UNIVERSITY LECTURE

MANAGEMENT OF NIGERIAN SOIL RESOURCES: AN IMPERATIVE FOR SUSTAINABLE DEVELOPMENT

by

AYOADE OLAYIWOLA OGUNKUNLE

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The Vice-Chancellor, Deputy Vice-Chancellor (Administration), Deputy Vice-Chancellor (Academic), Registrar, Librarian, Provost of the College of Medicine, Dean of the Faculty of Agriculture and Forestry, Dean of the Postgraduate School, Deans of other Faculties and of Students, Directors of Institutes, Distinguished Ladies and Gentlemen.

Preamble

I thank the Almighty God and the University Management for the privilege to deliver this lecture on behalf of the Faculty of Agriculture and Forestry. I was reluctant at first when my Head of Department muted the idea, but considering the fact that I am one of the few that missed the opportunity of giving an inaugural lecture, I later accepted the offer, more so that it is coming exactly one year to my exit from the University.

The first in the series of university lectures from the Faculty of Agriculture and Forestry was delivered by late Professor V.A. Oyenuga of the Department of Animal Science in the 1975/76 session. The main title was, "Herbage, Flesh, the Quality of Human Existence": (i) The Herbage as Sources of Nutrients, (ii) Animal Flesh, Animal Products, the Quality of Life and (iii) Scientific Educational Challenges in Food Agricultural Production System. The second was by late Professor Q.B.O. Anthonio from the then Department of Agricultural Economics and Extension in 1983/84. The sub titles of his lecture were: (i) Nigerian Agriculture at the Crossroads, (ii) Nigerian Agriculture Revisited, and (iii) Improved Agricultural Marketing for Economic Development in Nigeria. The third was delivered by Professor Johnson Ekpere of the then Department of Agricultural Extension in the 1989/1990 session. His lecture was titled: "Agricultural Extension": (i) The Original Concept, (ii) The Search, and (iii) The Bottom-line. The fourth was by late Professor OlaOlu Babalola of the Department of Agronomy—my Department, in 2000/2001. His lecture was titled: "Nigerian Agriculture": (i) Basis for Hope, (ii) Hurdles and against

Hope, and (iii) Hope for Tomorrow. My Lecture is therefore the fifth in my Faculty and the second in my Department.

When I was asked to submit the titles for the lecture, I submitted 3 sub titles as was usually the case, but my Head of Department came back to inform me that the University Management, in its wisdom, had taken a decision to reduce the University Lecture to only one part instead of three. I believe that this decision must have been based on some cogent reasons. Even then, I strongly feel that although five lectures can be squeezed into one, the issues discussed in university lectures deserve more attention and should be given a longer time of presentation than the inaugural lecture. This must have informed the original decision to make it three lectures. Besides, there should be a difference between the two; otherwise there may be no need for the university lecture again. However, I believe there is a place for the university lecture; therefore I wish to suggest that the new decision be revisited for a consideration of at least two parts/lectures instead of only one.

The title of my lecture is: "Management of Nigerian Soil Resources: An Imperative for Sustainable Development". It is discussed under the following sub-headings: Man, Soil and Development; Nigerian Agriculture; Nigerian Soil Resources; Soil Degradation; Food Security; Soil Management and Sustainable Development; Established Systems of Sustainable Land/Soil Management; Conclusion and Recommendations.

Man, Soil and Development

The challenges facing humanity globally are so enormous as if human beings and the natural world are on a collision course. Human activities inflict harsh and often irreversible damage on the environment and on critical resources. If not checked, many of man's current practices put the future that we wish for human society and the plant and animal kingdoms at serious risk, and may so alter the living world that it will be unable to sustain life in the manner that we expect. Natural resource depletion and adverse impacts of environmental degradation, including desertification, drought, land degradation, freshwater scarcity and loss of biodiversity, add to and exacerbate the challenges which humanity faces. The situation is worsened by climate change whose adverse effect on natural resources undermines the ability of many nations to achieve sustainable development (UN 2015).

Land is universal and, according to the Millennium Ecosystem Assessment (MEA 2005), it is a major component in all the four ecosystem services of Supporting, Provisioning, Regulating and Cultural services. In an agrarian economy, the land as a major factor of agricultural production provides the needed fulcrum upon which sustainable development would blossom. Soil is a component of land resources and a major component of the ecosystem. It is the real wealth of a nation as it is basic to human existence. Soil is a vital and a non-renewable natural resource, on a human time scale. It provides an essential interface between water, nutrient and atmospheric cycles. Soil is essential for food, feed, fibre and fuel production hence it deserves to be at the top of national and international agenda for its role in sustaining life through food security. Soil provides many other goods and ecosystem services, making it invaluable to humankind. Unfortunately, in Nigeria, until recently, many developmental policies and decisions leave out the soil as if it does not matter or that it is optimally available and will continue to be so.

Available data show that about 24% of the world's land area is affected by degradation. Every year, 24 billion tons of soil is lost due to wind and water erosion, construction activities, compaction, resource extraction or exhaustive cultivation, thereby impacting 1.5 billion people globally (UNCCD Secretariat 2013). In the affected areas, land degradation correlates closely with extreme poverty, increased water scarcity, food insecurity and child mortality. Inventories of soil productive capacity indicate human-induced degradation on nearly 40% of the world's agricultural land as a result of soil erosion, atmospheric pollution, extensive soil cultivation, over-grazing, land clearing, salinization, and desertification (Oldeman 1994). Indeed, degradation and loss of productive agricultural land is one of our most pressing ecological concerns, rivalled only by human-caused environmental problems like global climate change, depletion of the protective ozone layer, and serious declines in biodiversity (Lal 1998).

Global estimates of food-insecure populations stand between 825 million (Lobell et al. 2008) to 850 million (Borlaug 2007). Regional estimates of the food insecure population include 263 million in South Asia (SA), 268 million in China and Southeast Asia, 212 million in Sub-Saharan Africa (SSA), 60 million in South and Central America and the Caribbean, and 50 million in other regions of the world. Thus one of the United Nations' (UN) Millennium Development Goals of cutting hunger by half by 2015 could not be achieved. The number of food-insecure populations in the world is increasing and may continue to increase. An estimated 75% of the world's poor (< $2/day income) live in rural areas and depend directly or indirectly on agriculture (FAO 2006; Lal 2009).

