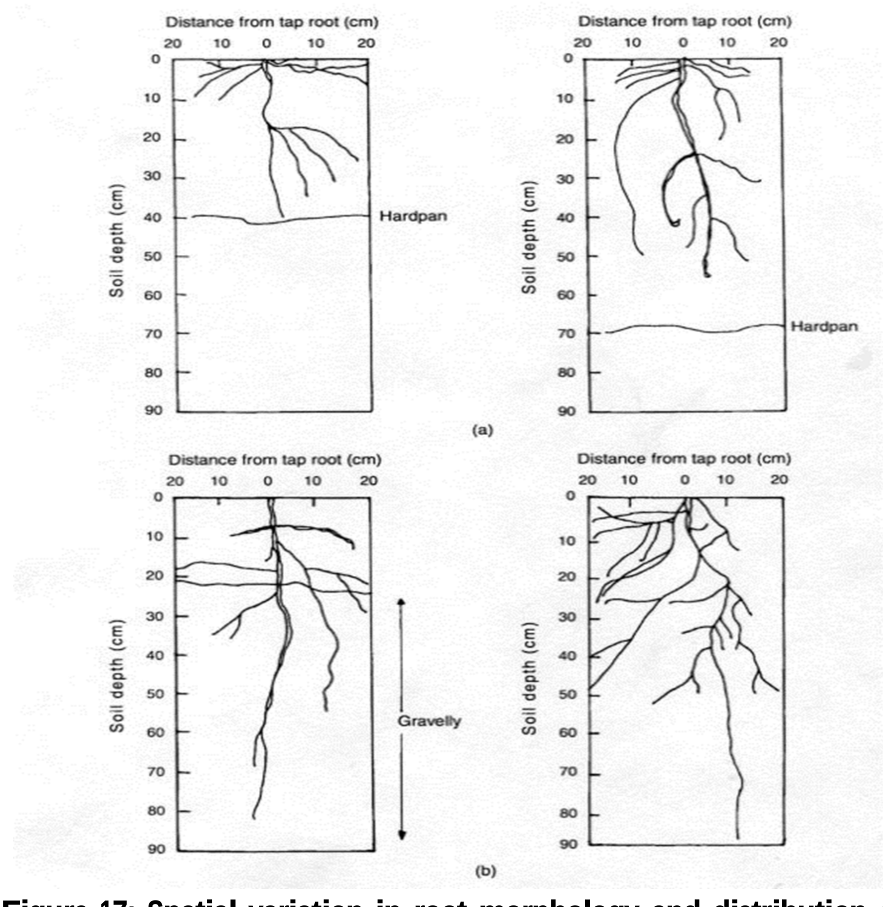


Figure 17: Spatial variation in root morphology and distribution of *Lablab purpureus* at 17-18 weeks after planting in (a) Kasuwan Mangani, near Kaduna, northern Nigeria in the northern Guinea savanna and (b) Alabata, near Ibadan, southwest Nigeria in the derived savanna (Source: Salako *et al*., 2002).

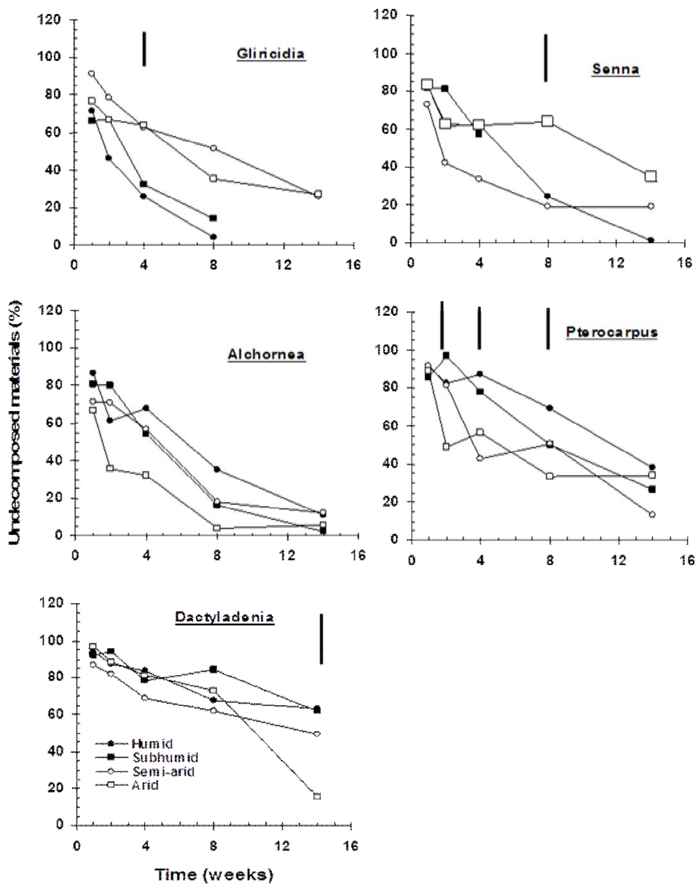


Figure 18: Decomposition of plant residues of various qualities in 4 agroecological zones of West Africa during the rainy season (Source: Tian *et al*., 2007)

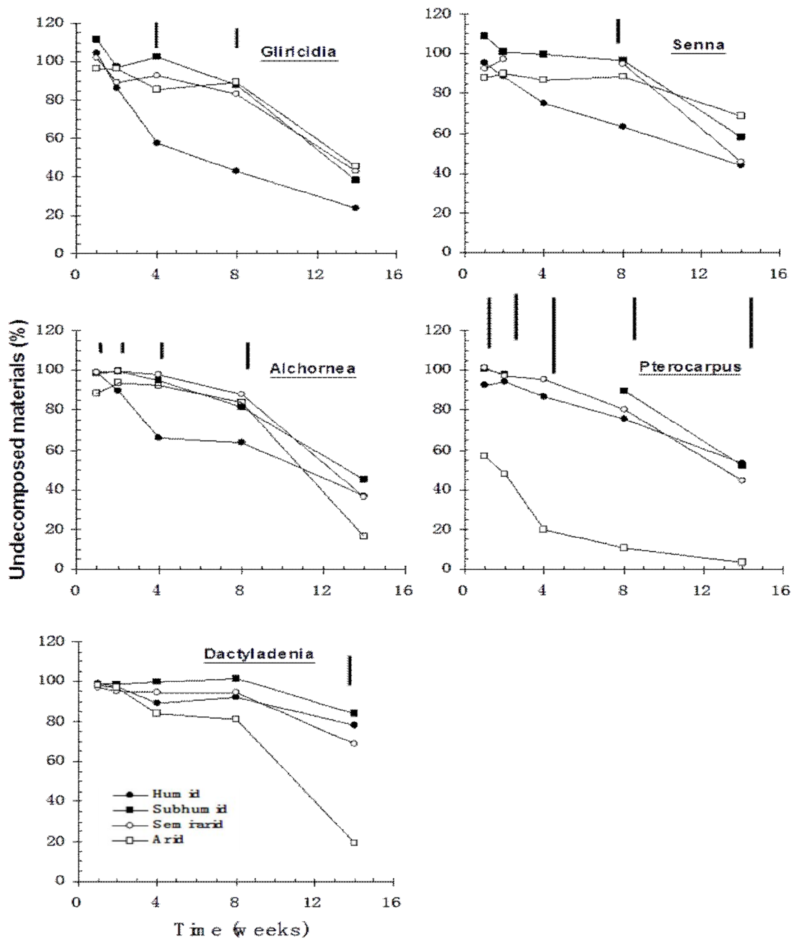


Figure 19: Decomposition of plant residues of various qualities in 4 agroecological zones of West Africa during the dry season (Source: Tian *et al*., 2007)

Table 26: Soil chemical properties (0-15 cm depth) under a 7-year fallow of planted trees on an Alfisol at Ibadan and an Ultisol at Onne, southern Nigeria

Species	pH (1:1 $H_2$0)		Organic C (g kg-1)		Available P (mg kg^{-1})	
	Ibadan	Onne	Ibadan	Onne	Ibadan	Onne
Alcornea cordifolia	6.6	4.5	25.2	14.2	1.9	40.3
Dactyladenia barteri	5.9	4.5	19.5	12.7	6.9	48.1
Dialium guineense	6.5	4.6	16.3	15.9	6.5	69.6
Grewia pubescens	6.2	4.5	13.6	12.6	0.2	38.6
Inga edulis	5.7	4.3	18.6	14.8	1.6	52.3
Irvingia gabonensis	6.7	4.4	14.1	13.9	26.2	52.7
Nauclea diderrichi	6.4	4.5	13.2	15.9	3.4	63.6
Pterocarpus santalinoides	5.9	4.5	18.7	12.8	12.2	41.0
Treculia africana	6.4	4.3	18.0	15.1	3.4	75.2
Natural regrowth	6.9	4.5	15.7	13.0	19.9	34.0
Forest	6.9	4.7	20.7	18.0	13.9	80.5
Mean	6.4	4.5	17.6	14.4	8.7	54.2
	LSD ($P < 0.05$)					
Location means	1.9		3.14		45.43	
Species at Ibadan	0.4		5.58		11.97	
Species at Onne	NS		NS		10.92	
Species x different locations	6.1		5.54		12.33	

(Source: Salako and Tian, 2005)

2.5.4. Canopy coverage

Ground cover is a basic requirement for the prevention of soil erosion. Using a light meter, Salako *et al*. (2002) reported that at about 18 weeks after planting, legumes such as *Cajanus cajan, Lablab purpureus, Mucuna pruriens* and *Pueraria phaseoloides* with potential to grow roots beyond 60 cm depth and which intercepted about 95% of incident sunlight could be recommended for sustained growth and rapid regeneration after cutting or browsing in southwestern Nigeria. At 8 weeks after planting on a degraded land in Abeokuta, rice canopy cover was between 5 and 17% (Salako *et al*., 2006b). It is desirable to mulch or plant fast-growing cover crops with cereals or crops with poor canopy coverage at the initial growth stage (Salako *et al*., 2007a).

2.6. Soil Physical Characterization, Geostatistics and Fractal Analyses

As a Soil Physicist, it was normal for me to place emphasis on soil physical properties. I did not only do this, I explored current tools in the various characterizations. Such tools included geostatistics and fractal analyses for the characterization of soil variability. I ventured into the use of these tools at a time their application in Soil Science was emerging worldwide, but with no known application to Nigerian soils. I also had the opportunity of using some state-of-the-art equipment then (e.g., disc permeameter (tension infiltrometer), digital profile-meter and penetrometer) for soil physical characterization. Furthermore, I was interested in characterizing soil profiles (0-200 cm), rather than limiting my studies to the surface soil (0-20 cm), because only a few soil physical properties were usually included in standard soil survey reports.