The challenges of food insecurity facing the society now and over the next decades are mainly due to loss of soil and water resources and associated ecosystem services, energy security and climate change. There is a shortage of good quality soil to bring about the desired increase in food production (Lal 2009). Available data (e.g. Beinroth et al. 2001; Blum 2013) also show that lands of inherently high quality (Class I) soils are uncommon globally. Such lands of high quality soils with few limitations for crop production, high response to management and capacity for high yield of crops at minimal cost, occupy only about 2.38% of the global land surface. On the other hand, land of poor quality soils (with low moisture, low organic matter and plant nutrients, poor physical properties and/or steep slope) occupies 45.30% of the global land surface. The lands with soils that can be adjudged fit (Classes I – IV) for agriculture (crop production) occupy only about 15% of the global land surface (Blum 2013). The situation is not different in SSA and also Nigeria.

The ecosystem in most Sub-Saharan African countries is seriously threatened through overuse/misuse. This is a direct result of the increasing needs of a growing population, often combined with inappropriate land/soil management practices. Thus, on the one hand, the population is growing at over two percent a year (FAO 2008), requiring a doubling of food production by 2030 to keep pace with demand; on the other hand, productivity of natural resources is in general decline. Additionally, the number of natural disasters has increased and climate change is already taking its toll. With the alarming rate of population expansion, the competition between agricultural and non-agricultural uses (urban, industrial etc.) is becoming very stiff. Soil abuse, misuse and pollutions combined with the negative effects of climate change result in the high degree of soil degradation. Food insecurity is the most obvious consequence of soil degradation.

Sub-Saharan Africa (SSA) remains the only region in the world where the number of hungry and malnourished populations will still be on the increase even by 2020 (Rukuni 2002). While other regions have improved per capita food availability since the 1970s, food production and availability have perpetually declined in SSA. It is both a technological and political/economic challenge, and cannot be ignored any longer. Agrarian stagnation in SSA has defied numerous attempts at transforming subsistence agriculture, even with due consideration to issues related to biophysical constraints and the human dimensions challenges (Otuska 2006). Traditional agricultural practices in SSA have been addressed in relation to soil degradation (Chokor and Odemerho 1994), soil nutrients and SOM depletion (Stromgaard 1991; Dakora and Keya 1997; Sanchez and Leakey 1997; Nye and Greenland 1958), soil pests (Hillocks et al. 1996), pest management (Abate et al. 2000), and plant defense mechanisms (van der Westhuizen 2004).

Sustainable development simply means all-round well-being today and in the future. A hungry person cannot be said to be well, hence food security is an important factor in sustainable development. Thus, one of the Millennium Development Goals (MDG1) was to "Eradicate extreme poverty and hunger by the year 2015". Furthermore, 3 (Goals 2, 3 and 15) of the 17 Sustainable Development Goals that replaced the MDGs at the end of 2015 (emphasize ending hunger, promotion of well-being and ecosystem preservation and sustainability respectively *https://sustainabledevelopment.un.org/sdgsproposal.htm*).

Obviously, there cannot be any true development in the face of poverty and hunger/food insecurity and degraded ecosystem. An important means to eradicate hunger and food insecurity (and thus achieve sustainable development) is to manage soil resources in a way that avoids all forms of degradation or at least reduce it to the barest minimum. The thin layer of soil covering the surface of the earth represents the difference between survival and extinction for most land-based life (Doran et al. 1996). Management of soil encompasses a wide range of practices with the express purpose of improving the capability of the soil to perform its various functions.

The quality of soil is impaired as soon as it is opened up for use or exposed to unfavourable climatic conditions. The highly efficient old traditional soil management system of shifting cultivation/bush fallow system (Nye and Greenland 1960) can no longer be sustained because of shortage of land space resulting from population explosion and competition from non-agricultural land uses. Fertilizer applications as currently practised by most Nigerian farmers are not based on soil data, and can do more damage to the crops some time later. Embracing science-based soil management practices that directly respond to these challenges is crucial, essential and urgent for the long-term sustainability of soil resources in the performance of their functions, among which food security is major. The intent of this lecture therefore, is to draw the attention of Nigerians, particularly policy makers, to the fragile nature of the soil resources of Nigeria, the high degree of soil degradation to which the soils are subjected and the combined negative impact on arable crop yield/food production. Hence, the urgent need for the adoption of appropriate management packages and actions that sustain soil quality, arrest food insecurity and enhance sustainable development in the country.

Nigerian Agriculture

Agricultural development in Nigeria has evolved through a long history bedevilled by many constraints which restrict the sector's growth and productivity. In the 1960s, Nigeria was mainly an agricultural economy. It was among the world's leading producers of Cocoa, Palm oil, Groundnuts, Cotton, Rubber, and Hides and Skin. The agricultural sector contributed over 60% to the Gross Domestic Product (GDP), supplying 70% of export and 95% of food needs. Despite its current reputation as petroleum resource dependent, Nigeria remains an agrarian economy, with between 60 and 70% of the population productively engaged in farming (Ukeje 2003; Nwajiuba 2010).

Nigeria has about 79 million hectares of arable land, of which 32 million hectares are cultivated. Over 90% of agricultural production is rain-fed. Smallholders, mostly subsistence producers account for 80% of all farm holdings. Crop production remains below potentials partly due to inadequate access to high quality seeds, low and/or inappropriate fertilizer use and inefficient production systems. Despite a 7% growth rate in agricultural production (2006–2008), Nigeria's food import bill has risen. The growing population is dependent on imported food staples, including rice, wheat and fish. Nigerian agriculture contributes, to a small extent, to global warming through bush burning and other poor land management practices.

Before the discovery of oil, agriculture was the main income earner of Nigeria in terms of GDP, foreign exchange, and employment of labour. The Federal Government established several agricultural policies and/or programmes. These include: Farm Settlement Scheme, World Bank assisted Agricultural Development Programmes (ADPs), Crop Research Institutes (increased to 18 in 1977), Marketing Commodity Boards (7) for various crops, River Basin Development Authorities (RBDAs), Nigerian Agricultural, Cooperative and Rural Development Bank (NACRDB), Agricultural Credit Guarantee Scheme Fund (ACGSF) and Federal Agricultural Coordinating Unit (FACU).

Between 1975 and 1983, Government established the National Accelerated Food Production Project (NAFPP), National Grains Production Company, National Livestock Production Company, Nigerian Food Company, National Fish Production Company, etc. In 1976, Government launched Operation Feed the Nation (OFN) and in 1980, OFN was replaced with the Green Revolution and Directorate of Food, Roads and Rural Infrastructures (DFFRI). However, all these efforts to revamp agriculture had little, if any effect on the development of the agricultural sector, the major determinant of the Nigerian economy mainly because the efforts were not pursued with sincerity of purpose. The projects were not funded and many were abandoned within 2 or 3 years of their existence; this resulted in the neglect of the agricultural sector by the Federal Government and the concentration on oil (Izuchukwu 2011).

Apart from the abandonment, the handling of agriculture before and after the oil 'boom' showed an almost total neglect of the role of soil resources in agricultural production. Knowledge about the nation's soil resources was rudimentary and the impact of soil conditions on crop performance was taken for granted. Crop production system did not include any serious soil management apart from the old practice of shifting cultivation invented by the traditional small-holder farmers based on their experience in the field (Nye and

Greenland 1960). Inorganic fertilizer application was the only soil chemical fertility management practice that was available to farmers for a very long time. Even then, the fertilizer applications were done haphazardly on 'blanket' basis and were never based on results of soil analysis or soil test.

There seemed to be an erroneous assumption that Nigerian soils have the unconditional capacity to support high crop production for as long as was required, even among intellectuals in the agricultural profession. Let me illustrate this with my experience with a colleague in my Faculty in 1991. He was approached by a farmer for feasibility study for a 250 ha fruit orchard in a village in Ogun State, and invited those of us that he considered relevant to the study. He then showed us the costing where he allocated about 80% of the fund to market survey (for a product for which we were not sure whether the location was suitable or not). He allocated the remaining 20% to soil and other studies, so soil could not even have up to 20% of the fund. So, if a colleague agriculturist can do that, then the neglect of soil resources by policy makers should not be a surprise.

The first time that serious consideration was given to the importance of soils in agriculture was in 1951 when the Western Region Government commissioned its Department of Agricultural Services, Research Division (now IAR & T) to conduct the soil survey of the Central Western Nigeria for Cocoa cultivation. The results of the soil survey are contained in a publication which has served as a soil manual for soil scientists within and outside the region (Smyth and Montgomery 1962). Around the same time, similar actions were taken in the then Northern and Eastern Regions (Klinkenberg and Higgins 1968; Jungerius 1964). In the Western region, the results of the soil survey were also used for the allocation of the Farm Settlements according to the kind and potentials of the soils.

The Federal Government showed very little concern for soils in agriculture until 1980 when it established the Federal Department of Agricultural Land Resources (FDALR) in the

Federal Ministry of Agriculture and Natural Resources with a School of Soil Conservation. The Department was established for detailed and accurate inventory of Nigerian soil resources and their characteristics, classification, capacity for the various crops and appropriate management for optimum crop production. In 1992, with further realization of the unique role of soils, in terms of information on its characteristics and the impact of soil loss on agricultural (crop) production, the National Agricultural Land Development Authority (NALDA) was created from FDALR to conduct soil surveys for agricultural projects and handle all land development projects. But NALDA was scrapped in 1999, seven years after its establishment.

One major negative consequence of the neglect of soil resources is that, at the moment, Nigeria does not have a National Soil Classification system. This is a clear indication that the importance of soil resources to agricultural production is not appreciated by the policy makers. It was in 1990 that FDALR, with the assistance of the United States Department of Agriculture (USDA), produced the first soil map of Nigeria based largely on geomorphological/soil order units of the USDA Soil Taxonomy (FDALR 1990). Obviously, this map cannot achieve much in view of the very broad units of mapping, and this is confirmed by field and cartographic evaluation (Olaniyan and Ogunkunle 2007a& b). The predictive value and utility of this map cannot be high because it was not based on the soil classes identified on the Nigerian soil classification system. The level of the USDA soil classes employed is too broad that it cannot be appropriate even for land use planning.

Agriculture Transformation Agenda

The Agriculture Transformation Agenda (Vision 2020, NTWG 2009) of the Federal Government from 2011 to 2014 was a success story because government decided to do things differently from the old practice and had a focussed, committed and convicted person to drive it. Government decided to:

(A) Stop doing certain things: (i) Treating agriculture as a development project, (ii) Spending on projects that do not clearly grow the sector in a clear and measurable way, (iii) Big government crowding out the private sector; and,

(B) Start doing certain things: (i)Treating agriculture as a business; (ii) Integrating food production, storage, food processing and industrial manufacturing by value chains ('farm to fork'); (iii) Focusing on value chains where Nigeria has comparative advantage; (iv) Using agriculture to create jobs, wealth and ensure food security; (v) Investment-driven strategic partnerships with the private sector; (vi) Investment drives to unlock potential of the States in agriculture (joint drives with State Governors).

The outcome of these efforts is well known to all, including:

- Rebirth of local fertilizer industry;
- Employment opportunity;
- Higher crop yield (cassava, rice);
- Commercialized cassava bread industry;
- Youth showing interest in agriculture;
- Emergence of food crop processing centres (14).

The Agricultural Transformation Agenda recognized the importance of soil resources to the success of crop production. This is confirmed by the fact that, for each of the value-chain crops (including cash crops), soil studies were commissioned for the locations of interest. Even then, this is only a temporary measure. There is no alternative to a comprehensive soil survey of the country for data on soil types, their extent, characteristics and potentials. Due consideration must be given to sustainable environmental (land/soil and water) management to guide fertilizer application and other cultural practices that may be required for optimum crop performance. Soil quality involves far more than chemical fertility.

The Nigerian Ecosystem

Nigeria is characterized by a very rich diversity of natural ecosystem resources, including soils, vegetation, watersheds and genetic diversity. Together, these constitute the nation's main natural capital. It is from these assets that the provision of food, water, wood, fibre, industrial products, and essential ecosystem services and functions are derived. It is from the land that over 60% of the people directly derive their livelihoods (FAO 2004). The key factors of the ecosystem that have strong impact on agriculture are climate and soil. The Nigerian climate is sub-tropical/tropical to semiarid with rainfall decreasing from the south (400 cm/yr.) to the north (75 cm/yr.). Pan evapotranspiration ranges between 1632 mm in Port Harcourt and 3512 mm in Kano. Length of dry season ranges between about 120 days in Port Harcourt to about 300 days in Kano. The high variation in climatic conditions across the country has produced 8 agro-ecological regions (fig.1) with different vegetation and adaptive crop types. In addition, marked climatic changes in the last three to four decades have resulted in desert encroachment (advancing at the rate of 0.6 km/year (FADE 2013) from the Sahara, threatening agriculture in the north while rainfall in the south is becoming erratic and unpredictable.