2.6.1. Particle size distribution, gravel, bulk density and soil strength

For soil particle size distribution, I took a particular interest in separating sand (Tables 10 and 11; Salako *et al*., 2006a) for the purpose of measuring erodibility and applying fractal analysis for soil description. Gravel are rock fragments with diameter from 2-75 mm that are strongly cemented together or resistant to rupture (Soil Survey Staff, 1993). They are quite abundant in soils formed over basement complex in southwestern Nigeria (Tables 10, 11 and 13; Smyth and Montgomery, 1962; Moormann *et al*, 1975) , usually concentrated between 20 and 102 cm depth (Salako *et al*., 2006a). Salako et al.(2006b) characterized different levels of soil erosion with the exposure of gravel of different sizes (Table 13). Nosiru et al. (2009) reported the erodibility of soils within watersheds in FUNAAB (Table 27), based on particle size distribution and some other soil properties required in the Wischmeier and Smith (1978) nomograph.

Soil strength is the capacity of the soil to withstand stress. A measure of soil strength is an indication of cohesiveness of soil under the prevailing condition, and this has implication for mechanization of farms and construction of buildings. Salako *et al*. (2007b) observed that although soil strength, measured with an auto-recording (digital) penetrometer decreased with soil water content, it also increased with gravel concentration in Abeokuta (Table 28).

Table 27: Variations in surface soil (0-20 cm) erodibility of watersheds in the Federal University of Agriculture, Abeokuta, Nigeria

Watersheds	Erodibility factor, (*K*) ($Mg.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}$)
Alakata	0.02
Ole	0.04
Arakanga	0.04
Tigba	0.02
Ofu	0.02

(Source: Nosiru et al., 2009)

Table 28: Soil strength as affected by soil water content, gravel concentration and gravel size up to 30 cm depth at a constant bulk density in a laboratory-packed soil

Water content (cm^3 cm^{-3})	Gravel concentration (g kg^{-1})	Gravel size (mm)	Penetrometer resistance (kPa)
		4.0	262.3
	100	8.5	443.1
		16.5	489.6
		4.0	523.6
	200	8.5	317.6
		16.5	674.1
0.05		4.0	473.1
	300	8.5	441.3
		16.5	687.9
		4.0	493.8
	500	8.5	605.4
		16.5	379.8
		4.0	488.0
	100	8.5	319.6
		16.5	499.3
		4.0	273.0
	200	8.5	433.9
		16.5	286.2
0.31		4.0	349.4
	300	8.5	309.9
		16.5	291.5
		4.0	834.3
	500	8.5	609.3
		16.5	88.8
		4.0	45.3
	100	8.5	63.7
		16.5	35.9
		4.0	97.6
	200	8.5	466.4
		16.5	485.3
0.62		4.0	581.7
	300	8.5	329.4
		16.5	452.8
		4.0	400.2
	500	8.5	526.1
		16.5	284.9
LSD (P <0.05)			158.6
Water content (A)			84.0
Gravel concentration (B)			73.9
Gravel size (C)			NS
A x B x C			158.6

(Source: Salako *et al*., 2007b)

Increasing soil water content up to 0.62 cm^3 cm^{-3} caused lower soil strength at 100 g kg-1 gravel concentration for different gravel sizes than higher concentrations of gravel. Gravel concentration and soil water content influenced soil strength more than gravel size. This may be due to the fact that the most abundant gravel in these soils are in the grade of 2-4 mm (Table 29; Salako *et al*., 2007b).

There was a decreasing proportion of gravel as gravel size increased beyond 16 mm. Furthermore the middle and lower slopes had more gravel than the upper slope. Given the finding that gravel could be transported in runoff even along gentle slopes in southwestern Nigeria (Tables 13 and 14; Salako, 2008b), the soil is highly vulnerable to erosion not just because of its inherent properties but also due to very high rainfall erosivity. Gravel from the upper slope could be deposited in the process either in the middle or lower slope depending on the carrying capacity of runoff. Microtopographic changes on eroded farmlands monitored using the pin method had indicated that soil particles were deposited en-route during the erosion process of slopes in Abeokuta (Figure 16; Sotona *et al*., 2014). Sotona *et al*. (2014) further revealed, using geostatistical tools, that soil erosion could be predicted within a range of 5–8 m distance along slopes in Abeokuta.

Salako *et al*. (2007b; 2007c) reported that soil strength increased with depth for the gravelly soils of southwestern Nigeria, irrespective of slope position (Figure 20). Salako *et al*. (2007b) proposed the following equations to estimate soil strength (Y axis, kPa) from soil depth (X axis, cm) as maize grew through a moist gravelly Alfisol in southwestern Nigeria treated with different nutrient amendments and on different slope positions (number of observations, n = 56, P <0.0001):

Upper slope

NPK + urea

$$Y = 0.646x^2 + 6.22x + 2134 \qquad r^2 = 0.42 \qquad (7)$$

Poultry manure

$$Y = 0.88x^2 + 21.78x + 1800 \qquad r^2 = 0.42 \qquad (8)$$

No amendment

$$Y = -0.295x^2 + 101.72x + 988.8 \qquad r^2 = 0.88 \qquad (9)$$

Table 29: Gravel distribution in the surface soil (0-20 cm depth) of an Alfisol in University of Agriculture, Abeokuta, southwestern Nigeria and its influence on soil bulk density

29a: Fine earth and gravel distribution

Statistics	Fine earth (%)			Gravel concentration (%) 2-4 mm			4-8 mm			8-16 mm			> 16 mm		
	U*	M	L	U	M	L	U	M	L	U	M	L	U	M	L
Mean#	90.6a	65.6b	62.0c	6.1	16.7	20.6	1.4	11.0	10.3	1.0	3.7	3.9	1.2	3.1	3.0
Coefficient of variation (%)	7.2	33.7	26.0	52.3	45.1	28.5	158	85.3	74.5	185	88.2	72.5	222	155	138

29b: Bulk density with and without gravel

Statistics	Bulk density with gravel ($g\ cm^{-3}$)			Fine earth (without gravel) bulk density ($g\ cm^{-3}$)		
	Upper	Middle	Lower	Upper	Middle	Lower
Mean#	1.21c	1.42a	1.35b	1.16ab	1.19a	1.09b
Coefficient of variation (%)	8.10	13.19	11.22	9.45	18.59	18.94

Mean comparison for slope position of each group of soil strength; means with different letters are significantly different.
##Maximum reading of 5000 kPa, which was the maximum capacity reading of the equipment, was assigned at depths at which penetrometer could no longer penetrate the soil due to contact with rock fragments
* U = Upper slope position, number of observations = 40, M = Middle slope position, number of observations = 40, L = Lower slope position, number of observations = 41
(Source: Salako *et al*., 2007c)

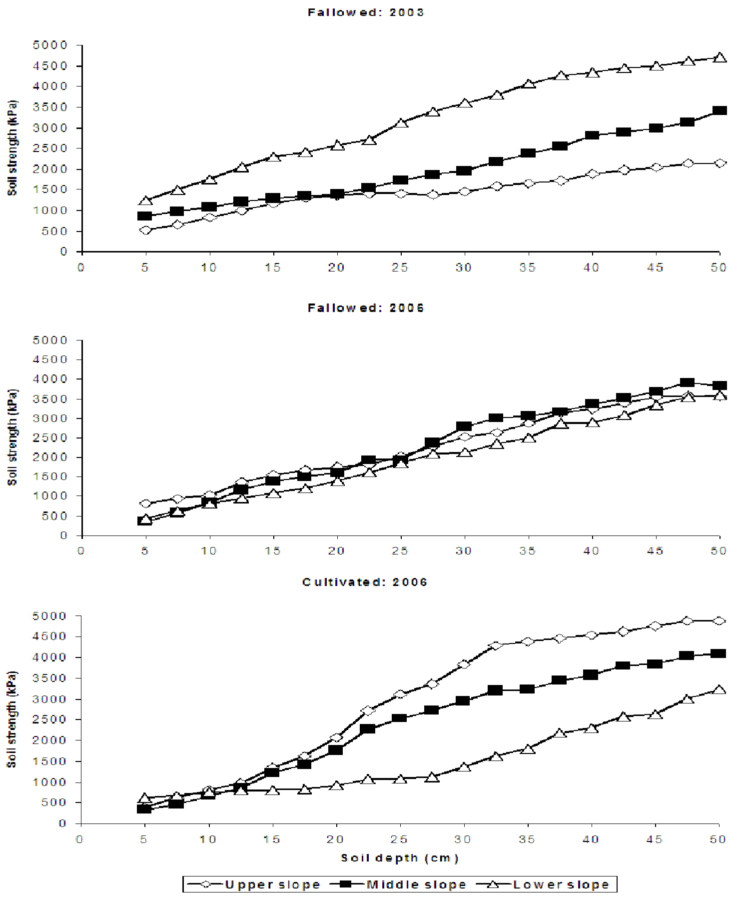


Figure 20: Variation of soil depth on a 7-year fallow land and a 6-year mechanically cultivated land (to sunflower, *Helianthus annus* and sesame, *Sesamum indicum*) at the Federal University of Agriculture, Abeokuta, southwestern Nigeria (Source: Salako *et al*., 2007c).

Lower slope

NPK + urea

$Y = -1.89x^2 + 168.96x + 411.6$ $r^2 = 0.72$ (10)

Poultry manure

$Y = -1.80x^2 + 155.15x + 73.8$ $r^2 = 0.59$ (11)

No amendment

$Y = -0.52x^2 + 127.75x + 39.6$ $r^2 = 0.87$ (12)

Increase in soil strength was due to overburden pressure (Sands *et al*., 1979). From 20 cm depth downward, soil strength was > 2000 kPa, which implies potential impediment to root growth. Also, mechanical cultivation had induced soil compaction, which must have been due to the fact that mechanized cultivation was carried out in July when the soil was wet.

Salako *et al*. (2007c) used the excavation method to determine soil bulk density, with and without gravel (Table 29b). They went further to develop a relationship between the fine earth bulk density (i.e., r_f in g cm^{-3}, without gravel) and total bulk density (i.e., r_t in g cm^{-3}, with gravel) as follows:

$r_f = 0.378 + 0.577r_t$, $P < 0.0001$, $r^2 = 0.28$, $n = 121$ (13)

Salako *et al*. (2006a) also defined a relationship between total bulk density, r_t, sand and clay contents of the gravelly Alfisol in southwestern Nigeria:

$r_t = 1.35 + 5.88 \times 10^{-5}\text{Sand} + 7.59 \times 10^{-4}\text{clay}$ $P < 0.001$, $r^2 = 0.34$ (14)

Soil (dry) bulk density (Tables 29 and 30) is a commonly measured physical property, which indicates compactness of soil and has implication for soil strength. Its value, however, depends on how carefully, soil samples are taken and processed. In spite of the role of gravel in influencing soil bulk density and soil strength, Salako *et al*. (2007c) stated that only the fine earth fraction ($\leq$ 2 mm soil) influenced total bulk density, r_t. This might be due to the fact that the soils were still dominated by the fine earth faction (Table 29a), which is the fraction that is more valuable for agricultural production. High concentration of subsoil gravel decreases soil porosity and available water holding capacity, and limits crop root growth (Babalola and Lal, 1977). Soil water plays a significant role in modifying these physical characteristics (Table 28).

Table 30: Variation in bulk density and some chemical characteristics of soil planted to *Gliricidia sepium and Acacia leptocarpa* in Mokwa, southern Guinea savanna

Soil depth (cm)	Bulk density (g cm^{-3})		Soil depth (cm)	Soil chemical properties *Gliricidia sepium*		
	G. sepium	*A. leptocarpa*		pH (1:1) H_2O	Organic carbon (g kg^{-1})	Available P (mg kg^{-1})
0-15	1.30	1.36	0-15	6.5	5.19	1.63
15-30	1.37	1.35	15-30	5.8	2.60	1.07
30-45	1.38	1.36	30-45	5.7	2.90	0.96
45-60	1.37	1.39	45-60	5.7	2.69	1.19
60-75	1.37	1.42	60-75	5.5	2.50	1.30
75-90	1.42	1.39	75-90	5.8	2.40	1.30
90-105	1.33	1.40	90-105	5.6	2.30	1.19
105-120	1.37	1.33	105-120	5.9	2.90	1.19
120-135	1.29	1.33	120-150	6.0	2.20	1.30
135-150	1.33	1.30	150-180	6.1	1.60	1.07
150-165	1.34	1.34	180-210	6.0	2.40	1.07
165-180	1.28	1.31	210-300	6.0	1.90	0.85
180-195	1.39	1.29	$LSD_{0.05}$	0.7	1.21	0.70
195-210	1.38	1.34				
210-240	1.51	1.61				
240-270	1.45	1.55				
270-300	1.40	1.37				
$LSD_{0.05}$ (Trees x Depth	0.08					

(Source: Salako and Tian, 2004b)

2.6.2. Fractal analysis

Application of fractal analysis to soil studies was relatively novel by 1997 (Anderson *et al*., 1998). Salako (1997), Salako *et al*. (1999 and Salako (2001) showed the possible application in the description of soil aggregate stability (Tables 31 and 32). Salako *et al*. (1999) reported its application to 4-10 mm aggregates whereas Salako (2001) reported the application to < 4 mm aggregates. For 4-10 mm soil aggregates (Table 31), Salako *et al*. (1999) attributed low fractal dimensions, D, to fallowing or stable aggregates and high D to cultivation or unstable aggregates. High D values imply a tendency of soil aggregates to fragment. Soil aggregates were more cohesive or stable in the dry season than the wet season while the upper slope was more stable than the lower slope (Table 32: Salako *et al*., 1999; Salako, 2001).

Given this logic, it was established by Salako *et al*. (1999) that aggregates without coarse fragments which had significantly higher D of 2.62 mm would be more unstable than aggregates with coarse fragment with D of 2.48 mm ($LSD_{0.05}$ = 0.1). This finding may be connected with the increase in soil strength conferred by the presence of gravel (Salako *et al*., 2007b; 2007c). The significant difference caused by interaction of slope and D suggest that the processes of soil degradation or aggregate breakdown would be different according to slope position (Table 32b; Salako, 2001). Although, the surface soil was vulnerable to aggregate breakdown by the intense rain of the area, this can be avoided or prevented with soil cover or non-intensive cultivation of the soil.

Further evidence of fractal dimension as an index of fragmentation of soils was obtained with analysis of soil particles across the savanna zones of Nigeria (Salako, 2006b, 2006c: Figures 21 and 22).

Table 31: Fractal dimension (D) of 4-10 mm surface soil aggregates of a gravelly Alfisol in southwestern Nigeria

Fallow system	Cropping Intensity				Mean
	Continuous cropping	1-y crop/1-y fallow	1-y crop/2-y fallow	1-y crop/3-y fallow	
January 1994(0-10 cm depth)					
Bush fallow	2.37	2.40	2.36	2.29	2.36
Pueraria	2.36	2.33	2.36	2.29	2.34
Leucaena	2.52	2.44	2.39	2.35	2.43
Forest	-	-	-	-	2.25
Mean	2.42	2.39	2.37	2.31	
March / November 1995 (0-5 cm depth)					
Bush fallow	2.72	2.47	2.55	2.59	2.58
Pueraria	2.58	2.60	2.66	2.68	2.63
Leucaena	2.67	2.67	2.67	2.61	2.66
Mean	2.66	2.58	2.63	2.63	

$LSD_{0.05}$	1994	1995
Fallow systems	0.101	NS
Cropping intensity	0.104	NS
Cropping intensity x same system	0.152	0.183
Cropping intensity x different system	0.190	NS

NS: Not significant

(Source: Salako *et al*., 1999)

Table 32a: Variation of fractal dimensions of 4-10 mm soil aggregates (in surface 0-10 cm soil depth) with seasons, slope and presence of gravel in an Alfisol in southwestern Nigeria

		Fractal Dimension, D	
Month	Season	With gravel	Without gravel
January	Dry	2.37	2.50
September 1994	Wet	2.67	2.80
March/November 1995	Wet/Dry	2.62	-
$LSD_{0.05}$		0.10	0.08
Slope position			
Upper slope		2.41	2.54
Lower slope		2.55	2.69
$LSD_{0.05}$		0.13	0.13

(Source: Salako *et al*., 1999)

Table 32b: Fractal dimension D of surface soil (0-15 cm depth) aggregates less than 4 mm diameter as affected by topographic position and seasons for an Alfisol in southwestern Nigeria

	Season of the year		
Slope position	Dry season (January, 1994)	Wet season (July, 1995)	*P*-value
Upper slope	2.79	2.99	<0.001
Lower slope	2.85	2.90	0.004

(Source: Salako, 2001)

		Silt+Clay
	2.768379	179.3529
	2.778598	212.8497
	2.863237	373.1776
	3.011505	637.0604
	3.024435	525.4029
	3.058851	626.5136
	2.654965	95.46162
	2.781534	173.3644
	2.730835	239.3264
	2.813508	385.0952
	2.920437	509.8573
	2.938239	523.0301
	2.832602	168.2415
	2.869699	207.5205
	2.899071	394.9616
	2.879445	411.9711
	2.873927	371.2539
	2.919555	385.5812
	2.87243	161.5419
	2.893877	178.5953
	2.805511	220.3346
	2.789914	208.454
	2.814025	240.424
	2.966717	294.7452
	2.827607	226.3881
	3.070396	576.1463
	2.988331	568.2818
	2.968543	598.1888
	2.973463	544.3636
	3.196398	355.804

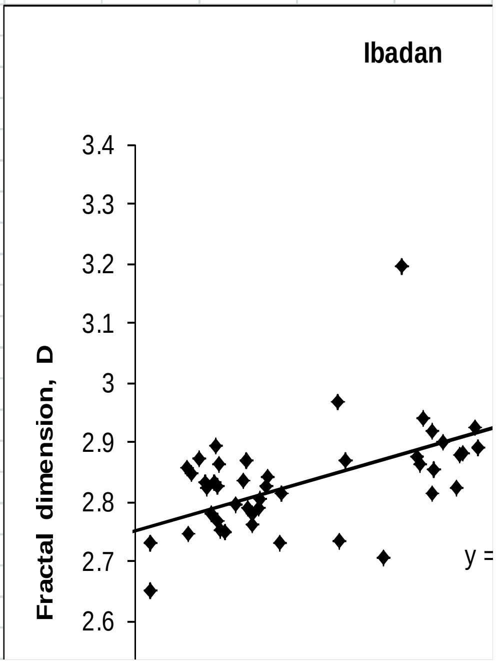


Figure 21: Fractal dimension as affected by particle size distribution in Ibadan and Alabata (near Ibadan), southwestern Nigeria (Source: Salako, 2006b)

1.346152	335.3789
1.393015	342.5605
1.372948	345.2032
1.380135	362.3954
1.286649	381.5752
1.372101	373.2139
1.382706	372.9566
1.29486	374.7828
1.497007	364.1846
1.537536	356.9346
1.415743	365.7602
1.163695	398.2579
1.350817	376.6954
1.298921	437.9724
1.628791	288.8325
1.329641	293.9061
1.32741	382.4043
1.326909	510.7674
1.379347	500.6944
1.291625	518.5077
1.204353	546.6965
1.183665	566.9369
1.326487	587.2726
1.155884	590.0092
1.098787	284.1333
1.193147	308.3528
1.279449	319.634
1.339436	356.1724
1.377968	433.0621
1.315889	415.5599
1.333337	421.3001
1.403722	439.568
1.324972	499.988
1.126101	533.3333
	D
	3.022
	3.082
	3.152
	3.202
	3.232
	3.212
	3.212
	3.232
	3.242
	3.252
	3.242
	3.262
	3.272
	3.262

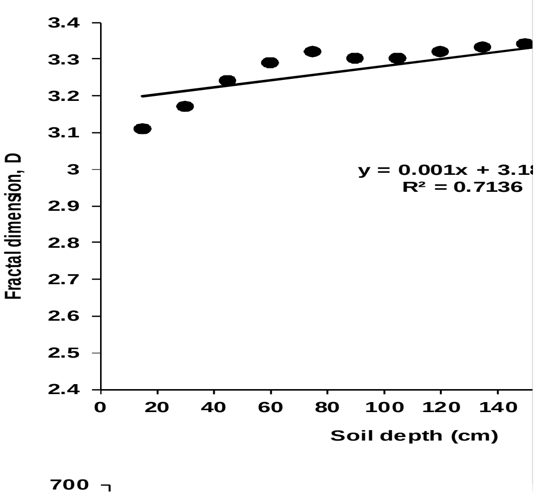


Figure 22: Fractal dimension and soil particle in relation to soil depth at Mokwa (southern Guinea savanna), Northwestern Nigeria (Source: Salako, 2006b)

First, fractal dimension increased with silt + clay contents of soil, indicating higher fragmentation tendency with fine particles (Figures 21 and 22). Second, these fine particles increase with soil depth in the savannas (Figure 22). Fractal analysis can also be used to describe soil water retention in soil (Salako, 1997; 2003). According to Salako (2003), the fractal dimensions for pores in the 0-15 cm soil depth of some fallow systems were between 2.92 and 2.93..

The interpretation of data after applying fractals to soil aggregation and a particle size distribution must differ. Although it is true that higher D connotes higher fragmentation, for soil aggregation, this implies instability of aggregates whereas for particle size distribution, it implies increasing presence of fine particles. Clay content and mineralogy, organic matter, and cations play significant role in soil aggregation (Hillel, 1998; Jury and Horton, 2004; Lal and Shukla, 2004). Therefore, aggregates are expected to be stable if clay particles flocculate and are cemented by agents like cations, organic carbon, mucilaginous substances and root exudates. Overall, high D for aggregates means disintegration of macroaggregates into more abundant smaller or microaggregates and for particle size distribution, more abundance of fine particles. The presence of gravel in soils formed over basement complex in southwestern Nigeria confers some level of compression on soil particles, which could aid aggregation and increase soil strength.

2.6.3. Soil water

Soil water (its retention, storage and flow or drainage or evapotranspiration) is an important component of the hydrologic cycle, just like rainfall and runoff. Apart from rainfall and runoff which I study as complements of soil erosion by water, I carried out studies also on other components of the hydrologic cycle such as soil water content and potential, saturated and unsaturated water flow, soil water infiltration, and evapotranspiration.