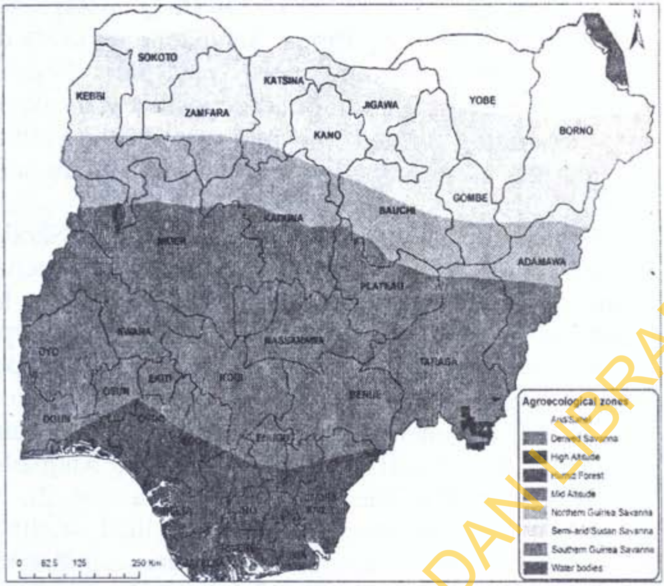

Fig. 1: Agro-ecological regions of Nigeria (IITA).

Nigerian Soil Resources

Underlying Geology, General Description and Distribution of the Soils

Available information (Moorman 1981; Ogunkunle 1986; Ogunkunle and Babalola 1986; Ogunkunle 2009; Esu 2005) shows that at least six (6) of the soil Orders of the USDA Soil Taxomy (8 of the WRB major Soil Groups of the FAO System) are found in Nigeria. They include: ***Alfisol, Ultisol, Entisol, Inceptisol, Vertisol and Andisol.*** The northernmost part covering about 15% of the country is occupied by Aeolian deposits from which immature, weakly developed, sandy Entisols (***Regosols/Arenosols***) have been formed. The most extensive geological deposit in the country is the Pre-Cambrian Basement Complex. It is made up of metamorphic and igneous rocks and covers a substantial portion of the southwest, southeast and the middle belt areas. The major soils on this deposit are the deep low activity-clay (LAC) Alfisols (***Luvisols, Nitosols***) at the upper and mid-slope positions, the shallow, rocky Entisol (***Lithosols***) at the crest and the sandy, deep, hill wash Entisols (***Regosol/Arenosols***) at the lower slope/valley positions. Sandstone deposits occur in the middle belt, immediate north of Rivers Niger and Benue, while the Coastal Plain Sand deposits extent from the southwest, extending through the mid-west to the southeast. Alluvial deposits are along Rivers Niger and Benue and the Niger Delta.

The soils on the Sandstone and Coastal Plain Sands are low activity-clay (LAC) Ultisols (***Acrisols***), with Inceptisols (***Cambisols***) and Entisols (***Arenosols***) occupying the lower slope and valley positions. The soils of alluvial deposits consist of immature and weakly developed Inceptisols (***Cambisols***) and Entisols (***Regosols/Arenosol***). Vertisols occur in limited amounts in the north eastern corner and the north of Benue River and around Lake Chad. Andisols are volcanic soils limited to the Jos Plateau area (fig. 2). More detailed information on these soils is provided in the next section while their major characteristics are summarised in table 1. Typical profiles of some of these soils are shown in figure 3.

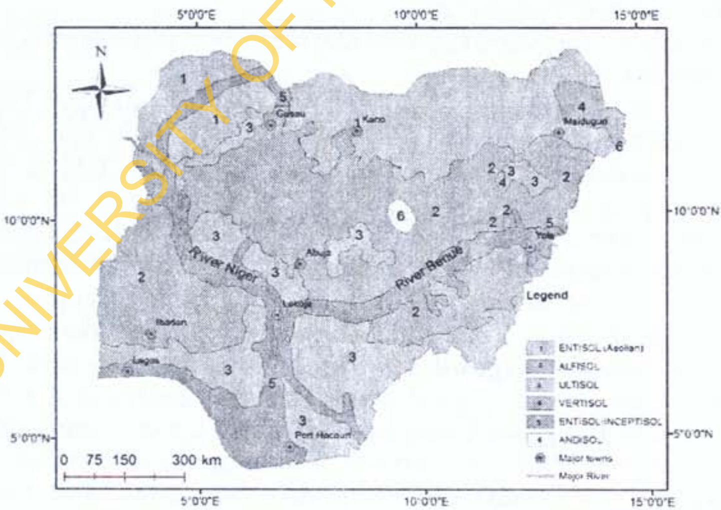

Fig. 2: Generalized soil map of Nigeria.

Table 1: Some Characteristics of the Major Soils of Nigeria

Soil Order	Land Coverage (Approx. %)	Parent Material	Clay Mineralogy	Bulk Density (gcm^{-3})	Surface Texture[1]	pH (H_2O)	OM (gkg^{-1}) (surface)	ECEC (cmol kg^{-1}) (subsoil)
Alfisol	35	Basement Complex (BC)	LAC Kaolinite, Sesquioxides	1.2-1.8	Loamy sand/Sandy loam	5-6.5	1-3	10-20
Ultisol	30	Sandstone, Coastal Plain Sand, Shale	LAC, Kaolinite, Sesquioxides	1.2-1.8	Loamy sand/Sandy loam	4-5.5	1.5-3	10-20
Entisol	15	Flood Plain, BC, Sandstone, Coastal Plain Sand	Kaolinite, Quartz	-	Loamy sand/Sandy loam	6-7	2-8	10-25
Inceptisol	10	Flood Plain, BC, Sandstone, Coastal Plain Sand	Kaolinite, Quartz	-	Loamy sand/Sandy loam	6-7	2-8	10-25
Vertisol	5	Shale, Basalt, Clay, Alluvium	Smectite, Kaolinite, Illite	-	Clay	6-8	0.2-1	20-50 (CECpH7)