2.6.3.1. Soil water content and potential

Soil water characteristic curve for the gravelly Alfisol of southwestern Nigeria has been described (Figure 23; Salako *et al*. (2006a). Salako *et al*. (2006a) went further to develop relationships by which the water retention of the soil can be predicted from commonly measured particle size distribution. Accordingly, soil water retention at field capacity (FC, -10kPa) and permanent wilting point (PWP, -1500 kPa) water content (cm^3 cm^{-3}) at Alabata can be predicted ($P < 0.001$) from total sand ($g\ kg^{-1}$) and clay ($g\ kg^{-1}$) as follows (n = 41):

$$FC = 1.01 - 1.04 \times 10^{-3}\ Sand - 5.88 \times 10^{-4}\ clay \qquad r^2 = 0.55 \qquad (15)$$

PWP = 0.573-6.09 x 10^{-4}Sand – 1.65 x 10^{-4}clay r^2 =0.55
(16)

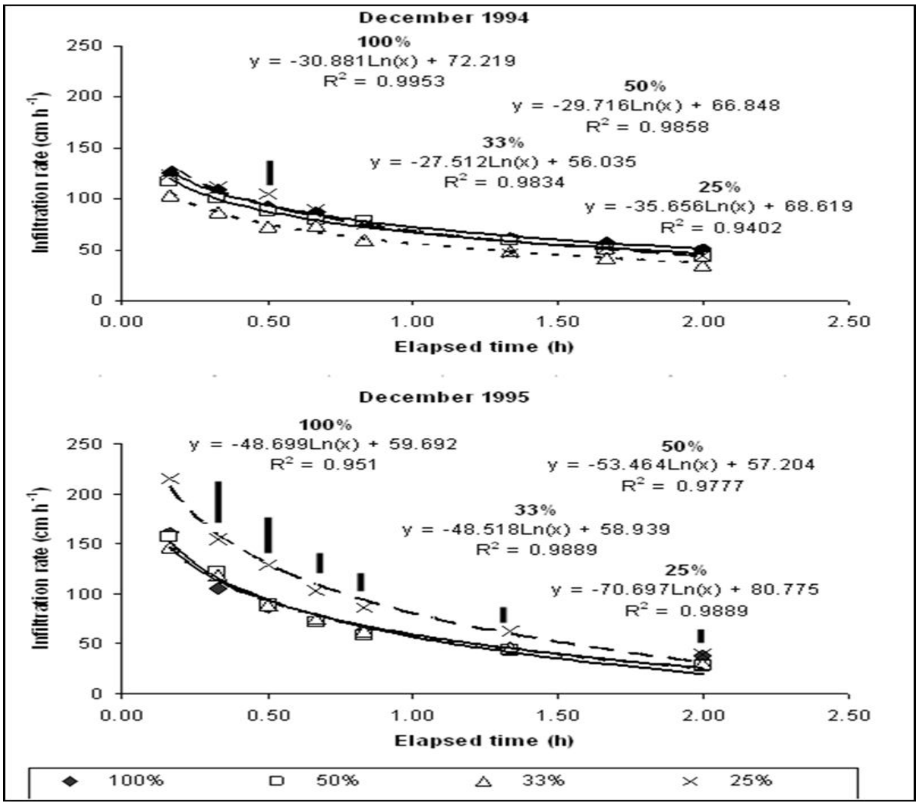
These relationships (pedotransfer functions) serve as a tool for estimation of soil water characteristics for similar soils because equipment and actual measurements are difficult to come by. It is noteworthy that the soil water characteristic curves for the different soil layers (Figure 23) have implication for soil water flow and its impedance.

In Alabata, near Moniya, Ibadan, southwestern Nigeria, Salako and Tian (2003a) reported that soil water potential < -10 kPa, measured on the field between 0 and 30 cm depth using tensiometers, were observed mainly between 6 and 12 weeks after planting thirteen leguminous cover crops, and by 20 weeks after planting when the cover crops had matured and rainfall frequency was low. This study was carried out to select cover crops based on their soil water requirements in relation to intercrops**. In many advanced countries today, particularly Israel, digital tensiometers are connected or linked to remote sensors/satellites to alert farmers on cell phones or home/office computers on when to irrigate crops (GIMI, 2014). Thus, data from soil water retention either in the laboratory or on the field can guide in soil water management if properly applied.**

2.6.3.2. Saturated and unsaturated water flow

Initial water infiltration on dry soil could exceed 200 cm h^{-1}, and decrease later after about 2 hours to less that 50 cm h^{-1}, asymptotically (Figure 24; Salako, 1997). Thus, saturated water flow was very high in the soil, even under continuous cropping that had spanned 6 years. However, measurements of infiltration rate or cumulative infiltration using the double-ring infiltrometer reflect conditions possible under flood irrigation with the water head maintained between 6 and 12 cm, but not conditions obtainable most of the time under rainfall (Figure 24). Based on such measurements, it was found that two-hour infiltration rates with different fallow management practices ranged between 27 and 72 cm h^{-1} on an Alfisol in Ibadan, southwest Nigeria (Salako, 2002b).

Runoff or overland flow hardly exceed 1 cm depth on soil surface. This prompted the use of tension infiltrometers (a variant called disc permeameter) to measure water infiltration under saturated and unsaturated conditions (Salako and Kirchhof, 2003; Salako *et al.*, 2006c). Comparison of sorptivity and infiltration rates measured with double ring-infiltrometer (10 cm water head) and disc permeameter (1 cm water head) showed similar results in spite of the differences in time spent to measure the characteristics (Table 33; Salako and Kirchhof, 2003).



100% cropping intensity: Continuous cropping, 1989-1995, 50%: 1-year cropping/I-year fallow. 33%: 1-year cropping/2-year fallow, 25%: 1-year cropping/3-year fallow

Figure 24: Water infiltration into an Alfisol under different cropping intensities measured using double-ring infiltrometer in southwestern Nigeria (Source: Modified from Salako, 1997; 2002b).

This implies that with the disc permeameter the stress and rigor of using large quantity of water is removed, without compromising the integrity of data. Negative water supply heads of a disc permeameter are used to measure unsaturated water flow while the positive heads measure saturated flows (Figure 25; Salako and Kirchhof, 2003).

Unsaturated water flow (-1 cm water supply head) through mounds was reported by Salako *et al*. (2006c) to give sorptivity of 10.42 cm $h^{-½}$ for cowpea plot, 11.48 cm $h^{-½}$ for *Mucuna* and 12.39 cm $h^{-½}$ for *Pueraria* with a significant difference only between cowpea and *Pueraria*. The mounds had a significantly higher sorptivity of 14.34 cm $h^{-½}$ whereas the furrow had a sorptivity of 8.51 cm $h^{-½}$. **This study was about the first to draw attention to the hydrologic conditions under mound tillage in Nigeria.** This is very important given that the adoption of mound tillage for root and tuber crops cultivation is widespread in Africa (Babalola and Opara-Nadi, 1993).

Busari *et al.* (2012) working on upland and lowland soils at Ajegunle Farm Settlement, Ajebo road, near Abeokuta, southwestern Nigeria reported that application of poultry manure (PM) with NPK fertilizer significantly raised soil saturated hydraulic conductivity and resulted in 40% and 59% increases in soil infiltration rate at the lower and upper slopes, respectively.

Table 33: Comparison of sorptivity (cm $h^{-½}$) and infiltration rate (cm h^{-1}) measured with disc permeameter and double-ring infiltrometer on an Alfisol in southwestern Nigeria in 1999

	Sorptivity		
Cropping intensity (%)	Disc permeameter: 1-h run	Double-ring infiltrometer: 2-h run	*P* > t
100	138 ± 81	93 ±67	NS
25	155 ± 95	165 ± 63	NS
	Infiltration rate		
100	52 ± 28	90 ± 23	NS
25	72 ± 30	107 ± 21	NS

± Standard error (n = 12)

(Source: Salako and Kirchhof, 2003)

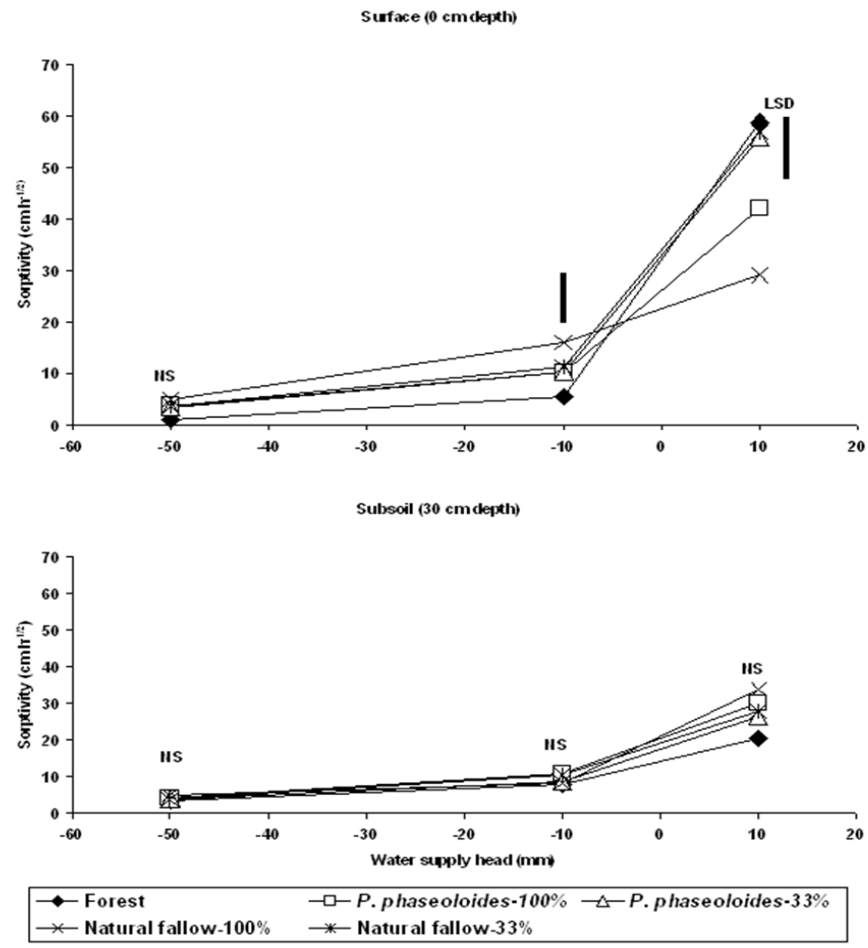


Figure 25: Sorptivity (cm h-½) measured with disc permeameter on al Alfisol under various fallow management systems in December 1996 in southwestern Nigeria
(Source: Salako and Kirchhof, 2003).

The results showed infiltration rate at the upper slope was higher than that of the lower slope by about 190%. Such high rates were also reported by Busari and Salako (2012; 2015). Busari and Salako (2012) working in Abeokuta, southwestern Nigeria reported that the infiltration rate of 10.87 cm h^{-1} observed in 2008 with 20 t ha^{-1} poultry manure application decreased to 6.19 cm h^{-1} in 2009 possibly due to reduction of large pores of the sandy soil by repeated application of poultry manure, suggesting leaching of nutrients would be reduced by this treatment

It should be noted that although infiltration capacity and saturated hydraulic conductivity of the soils were generally high (Figures 24 and 25; Table 33), these properties would only be of advantage when rainfall intensity is low and duration is short. Unfortunately this is not so in the tropics (Salako, 2002c) where, as reported in earlier Sections, very high rainfall intensities are sustainable for an average duration of 1-3 h, and at times for 24 h. Runoff is bound to occur with sustained high intensities and large amounts of rainfall, occurring at short intervals during the peak period of the rainy season.

2.6.3.3. Soil water depletion and evapotranspiration

A practical application of Soil Physics is Irrigation of Crops and Drainage of Soil Water. This suggests knowledge of crop water requirement, soil water content and potential. Tensiometers can be used to measure or generate data to quantify these attributes, and by extension used to deduce soil water depletion and evapotranspiration. As indicated earlier, tensiometers play a significant role in deciding when to irrigate field crops, and are becoming more important with current advances in its technology, in particular, and agricultural technology, in general (GIMI, 2014).

Vacuum-gauge tensiometers (manual recording) were used at Alabata (near Moniya), Ibadan, southwestern Nigeria to characterize soil water depletion by various leguminous cover crops (*Aeschynomene histrix, Centrosema brasilianum, Centrosema pascuorum, Chamaecrista rotundifolia, Cajanus cajan, Crotalaria verrucosa, Crotalaria ochroleuca, Lablab purpureus, Mucuna pruriens, Psophocarpus palustris, Pseudovigna argentea, Pueraria phaseoloides* and *Stylosanthes hamata*) in 1993 and 1994 (Salako and Tian, 2003b: Figures 26 and 27). **Apart from irrigation scheduling, the study was also significant for application in terms of crop water requirement. It is important in the selection of an appropriate cover crop either as a sole crop or as an intercrop of an arable crop, using soil water depletion as a criterion.**

Using Penman-Monteith (PM), Hargreaves (HG) and Pan methods as recommended by the Food and Agriculture Organisation, FAO (Allen *et al*., 1998), Salako (2008d) computed reference evapotranspiration for different ecologies of Nigeria (Figures 28 and 29**.) Although water supplement through irrigation was not obviously necessary in the coastal and humid zones, it would be of advantage if excess water during the rainy season is conserved for irrigation purposes during the dry season or even during dry spells within the rainy season. Crop production during the dry season with irrigation is necessary for food security in Nigeria. Autocorrelation coefficients showed that similarity of ET_o could only be expected for three consecutive years, after which a significant change would occur in the trend (Figure 30).** Regression between *PM* and other methods for the daily means obtained on weekly basis (Figure 28) resulted in the following equations (N = 52) (Salako, 2008d):

Onne

$$PM = -0.189 + 0.782HG,\ P < 0.0001,\ r^2 = 0.93 \quad (17)$$

$$PM = 0.847 + 0.954Pan,\ P < 0.0001,\ r^2 = 0.93 \quad (18)$$

Ibadan

$$PM = -0.595 + 0.881HG,\ P < 0.0001,\ r^2 = 0.91 \quad (19)$$

$$PM = 1.044 + 0.873Pan,\ P < 0.0001,\ r^2 = 0.91 \quad (20)$$

Kano

$$PM = -1.730 + 1.327HG, \ P < 0.0001, \ r^2 = 0.72 \qquad (21)$$

where

N = number of observations

PM = FAO-Penman-Monteith method is recom mended for the evaluation of reference evapotranspiration (ET_0)

HG = the Hargreaves

Pan = Pan evaporation methods,

P = probability level of significance, and

r^2 = coefficient of determination

		15-30 cm soil depth											
		C. brasilian	*C. rotundifol*	*L. pupureus*	*S. hamata*	*P. palustris*	*P. argentea*	*M. pruriens*	*C. verrucosa*	*C. ochroleu*	*C. cajan*	*C. pascuoru*	*A histrix*
12-Jul-93	4	5.5	5	7.5	5	4.5	3	3.5	5	4.5	2.5	2.5	6
26-Jul-93	6	8.5	5.5	22	6	9.5	5	38	2	7.5	5	4	7
9-Aug-93	8	5	4.5	8.5	7	11.5	39.5	0.5	5.5	6	35	5.5	3.5
#######	10	8.5	5.5	23.5	3.5	7.5	4	31	0.990016	7	7	7	6
#######	14	2.5	1.5	2.5	1.5	2	1	4.5	0	5.5	1	1.5	4.5
4-Oct-93	16	3.5	1	3	2.5	3	1.5	0	0	0	2.5	2	4.5

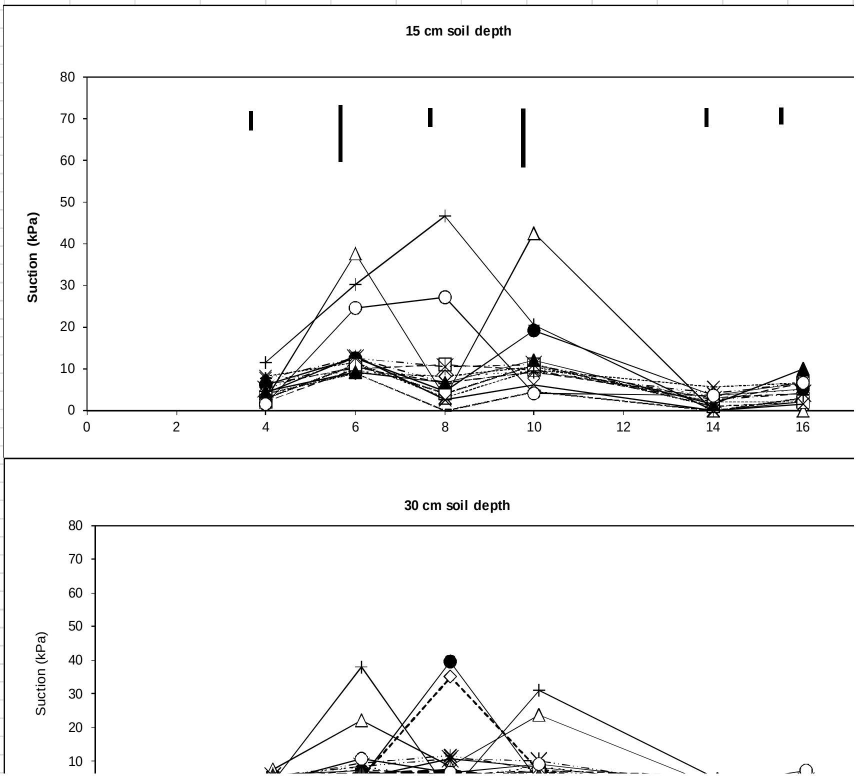


Figure 26: Soil water suction at 15 and 30 cm depth at different growth stages of cover crops in 1993 at Alabata: LSD bars (vertical bars) are for interactions of cover crop with depth (Salako and Tian, 2003b)

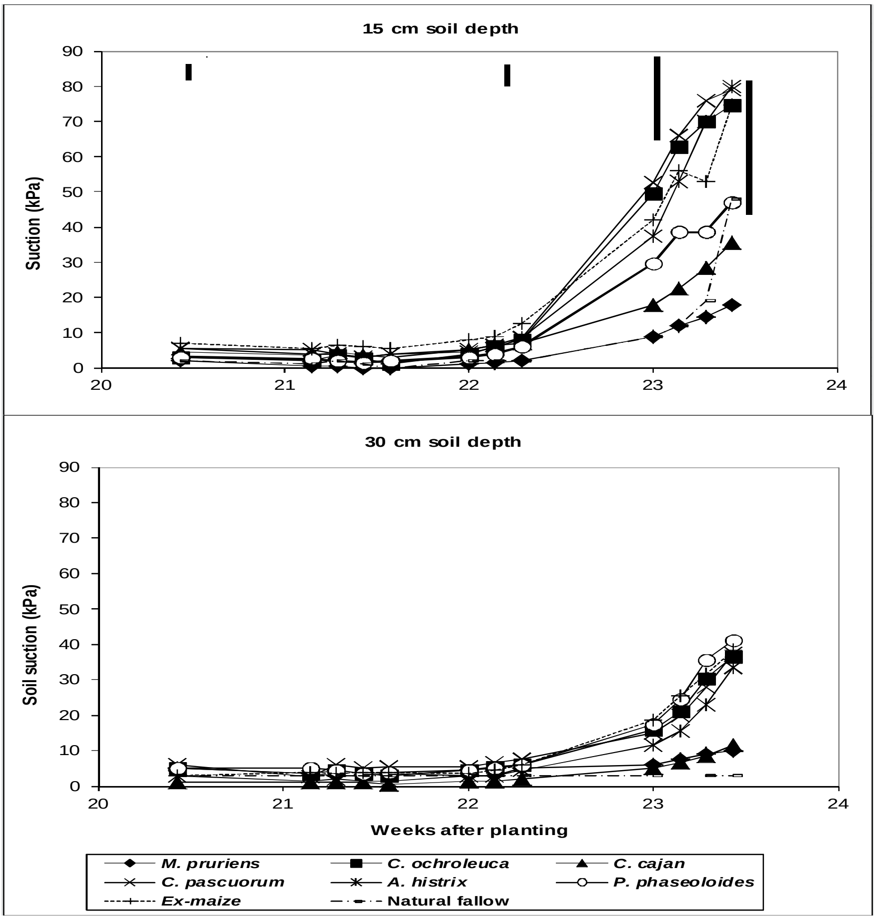


Figure 27: Soil water suction at 15 and 30 cm depth at different growth stages of cover crops in 1994 at Alabata: LSD bars (vertical bars) are for interactions of cover crop with depth (Source: Salako and Tian, 2003b)

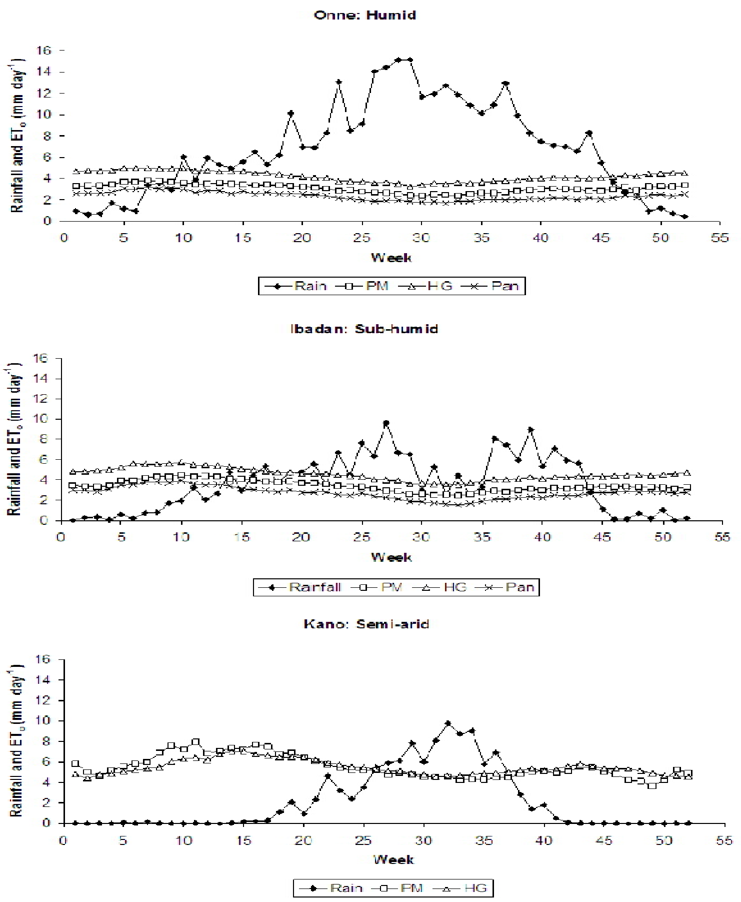


Figure 28: Daily means of rainfall and reference evapotranspiration (ET_o) in each week of the year from 1990-2005 in Onne, Ibadan and Kano, Nigeria (Source: Salako, 2008d).