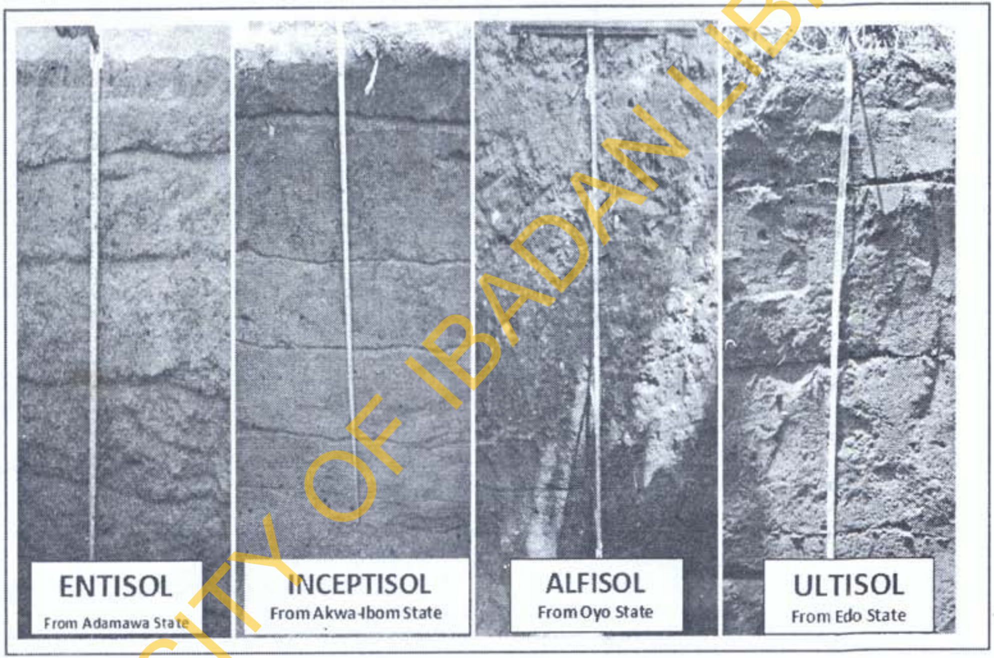

Fig. 3: Typical soil profiles from some locations in Nigeria.

Alfisols and Ultisols (Luvisols/Nitosols and Acrisols)
Alfisols and Ultisols are soils with clay accumulation in the sub-soil. The two soils together constitute about 65% of the soils in Nigeria. They are deep to fairly deep soils with loamy sand/sandy loam surface, increasing in clay content with depth to sandy clay loam/sandy clay or clay. The two soils occur in the savanna and rainforest regions. Alfisol is more predominant on Basement Complex while Ultisol is more on Sandstone/Coastal Plain Sand/Shale. Presence of argillic horizon (clay accumulation) is diagnostic for both soils. There is great variation in colour; from 10YR/7.5YR hue in the surface to 5YR/2.5YR/10R in the lower depths. Alfisols often contain Fe-Mn concretions/nodules in the subsoil at about 80-120cm. In the rainforest and guinea savanna regions the concretionary layer at this depth is prominent and has been referred to as stoneline (Ahn 1970). Some Alfisols in the rainforest region (e.g. Egbeda and Olorunda series) contain characteristic light red (2.5YR6/8) pedogenic "mottles", even though they are well drained. Ultisols are generally less gravelly except in locations with high degree of fluctuations of water-table where plinthite is formed. The profiles are more uniform in colour, especially when well drained.

Both soils have low bulk density. The initial soil structure is good, crumb (under rainforest) or subangular blocky (in the savanna) due to flocculation/cementation of clay by organo-mineral complexes to form stable aggregation. However, the soil structure easily breaks down once the vegetation is removed for cultivation. This makes them susceptible to erosion. Soils in regions with prolonged dry-seasons are desiccated up to about 1m depth, being subjected to high temperature extremes when at low moisture content. The soils are thus prone to developing surface seals and crust formation with low water-transmission properties. They are very deep (≥200cm) although the effective rooting depth in some upper-slope Alfisols is shallow (<100cm) due to adverse soil physical properties (Vine et al. 1981; Babalola and Lal 1977). Most upland with low-activity clay (LAC) soils have low plant-available water reserves and are generally less than

10cm in the root zone. Consequently, seasonal crops are prone to periodic drought stress throughout the growing season (Lal 1986).

Alfisols are less acidic (pH of 5-6+) than Ultisols (pH of 4-5+) and the acidity increases with movement from the savanna to the forest regions. Both soils are low in organic matter, nitrogen, available phosphorous and exchangeable cations (Ca, Mg, K and Na), and cation exchange capacity (CEC). The Ultisols are lower in these nutrients than the Alfisols.

Entisols and Inceptisols (Regosols/Arenosols and Cambisols)

These are young (at early stage of development) soils, but Entisols are younger and less developed than Inceptisols. Both of them occur on all the parent materials and agro-ecological zones, particularly in sand dunes, coastal deposits, flood plains in lower slope or valley bottom positions and shallow, rocky terrains. Entisols have not developed to the stage of having diagnostic subsoil (B) horizons, but Inceptisols show structural development (Cambic horizon) in the subsoil. The sand dune Entisols (Psamments) are very deep with single grain structure in the upper 10-20cm layer of sand/loamy sand texture. The texture can be loamy sand down to a depth of 150-200cm, but can change to sandy loam at this depth in others (FDALR 1990). Similar profiles occur in alluvial deposits along river courses (e.g. Niger and Benue) and the Niger Delta except that in the latter, organic matter content is higher and decreases irregularly with depth. Entisols constitute about 15% and Inceptisols about 10% of the soils in Nigeria (Ogunkunle 1986; Esu 2005).

Generally, sand dune soils are very low in plant nutrients while most flood plain soils are very high in plant nutrients (N, P, K, Ca and Mg) as a result of high organic matter (Esu and Ojanuga 1989). The sand mineralogy of dune soils is dominated by quartz while the clay mineralogy is dominated by kaolinite and quartz. Some amount of smectite occurs in the clay fraction of poorly drained Aquepts and Aquents.