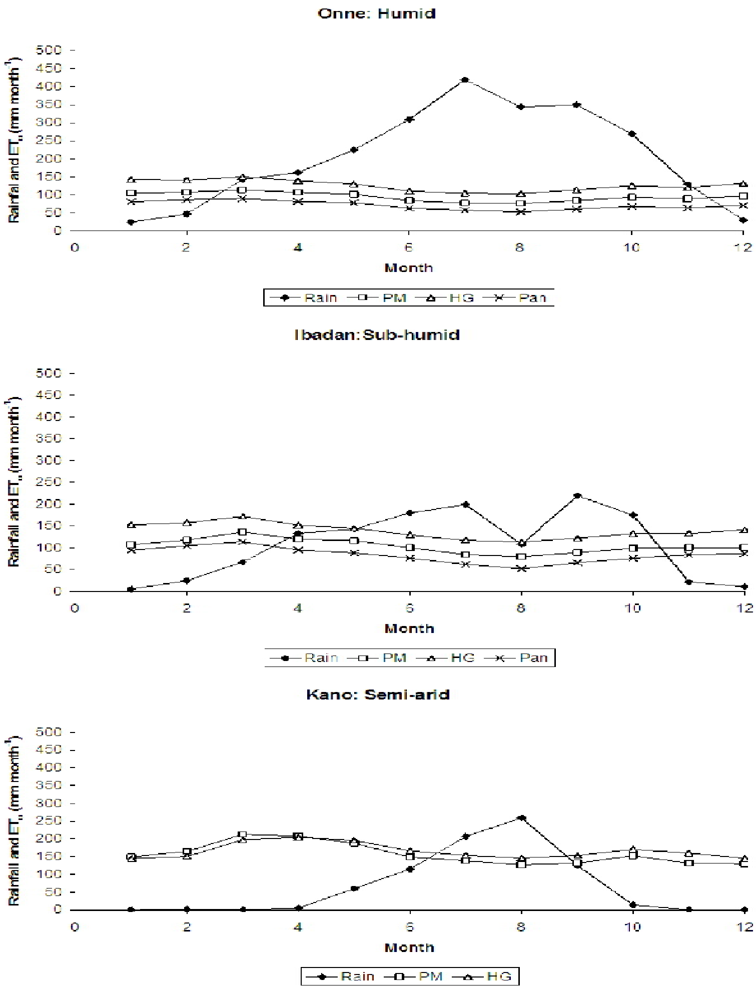


Figure 29: Monthly sums of rainfall and reference evapotranspiration (ET_o) from 1990-2005 in Onne, Ibadan and Kano (Source: Salako 2008d)

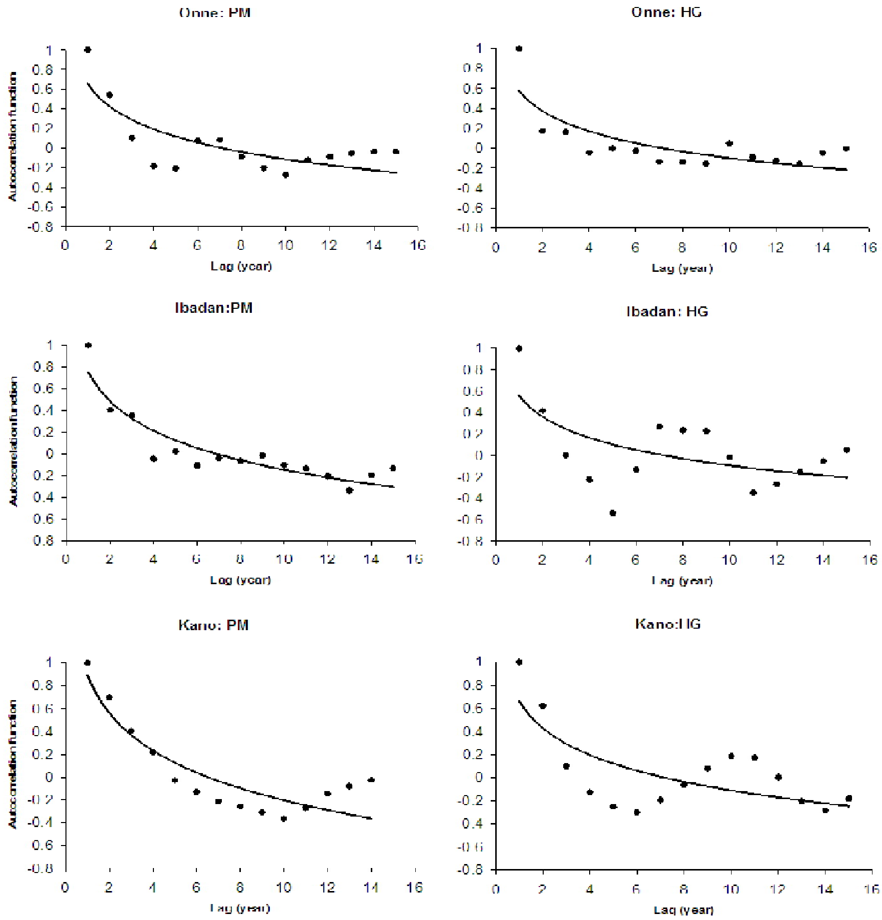


Figure 30. Autocorrelograms for annual reference evapotranspiration using Penman-Monteith (*PM*) and Hargreaves (*HG*) methods from 1990-2005 in Ibadan, Onne and Kano, Nigeria (Source: Salako, 2008d)

Busari *et al*. (2013) used stable isotopes of water to measure soil water evaporation under tillage systems and maize growth in Abeokuta, southwest Nigeria. They reported that annual evaporation estimated using the vapour diffusion equation ranges from 46-70 mm year^{-1} under zero tillage and from 54-84 mm year^{-1} under conventional tillage, suggesting that conventional tillage led to more soil water evaporation than zero tillage. I had earlier carried out a similar unpublished work in an island of Venice, Italy in 2007, from where the idea of replicating it in Abeokuta, southwestern Nigeria by Busari *et al.* (2013) was mooted. Of course, this necessitated subsequent visits to Italy for isotopic analysis by Dr. Mutiu Abolanle Busari of the Department of Soil Science and Land Management, Federal University of Agriculture, Abeokuta, Nigeria.

Understanding of spatial variability with the use of tools like geostatistics and fractal analysis is a basic requirement in developing precise soil management tools, and the likely area where there could be a dearth of data in the tropics was in the area of soil physical properties. Hence the peculiar interest in characterizing soil profiles. The various studies on soil profile physical properties provided insight into how they influenced or could influence crop/plant growth. The various equations de-

veloped based on these measured properties are tools or models that can be used for soil physical characterization, especially in developing nations of the tropics, where there is paucity of data to do so. The strength of the results and the models lies in the use of advanced tools for data collection and analyses. It is interesting to note that while Salako et al. (1999) and Salako (2001) at Ibadan found that the upper slope of the gravelly soil there had more stable aggregates than lower slope using fractal analysis (Table 32), Salako et al. (2007b) reaffirmed this with the finding that the upper slope of the gravelly Alfisol at Federal University of Agriculture, Abeokuta was more resistant to degradation, after being desurfaced artificially (Table 15). Busari *et al.* (2012) working on soils in Ajegunle Farm Settlement near Abeokuta made a similar observation. Thus, the results obtained through these mathematical analyses had practical significance even beyond the location of study. Many of the equations presented in the various studies carried out are often referred to as "pedotransfer functions" because they serve as tools for estimating soil properties that are either cumbersome to measure or not just routinely measured

2.7. Soil Productivity under Different Soil Management Options

Soil productivity implies adequacy of soil physical, chemical and biological properties. Although my focus was in the sub-discipline of Soil Physics/Soil Conservation, my studies were generally aimed at improving Soil Productivity, with crop yields as indices (Sub-section III; Table 10). Invariably, soil chemical and biological properties were measured along with soil physical properties in many of the studies, while also using treatments such as inorganic and organic fertilizers (Tian *et al*., 2001b).

Salako and Tian (2004b) noted that "while soil physical characteristics might not be sensitive to change under fallow management systems, other parameters such as soil microbial or biological properties might be found to indicate change within a short fallow period". They stated further that "it is important to define sustainability in the appropriate context in terms of expected output and time frame in order to determine the efficiency of proposed agroforestry, cover cropping, conservation tillage and mulching technologies among a plethora of sustainable systems in the tropics".

My intention under this Sub-Section is to bring to fore Crop Yields under the various Soil Management Options using two long-term experiments as major examples:

(i) A long-term experiment after clearing a secondary forest, with practices to sustain soil productivity for a period of 10-years (Tian *et al*., 2005)

(ii) A long term-experiment to restore soil productivity after practices such as mechanical operations, and events such as soil erosion rendered the site severely degraded (Kang *et al*., 1997; Salako and Tian, 2003b)

Crop production was expected to be sustained under a 11-year old long-term experiment involving cover cropping with *Pueraria phaseoloides*, alley-cropping with *Leucaena leucocephala* and natural fallow in which intercropped cassava and maize yields were measured (Table 34; Figure 31; Tian *et al* 2005). This low-input cropping practice (manual clearing and field maintenance, no-tillage and no fertilizer addition) included no fallow; 1-year of cropping/1year of fallowing, 1-year of cropping/2-years of fallowing and 1-year of cropping/3-years of fallowing. The land was cleared at onset from a 23-year old secondary forest. Although average yields were generally within average values expected for maize, they were not for cassava (Table 34).

Tian *et al*. (2005) stated that "transforming shifting cultivation to a permanent cropping, fallow with natural vegetation (natural fallow), herbaceous legumes (cover crop fallow) and woody legumes (alley cropping) can contribute to the maintenance of crop production and soil fertility, however, length of fallow does not need to exceed 2-years.

When the fallow length is reduced to 1 year, a better alternative to natural regrowth would be the cover crop for higher maize yield and alley cropping for higher soil organic matter. For fallow length of 2 years, West African farmers would be better off with the natural fallow system". In effect, planted fallow might not necessarily be better than natural fallow when it comes to sustaining crop production. The diverse vegetation in natural fallow seemed to complement each other in improving soil productivity. Planted fallows must be targeted at achieving rapid restoration of soil productivity and other economic benefits.

The second long-term experiment also proved that natural fallow was not really bad for restoring crop production (Tables 18-21; 35-36; Kang *et al*., 1997; Salako and Tian 2003b). The adoption of planted fallows must be based on targeted benefits, which in terms of soil quality, our researches have contributed to. Although, Kang *et al*. (1997) found that intercrop yields were generally acceptable within the first year of cropping after a 3-4 year fallow period, this reduced drastically for maize by the second year of cropping but within average values for cassava (Table 35). Fallowing the severely degraded land further for 6-years gave better yields, especially with mounding and addition of inorganic fertilizer (Tables 18-21, and 36; Salako and Tian 2003b). Invariably, the severely degraded soil was rehabilitated by fallowing for 6 years, application of mound tillage and fertilizer. Combined use of NPK and poultry manure was also effective in restoring the productivity of artificially desurfaced soils along a toposequence in Abeokuta, southwestern Nigeria (Table 15; Salako *et al*., 2007b).

Table 34: Mean yield of intercropped cassava from 1993-2000 under various fallow and cropping systems on an Alfisol manually cleared from a secondary forest in Ibadan, south-western Nigeria

Fallow/Cropping System	Crop yield (t ha^{-1})			
	Length of fallow (y)	Maize grain	Maize stover	Cassava fresh root yield
Natural fallow	0	0.61	1.05	5.4
	1	1.58	1.88	8.1
	2	2.30	2.71	9.5
	3	2.42	2.91	9.8
Cover cropping (*Pueraria* fallow)	0	0.87	1.24	4.9
	1	2.02	2.30	7.6
	2	2.21	2.65	8.8
	3	2.44	3.02	9.4
Alley cropping (*Leucaena* fallow)	0	0.77	1.09	4.3
	1	1.30	1.61	5.5
	2	1.83	2.44	6.3
	3	1.95	2.41	6.7

(Source: Tian *et al*., 2005)

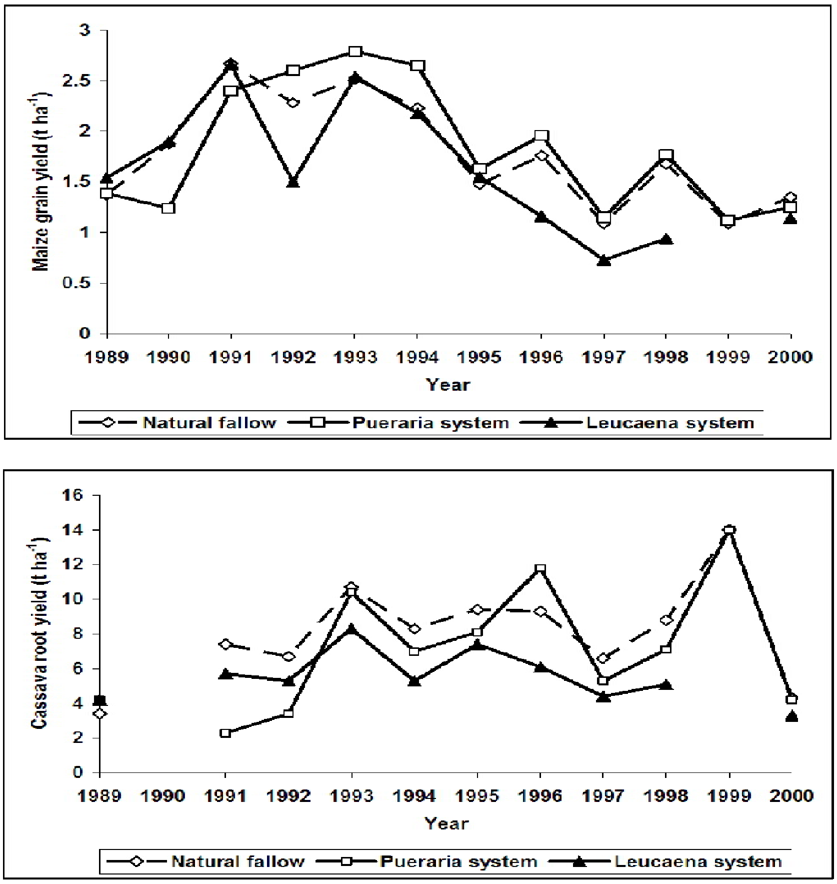


Figure 31: Yields of intercropped maize and cassava grown under herbaceous *Pueraria* and woody *Leucaena* fallow and cropping systems between 1989 and 2000 on an Alfisol which was manually cleared of a 23-year old secondary forest and cropped without the use of inorganic fertilizer (Source: Tian *et al*., 2005).

Table 35: Intercropped maize grain and cassava root yields after fallowing a degraded Alfisol for 4 years in Ibadan, south-western Nigeria (Source: Kang *et al*., 1997; Salako and Tian, 2003b)

35a: Under flat minimum surface disturbance (1993-1995) (Kang *et al*., 1997)

Fallow	Maize grain (t ha^{-1})		Cassava root (t ha^{-1})	
	1993	1994	1993/94	1994/95
Pueraria phaseoloides	0.73	0.69	16.0	11.8
Psophocarpus palustris	1.17	1.19	14.0	12.4
Senna siamea	0.73	0.99	11.0	7.3
Leucaena leucocephala	0.98	0.82	9.0	8.9
Acacia leptocarpa	0.65	0.82	10.0	10.0
Acacia auriculiformis	0.90	0.50	8.0	6.3
Natural regrowth	0.88	1.02	13.0	12.3
Continuous cropping	0.43	0.36	6.0	9.3
$LSD_{0.05}$	0.37	0.59	5.0	NS

35b: Under Mound and Level (Minimum) Tillage 1995-1996 (Source: Salako and Tian, 2003b)

Fallow	Maize grain (t ha^{-1})		Cassava root (t ha^{-1})	
	Mound	Level	Mound	Level
Pueraria phaseoloides	0.40	0.32	12.0	7.3
Senna siamea	1.22	0.88	17.0	12.5
Leucaena leucocephala	0.97	0.59	16.1	9.0
Acacia leptocarpa	0.68	0.37	13.3	8.9
Acacia auriculiformis	0.86	0.38	10.5	7.7
Natural regrowth	1.10	0.56	14.9	9.2
Continuous cropping	0.32	0.30	9.8	5.7
$LSD_{0.05}$ (Tillage x Fallow)	0.656		0.480	

Table 36: Effects of tillage and different levels of N on intercropped maize and cassava yields in 1995 and 1996* on a degraded Alfisol in southwestern Nigeria (Source: Salako and Tian, 2003b).

Nitrogen level (kg ha^{-1})	Intercropped maize grain yield (t ha^{-1})				Intercropped cassava root yield (t ha^{-1})	
	1995		1996		1995/96	
	Mound	Level	Mound	Level	Mound	Level
0 N	2.37	2.08	0.75	0.20	19.9	15.7
30 N	2.26	2.02	0.83	0.63	17.1	15.2
60 N	2.47	2.31	1.60	1.11	19.8	16.3
Continuous cropping (> 12 years)	-	-	0.24	0.06	13.7	9.0
LSD< 0.05 (Tillage x N level)	NS		0.69		4.54	

* 1995 = One year of cropping after 6 years of fallowing
1996 = Two years of cropping after 6-years of fallowing

3.0. CAPACITY BUILDING AND EXTENSION SERVICES

I started my career as a Consulting Soil Scientist, a job which saw me leading a Soil Survey team to study soils of areas more than 30000 ha along River Gongola in the old Bauchi State, and along the Sokoto-Rima River in Birnin Kebbi for the purpose of irrigation development. I had the privilege of being guided by Prof. A. G. Ojanuga who was then of the University of Agriculture, Makurdi. My team met friendly rural community dwellers who accommodated us and advised us ahead not to venture into jungles of wild animals without extraordinary measures. Beyond this, I worked on Coastal Erosion Control, a responsibility that made me to interact for some time with the Aiyetoro Community in Ondo State. I cannot forget easily my concern for safety, travelling by boat from Igbokoda, Ondo State through water hyacinth-infested waterways to this community, renowned earlier for its socialist ideology; **but the job must be done and it was done**.

As a lecturer, I have participated in supervising more that forty undergraduate projects and more than twenty postgraduate projects, dissertations and theses. Dr. Mutiu Abolanle Busari, a lecturer in the Department of Soil Science and Land Management, FUNAAB, was my M. Sc. and Ph.D. student. Mrs. Olabisi Onasanya (nee Sonuga), now an Assistant Lecturer in the Department, was my B. Agric. and M. Sc student, and she is currently on her Ph. D. under my supervision. Dr. Pius Dada of Agricultural Engineering Department was my M.Sc. student and I co-supervised his Ph.D. I have also co-supervised postgraduate theses in my own Department and College as well as the Departments of Physics, and Agricultural Meteorology and Water Resources Management. I am privileged to note that many of the students I supervised are in various agricultural and related institutions in the country and in Niger Republic, while some have changed course, but are progressing in their chosen careers. I am proud to be associated with all these former students. May God continue to bless them and lift them higher.

My assignments in IITA and FUNAAB have made me to be more involved in Community Development. In IITA, I worked in rural areas of southern and northern Nigeria. As Director, Agricultural Media Resources and Extension Centre (AMREC), FUNAAB (2008-2011), and pioneer Director, Community-Based Farming Scheme (COBFAS), FUNAAB (2011), I worked with teams of highly committed staff who made specific impacts in agricultural and human developments of communities in southwest Nigeria, particularly in our host state, Ogun. By the grace of God, I was challenged by the then Vice-Chancellor, Professor Oluwafemi Olaiya Balogun, to make AMREC self-sustaining through external funding or grants. By so doing, I left the Centre financially healthier than I met it, and funds left behind serve in the empowerment of southwestern Nigerian farmers till now.

Adeoti *et al.* (2014) at a seminar on "Innovation for Inclusive Development: The role of Nigerian Universities" presented at Nigerian Institute of Social and Economic Research (NISER), Ibadan on Tuesday November 11, 2014 recommended as follows: "**make COBFAS a model for practical training in Agriculture in Nigerian Universities: The network of interaction exemplified by COBFAS should be encouraged**".