Vertisols

These are heavy black clayey soils associated with calcium rich parent rocks and relatively dry savanna climate. They occur in the north-eastern part of Nigeria around Lake Chad (Esu 2005), notably Bornu, Yobe, Adamawa and Bauchi. They constitute about 5% of the soils of Nigeria. They are characterized by a very heavy texture with montmorillonite as the dominant clay fraction, usually with free calcium carbonate which forms concretions in the sub-horizons. They are derived from diverse parent materials including lacustrine clay deposits, olivine basalt, ancient alluvial deposits and ancient marine shales. They crack on drying and are difficult to cultivate because of their stickiness when wet and hardness when dry. Although reserves of weatherable minerals are often high and the exchange complex is well saturated with cations, the nutrient status of vertisols is rarely balanced (Jones and Wild 1975). They are underutilized because of poor understanding of their management (Ahmad and Mermut 1996).

Andisols (Andosols)

These are soils formed from materials of volcanic origin. They occur in the Jos Plateau. They were classified as Inceptisols (Andepts) in the USDA, Soil Taxonomy until recently. The soils have high organic matter and low bulk density, appreciable amount of allophane of high exchange capacity. They are dark brown on the surface and yellowish at depth. They have relatively high silt and (amorphous) clay content. The consistency is greasy but neither sticky nor plastic. Andisols have a high agricultural potential. They have high available water capacity and are freely drained except when silcrete is present. The natural fertility is high. Together with other soils (e.g. organic soils—Histosols) they constitute < 5% of the soils in Nigeria.

Dryland (Arid) Soils

By and large, the drylands are dominated by Aridisols, Alfisols Calcisols and Histosols; Aridisols being the most common soils. They have been observed to be devoid of vegetation for 7-8 months of the year outside of the rainy season. In Sokoto, they have been described as soils having high sand content at the surface, formed on aeolian sand cover with low organic matter content ($\leq$2%) (Sharu et al. 2013; Landon 1991), which Yakubu (2001) attributed to factors such as continuous cultivation, frequent burning of farm residues commonly carried out by farmers in the area, a practice that tends to destroy much of the little organic materials that could have been added to the soils. Agbu and Ojanuga (1989) associated the low soil fertility of the drylands to rapid decomposition and mineralization of organic materials contributed by sparse vegetation in the hot semi-arid climate, promoted by high solar radiation (Noma et al. 2011).

Wetland (Fadama) Soils

In fadama land, the common soil types are: Entisols, Inceptisols, Vertisols and Mollisols. Their physical features are good surface conditions and higher clay/silt content compared to those in the dry land. In a study of fadama soils in Sokoto, Singh and Babaji (1990) described the soils as poorly drained (Gleysols) and texturally finer and nutritionally richer than the surrounding upland soils. Soils in back swamps are poorly drained (Gleysols/Fluvisols) especially in the rainy season; hence they are mottled in the subsoil (and in some cases from the surface). They are highly variable in texture, colour etc., laterally and with depth. Generally, fadama soils retain a high level of moisture in any season of the year and are therefore more suitable for many forms of agricultural production, especially lowland rice, vegetable and horticultural crops and some other cultivated crops, all-year-round.

Capacity of Nigerian Soils for Crop Production

There is a lot of misconception about the capacity of Nigerian soil resources for crop production. Such statements as

"Nigeria is blessed with vast expanse of fertile land for agriculture" (Aribisala 1983) are very common among politicians and policy makers. Available information (FAOSTATS 2005; Hartmans, 1984; Ogunkunle, 1987, 1988; Lal 2009) however, shows that Nigerian soils are very fragile and cannot sustain crop productivity for more than one or two years (cropping) after the land is opened up from natural vegetation. This is mainly because of the clay mineralogy of the soils which is dominated by low activity clays (LAC), mainly kaolinite and oxides and hydrous oxides of iron and aluminum (Hughes 1978; Juo 1979). Thus, the nutrient holding capacity of the soils depends almost exclusively on the soil organic matter (SOM) which gets mineralized very fast under intense solar radiation and cultivation. This explains the rationale behind the practice of shifting cultivation/bush fallow whereby farmers abandon the plot after 2-3 years of use (to allow it recuperate through vegetation growth and organic matter accumulation) and move to a fallow land or open up a new plot.

Contrary to the belief by many Nigerians, data from practical farming and research (e.g. Ogunkunle 1981, 1989; Ogunkunle and Akoroda 1992) show that the capacity of Nigerian soils for crop production ranges between marginal and low (tables 2 & 3). The data on the tables emanate from research studies on soils in the northern and southern parts of the country. Table 1 reveals that by Land Capability Classification system (LCC), only 8% of the soils have high potential, 4-31% are moderate and 26-64% are marginal. In table 2, the Land Suitability Evaluation (LSE) system shows that 16% of the soils have high potential for maize, 30-50% are moderate and 25-45% are marginal. The FAO Statistics (table 4) confirms these two results. It shows that none of Nigerian soils has high capacity for crop production, 5.5% are moderate, 46.5 are marginal and the rest (48%) are low. These data reinforce the fact that Nigerian soils are fragile and require careful, data-based management for optimum crop production.

Table 2: Land Capability Classification of Nigeria Soils

Location	State	Proportion (%) in Capacity Class								Size of Area (ha)
		I	II	III	IV	V	VI	VII	VIII	
		ARABLE				NON-ARABLE				
Oyo	Oyo	-	26	52	10	12	-	-	-	5,000
Jos	Plateau	-	22	26	25	5	22	-	-	12,000
Odogbolu	Ogun	-	31	43	-	20	-	5	-	2,900
Benue	Benue Flood Plain	8	4	64	12	-	5	-	-	80,000

Table 3: Land Suitability Evaluation (LSE) of Nigeria Soils

Location	State	Proportion (%) in Suitability (Maize) Class					Area Size (ha)
		S1	S2	S3	N1	N2	
Yenegoa	Bayelsa	-	50	45	5	-	80,000
Niger Basin	Niger	16	30	25	21	8	3,200
Kano	Kano	-	33	45	22	-	2080

Table 4: Productivity of Nigerian Soils (FAO Statistics)