4. RECOMMENDATIONS FOR SOIL TO OIL THE NATION, AGAIN

My experience over the years suggests that soil management implies climate management or climate-smart agricultural practices in the tropics because rainfed agriculture is largely practised. Climate is a factor of soil formation and contributes significantly to weathering, leaching and erosion, thereby playing a major role in the determination of soil properties and sustainability of soil management options. In order to manage climate effectively, we need vegetation. Therefore, a sound soil management plan must put into consideration soil, climatic and vegetation characteristics. These have been considered over the last three decades, by me as a Soil Scientist,

to arrive at the following recommendations:

1. I commend for use for Soil Conservation Planning in Nigeria the isoerodent maps developed by Salako (2010b). The philosophy, the number of studies and the amount of data involved make me thoroughly convinced that the maps have removed a ,major obstacle involved in the use of the Revised Universal Soil Loss Equation (RUSLE) for computing potential soil loss in Nigeria. **The choice of EI_{15} index removes the fear of underestimation if EI_{30} index but both are provided for to satisfy curiosity in terms of comparative assessments.** Complementary data for RUSLE can be obtained using the Wischmeier and Smith soil erodibility nomograph, topographic maps or field measurements of slope factor as well as crop and land management factors from available literature or by direct measurements.
2. The various models for computing daily, monthly and annual erosivity for situation- or location-specific conditions are also reliable, as tools for researchers. Again, these tools remove the problem of non-availability of auto-recording raingauges, which are not commonly available.
3. **We have developed various models or pedotransfer functions for the purpose of estimating soil properties which are not routinely measured. These are recommended for use in similar agro-ecological zones**

4. There is definitely a lot of water to conserve from the savannas to the humid forest Nigeria. If countries with just about 500 mm annual rainfall can produce crops for local consumption and exports, we only need to harness all the water "lost" in the water-balance equation to practise irrigated agriculture. Efficient water utilization for irrigation, such as in drip irrigation, can be considered for our soils. Such systems conserve soil and water.
5. Soil management options must be decided before embarking on land clearing or conversion of land to agriculture. This brings to fore the need for soil survey and land evaluation. This must be handled by experts. It is the practice in many developed nations to have detailed soil surveys which are reviewed regularly. Nigeria needs detailed Soil Surveys and Land Evaluation with full complements of all sub-discipline contributing to the work.
6. In this respect, I differ strongly from the traditional school of thought that Soil Survey and Land Evaluation should be limited to those who specialize in the sub-discipline of Soil Survey and Pedology. To me, the sub-discipline should be a basic sub-discipline to qualify as a Soil Scientist. A Soil Scientist must be distinct from a Scientist who works with soil, based on a deep knowledge of Pedology. Soil Scientists must study the soil deeper than the topsoil.
7. **There is a plethora of technologies available for sustainable crop production, which have been reported in**

this lecture. All point to the fact that Conservation Agriculture is the key to Sustainable Crop Production and Food Security. The fact that some technologies did not work well under a situation does not mean they cannot work well in others. It is clear that cover cropping, alley-cropping, fallowing for a minimum of six years, judicious use of organic manuring in combination with inorganic fertilizers are soil management options that can sustain crop production if soil erosion or degradation is prevented from land clearing stage. Minimum tillage can also be an option, depending on the crop to be grown and soil condition. It is high time Nigeria developed a policy on Conservation Agriculture.

8. Universities and Research Institutes or Centres need to invest both in field and laboratory equipment, as well as computer or laboratory equipment software regularly, for meaningful researches to be conducted in any scientific field. There must be adequate funds for research while specific mandates must be attached to each fund. The era of funding research for research sake is gone.
9. There is a need for more seriousness in collation of research results and their application in Nigeria. It is quite appalling that in spite of enormous researches carried out in this country, right from the colonial era, private firms run by expatriates and our own government parastatals often pretend such data are not in existence. Although we

have tried, we need to do more even in our University for us to showcase the knowledge-base from the abundance of experts in this Institution

10. University Researchers have been accused of not accessing funds provided by the Tertiary Education Trust Fund (TETFund). While TETFund must be commended for providing the funds in the first place, the reasons why the funds are not being accessed may be extra-ordinary and should be investigated before the Nigerian researcher is crucified. This is not ignoring the truth that there is a need for the re-orientation of some researchers to be more productive when funds are available and adequate. I wish to recommend that funds be provided also for the establishment of first-class Central Laboratories in various Universities, with well-trained technologists to handle (specialized) equipment. Without being pessimistic, we cannot really get to the promised land in science and technology if basic needs like electricity and clean potable water taken for granted in less endowed countries, cannot be provided, uninterrupted. I really struggle to work out with students how to get the desired result when the instruction is "oven dry soil samples at 105^{o}C for 24 h'' because it is certain the oven will not be powered continuously for even 10 h (?) in a day. Existing government institutions need to be strengthened to provide efficient and effective services for the growth of the agricultural, science and educational sectors. Nigerians must make these institutions work.

5. CONCLUSION

Over the past three decades, I worked with various scientists to promote technologies for sustainable agricultural development in the tropics, with agro-ecological zones in Nigeria as case studies for similar tropical ecologies. Technologies and assessment tools developed are applicable on both small- and large-scale farms. They focused on soil conservation, particularly protection and build-up of soil organic matter, prevention of soil erosion and sustained profitable crop production. The assessment tools can be used for rapid evaluation to proffer solutions on related agronomic problems. **For soil to oil the nation (again), farmers or agriculturists in Nigeria must adopt and practise Conservation Agriculture.**

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"*What is man that You are mindful of him, and the son of man that You visit him*" Psalm 8: 4 (NKJV). I am exceedingly grateful to God for fulfilling my boyhood dream of becoming a Professor. Beyond that I have consistently enjoyed his mercy and grace. All glory unto Him.

I am the last born of a family of seven children who God gave my parents, Late Mr. J. A. SALAKO and Mrs. R. W. SALAKO. My father passed on when I was 11 years, just as

I was leaving Primary 5 to Secondary School Form 1. He had, however, inculcated in me the discipline needed even in adulthood, and this has continued to pay off for me till today. He left enough resources for the education of all of us, and I am eternally grateful to God for having a disciplined mother who guided us properly until she passed on in 1995. My parents were excellent in all aspects of parenting; my mother, an epitome of motherhood. I thank my brothers (late Mr. E. T. Salako, and Messrs I. A. Salako and A. A. Salako) and sisters (Mrs. E. A. Ojerinola, Mrs. C. A. Oderinde and Dr. A. A. Majekodunmi) for the wonderful roles they played in my upbringing.

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I have already acknowledged the contributions of some of my teachers at the tertiary education level under the section, "Homage to the Fore-runners". It is worth repeating here that my teacher, the late Prof. J. S. C. Mbagwu fired my imagination in the field of Soil Science at the Department of Soil Science, UNN . He was a God-sent individual that I shall keep appreciating. I must thank other Lecturers in the Department who made Soil Science interesting. Prof. M. E. Obi, my M.Sc. thesis supervisor, was also good to me, and even recommend post-graduate students to contact me for supervision.

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Moving on to the (Federal) University of Agriculture, Abeokuta, as a Senior Lecturer was at the prompting of Prof. A. G. Ojanuga. I met him first in the final year of my undergraduate studies and he later mentored me in the area of Soil Survey and Pedology when I was a Consulting Soil Scientist. I doff my hat for a foremost Nigerian Soil Scientist. My colleagues in the Department of Soil Science and Land Management are wonderful. I must mention here that I have often benefited from the experience of Prof. M. T. Adetunji since I joined the Department and I continue to appreciate his fatherly role in the Department, College and University. I am grateful to my Dean, Prof. Goke Bodunde and my Head of Department, Prof (Mrs.) O. A. Babalola for their encouragement. The Dean played a significant role by encouraging me to deliver this Inaugural Lecture. My informal discussions with Profs. F. O. Olasantan, K. A. Elemo, O. A. Enikuomehin, Dr. M. A. Busari, Dr. F. A. Olowokere, Alhaji L.

Solarin and Mr. M. A. Jayeola whenever I am at a cross-road have always been very helpful. I cannot forget all the staff of AMREC and COBFAS who worked with me during my tenure as Director in each of the Centres. They contributed immensely to my experience in Community Development. The list of staff I am indebted to in FUNAAB is quite long. These include both academic and non-teaching staff. All of you are dear to me and I plead for your understanding for not listing all names here.

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By virtue of my responsibilities, I have been a member of the University of Senate for about 14 years now. My knowledge has been enhanced through the robust intellectual arguments I listen to in the Senate and the high quality of decisions taken. My sincere appreciation to all Senate members for providing necessary and needed support for me to serve our University.

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I am always very happy with my job as a lecturer. Students make me hopeful when they engage me in intellectual discussions and pose questions that are challenging. In these days of high-tech, when information is readily available on the finger tip (e.g., cell phones), a lecturer must be on guard by updating himself regularly. I appreciate all my students, both former and current. I pray for their progress and am happy with their progress. I am very happy having Dr. Mutiu Abolanle Busari and Mrs. Olabisi Onasanya (nee Sonuga) in our Department, teaching Soil Physics/Soil Conservation. I am also happy to be associated with other FUNAAB alumni in the Department: Dr. Jamiu O. Azeez in Soil Chemistry, Dr. A. A. Soretire in Soil Microbiology and Mrs. C. O. Ayodele (nee Olubuse) in Soil Survey and Pedology.

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I am married to Deaconess M. O. Salako. She is not just a spouse but a very reliable companion. Our children, by the grace of God, are; Damilola, Dolapo and Dimeji. Oluwagbemiga (2000-2013) was also with us; now with God and God is with us. May His name be praised forever and ever. My wife and children have contributed to my success in no small way. They bore it encouragingly when I had to work on Saturdays and Sundays as a price to pay for my part-time Ph. D. programme during the period I was a Research Associate in IITA. They bore it on the several occasions that I needed seclusion to write my research papers. Whenever I am at the nadir due to disturbances and distractions by adversaries, home is the place I run to for me to get back to the zenith; home is the place where my wife and children would remind me to cast my burden unto God; home is the place where I am told not to be afraid because "*The LORD is strong and mighty; The LORD is mighty in battle*" (Psalm 24: 8). I am very grateful to God for giving me my family. I love you all.

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I respect all men and women but **I worship and praise only God and God alone**. For this reason, I will appreciate it if you can join me in praising God in my *mother-tongue:*

Ẹ jẹ ka jumọ f'ọpẹ f'Ọlọrun
Orin iyin, at'ọpẹ lo yẹ wa
Iyanu n'ifẹ Rẹ si gbogbo wa
Ẹ kọrin 'yin s'Ọba Olore wa

Halleluyah! Ogo ni fun Baba
A f'ijo ilu yin Ọlọrun wa
Alaye ni o yin Ọ bo ti yẹ
Halleluyah! Ogo ni fun Baba

Ki l'a fi san j'awọn t'iku ti pa?
Iwọ lo f'ọwọ wọ wa di oni
'Wọ lo n sọ wa to n gba wa lọw'ewu
Ẹ kọrin 'yin s'Olutọju wa

Ohun wa ko dun to lati kọrin
Ẹnu wa ko gboro to fun ọpẹ
B'awa n'ẹgbẹrun ahọn nikọkan
Wọn kere ju lati gb'ọla Rẹ ga

(Credit for song lyrics: http://toluakande.bandcamp.com/track/j-ka-jumo-f-p-f-lorun-single)

The Vice-Chancellor, Sir; Ladies and Gentlemen I thank you again for being part of this memorable occasion.

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