Soil Productivity Grade	FAO Soil Classes	Area	
		km^2	% of total
High (1)		-	-
Good (2)	Fluvisols, Gleysols, Regosols	50.4	5.52
Medium (3)	Lixisols, Cambisols, Luvisols, Nitosols	423.6	46.45
Low (4)	Acrisols, Ferrasols, Alisols, Vertisols	289.2	31.72
Low (5)	Arenosols, Nitosols	148.8	16.32

Source: FAOSTATS (2005)

A major consequence of the marginal-average quality of Nigerian soils is the relatively lower yields of crops compared to their potentials under good management. Wudiri and Fatoba (1992) showed that the gap between the yields of most of the cereals and tuber crops in Nigeria compared to their potentials is 25 - 400% (table 5). This shows again and very clearly that the role of soil management in crop production cannot be taken for granted. Even with the most high-yielding hybrid crop variety, unless the soil condition is conducive in terms of the physical, chemical and biological characteristics, the potential of the crop cannot be attained. All the investments of several years of research, breeding, fertilizer application, weed and pest control etc. will continue to be a waste when due consideration is not given to adequate soil management.

Table 5: Average and Potential Yields of Cereal and Tuber Crops in Nigeria

Crop	Average Yield (tons/ha)	Potential Yield (tons/ha)	Gap (%)
Cereals			
Upland Rice	0.8 – 1.2	1.5 – 2.5	88-108
Lowland Rice	1.0 – 2.0	2.5 – 8.0	50-300
Maize	1.5 – 2.0	3.5 – 10.0	133-400
Sorghum	0.5 – 1.2	2.0 – 2.5	108-300
Millet	0.5 – 1.0	1.0 – 2.0	100
Tubers			
Cassava	11 – 12	20 – 25	82-108
Cocoyam	5 – 6	8 – 10	60-67
Irish Potato	10 – 12	14 – 15	25-40
Sweet Potato	10 – 12	14 – 15	25-40
Yam	12 – 14	18 – 20	43-50

Source: Wudiri and Fatoba (1992)

Soil Degradation

There is a growing recognition, among both policy-makers and soil specialists, that soil degradation is one of the root causes of the declining agricultural productivity in Sub-Saharan Africa (SSA) and that, unless controlled, many parts of the continent will suffer increasingly from food insecurity (Lal 1990; UNEP 1982). Soil degradation is the decline in soil quality caused by natural factors or, more often, by improper use/management, usually for agricultural, pastoral, industrial or urban purposes. Soil degradation may be exacerbated by climate change and encompasses physical, chemical and biological deterioration. Examples of soil degradation are erosion by water or wind, loss of organic matter, decline in soil fertility, decline in structural condition, topsoil loss and adverse changes in salinity, acidity or alkalinity, toxicity by chemicals, pollutants and excessive flooding (Charman and Murphy 2005).

Soil degradation has three kinds of consequences on the ecosystem/ecosystem services: (i) Ecological, (ii) Economic, and (iii) Social consequences (Douglas 1994). Ecological consequence is the most obvious; it includes soil loss, loss of crop yield, biodiversity, forest and other land resources. Each ecological consequence has associated economic and social consequences. For instance, loss of crop yield (ecological) if not checked, can lead to poverty (social) and poor financial capability (economic), e.g. low contribution to GDP. The most critical ecological consequences are soil erosion, loss of soil organic matter, soil nutrient depletion and loss of biodiversity (UNEP 2013).

Lack of information and basic knowledge of soil degradation and the characteristics of soil resources are major obstacles against reducing land degradation, improving agricultural productivity, and facilitating the adoption of sustainable land management (SLM) among Nigerian smallholder farmers (Liniger et al. 2011). The soil degradation process occurs in the following way: soil crusting and sealing, compaction of the surface soil, reduction of pore spaces and infiltration, low water-holding capacity, accelerated runoff resulting in severe erosion, decline of soil organic matter (SOM), decrease in pH, and nutrient imbalance. Erosion by water or wind is the most severe kind of soil degradation in Nigeria. Leaching of essential plant nutrients out of the root zone is also very severe in sandy soils, occurring in areas with heavy rainfall particularly in eastern Nigeria. The major factors of soil degradation in Nigeria are: expansion of area cultivated for agriculture, overgrazing, deforestation, population expansion, poverty, climate change, oil pollution and soil excavation/quarrying.

With the exception of oil pollution and quarrying, all the other factors are related to each other.

Water erosion poses the greatest threat to Nigerian soils and affects over 80% of the land (NEST 1991). Wind, sheet, gully and beach erosion affect different parts of the country at varying intensities. While erosion by wind is confined to the arid north, erosion by water is ubiquitous throughout the country. Areas most prone to sheet erosion are plots where farming has cleared the original vegetation, and the land became impoverished scrubland. Gully erosion is by far the most alarming type of erosion in Nigeria, particularly in the eastern region, because it often threatens settlements and roads. Although it affects a small fraction (less than 0.1%) of Nigeria's 924,000 km^2 of landmass, gully erosion claims large amounts of public funds annually for remedial action.

With continuous increase in population, there is increased demand for food requiring increased food production. This has been achieved mainly through expansion in the land area cultivated and very little from intensification i.e. increased yield per land area (Ogunkunle 2015a). The expansion of area for farming leads to shorter fallow period, the use of very fragile areas and the use of fire for land clearing, all of which reduce organic matter in the soil. Overgrazing causes soil compaction and reduced resistance to drought, although it is mainly restricted to the northern part of Nigeria. Deforestation has been caused by expansion of farming, housing needs due to population expansion or use of wood for energy due to poverty. Climate change is a major cause of desert encroachment and various unpredictable soil degradation activities. Oil pollution occurs in the oil producing regions of the south. It affects soil biological, chemical and physical processes negatively, particularly soil nutrient movement and organic matter mineralization. Indiscriminate quarrying is found all over Nigeria. This has resulted in gully erosions that have consumed houses and even entire villages, particularly in the eastern regions with generally sandy soils.

Soil degradation, particularly erosion, has assumed a serious dimension in Nigeria, affecting every part of the country (table 6, figs. 4 & 5). Soil erosion in the south-eastern part of Nigeria has been identified as the most threatening environmental hazard in the country (Abegunde et al. 2006). Secondary data on the study traced its origin to some 30 years ago when development began to creep into the region, following Nigeria's oil boom of the 1970s. Dugout pits, created from soil excavation activities, for foundation filling and sand for brick making and plastering of buildings produced deep craters and gullies due to perennial erosion from torrential tropical rains. The sandy nature of the geology of the area has worsened the situation. This, happening over many years, and not well managed had resulted to gullies, found in more than 1000 sites with over 700 of them located in Anambra State alone. Erosion has ravaged much of the vast lands in south-eastern Nigeria so much, resulting in active and inactive gullied surface areas with lengths ranging from 0.7 km in Ohafia to 1.15 km in Abiriba in Abia State. The widths of the gullies range between 2.4 km for Abiriba and 0.4 km for Ohafia.

Table 6: Erosion Types and Coverage in Nigeria

Type of Erosion	No. of States affected	Intensively affected States
Sheet	19	Ogun, Kwara, Oyo, Benue Gongola, Imo, Anambra
Gully	6	Imo, Anambra, Plateau, Cross River, Borno, Bauchi
Coastal	5	Rivers, Cross River, Lagos, Edo, Delta
Rill	4	Plateau, Anambra, Lagos, Imo
Surface-mining	3	Plateau, Anambra, Kwara

Source: Ogunkunle (2009)

Fig 4: An erosion site in Auchi, Edo State.

Fig 5: A gully erosion site in Abiriba, Abia State.

Further, a depth of 120km gullied surface has been recorded at Abiriba (Ofomata 2001). Also, the problems of widespread sheet wash erosion explain the failure of agricultural activities. This is why soil erosion is a stress on soil resources with some far-reaching consequences on man and his environment (Jimoh 2000). In the northern axis of Nigeria, erosion is equally serious, especially in places like Shendam and Western Pankshin in Plateau State, Ankpa and Okene in Kogi State. Sporadic rainfalls in 1994 rendered people homeless in Kastina State, while properties worth over 400 million naira (apart from lives) were lost. Gullied erosion is also prominent in Efon-Alaaye, Ekiti State in the western part of the country (Adeniran 1993).

Degradation of Soil Physical Properties

Erosion is a three-step process involving the detachment, transportation, and deposition of soil particles. All these three take place through a medium, which may be water or wind. The most common soil erosion however, is driven by rainfall erosivity i.e. the potential of rainfall to cause erosion. Detachment of individual soil particles may occur when raindrops strike the surface and overcome the forces holding the soil particles together. This is referred to as rain splash and it involves dislodgement of soil particles from the surface. When the rainfall rate and amount exceeds the combined interception by vegetation cover and the infiltration capacity of the soils, water begins to accumulate on the soil in micro-depression. If it continues to rain, the water eventually flows on the surface as runoff or overland flow. Runoff on slopes acts as a transporting agent, carrying away the dislodged soil particles.

Research has shown that there is significantly more sand in eroded soils than non-eroded soils (table 7). This is as a result of the loss of organic binding agents by rain action, leading to the loss of finer soil particles carried away by the force of erosion and flood water (Olusegun et al. 2011).

Soil erosion selectively detaches the colloidal fractions of soils and carts them away in runoff. These soil colloidal fractions (clay and humus) are needed for soil fertility, aggregation, structural stability, and favourable pore size distribution (Babalola 2007; Crosson 1995). The concentration of humus is usually higher in topsoils while that of clay is usually higher in sub-soils due to illuviation, and this is mostly true in Ultisols and Alfisols that constitute about 70% of the soils in Nigeria (Esu 2005; Ogunkunle 2010). Increased soil erosion promotes soil compaction (Mainville et al. 2006) and loss of weakened top layers of soil (Farella et al. 2001) especially in agroecosystems characterized by high rate of deforestation.

The aggregate stability of soils is reduced by erosion, especially the 2.0 mm fraction. Total, micro- and macro-porosity are also significantly lower in eroded than in non-eroded soils (Uwanuruochi and Nwachukwu 2012). Generally, silt and clay contents in eroded soils are lower while sand content is higher, suggesting great influences on surface water flow, which have eroded the lighter silt and clay in the soils (table 7). Thus, through erosion, soil structural indices are adversely affected as total porosity, hydraulic conductivity; infiltration and aggregate stability are all lower in eroded soil (Uwanuochi and Nwachukwu 2012). Reduced water infiltration tends to increase runoff which can lead to further erosion, and lower soil porosity has implications for reduced aeration and consequently, productivity. A reduction in the silt and clay fractions of the soil tends to also cause lower chemical reactions and exchangeable cations due to loss of topsoil which reduces the capacity of soil to function and restricts its ability to sustain future uses. Destruction of the physical characteristics of the soil through erosion will limit even the other uses of the land like urban and rural infrastructural developments.

Table 7: Effect of Erosion on Soil Particle Size

Location	Non-Eroded Soils			Eroded Soils		
	Sand g/kg	Silt	Clay	Sand g/kg	Silt	Clay
Isiukwuato	90.56	5.14	4.46	95.16	3.15	1.33
Ohafia	94.34	3.97	4.46	99.46	0.38	0.16
Ukwa	92.34	4.33	4.07	97.12	2.55	0.33
Ikwuano	72.00	11.2	16.80	80.80	14.30	4.88
Mean (x)	87.31	6.3	6.8	93.1	5.09	1.67
LSD (0.05)	2.3	3.1	2.3	2.3	3.1	2.3

Source: Uwanuruochi and Nwachukwu (2012)

Three months after an artificial removal of the top (5 cm) soil at three locations in southern Nigeria, Mbagwu et al. (1984) observed reductions in moisture retention capacity and saturated hydraulic conductivities of the exposed soil layer, which were greater in Ultisols than in Alfisols. Mbagwu and Lal (1985) later reported that limited moisture, more than increased compaction, caused greater reduction in root growth and dry matter of maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* L.) in those locations.

Apart from the usual degradation resulting from the opening up of land for cultivation for crop production, land/soil resources are being exploited by various activities without any control or check. A summary of some aspects of the uncontrolled exploitation of land resources in Nigeria, their description and impacts, is given in table 8.

Table 8: Environmental Impact of Uncontrolled Resource Exploitation in Nigeria

Activity Type	Exploitation Activities	General Effects
1. Exploration	Landscape disturbance	Aesthetic deterioration of landscape, path construction and trampling in wilderness.
2. Mineral extraction	Land degradation and ecosystem destabilization	Land surface devastation (including erosion), land subsidence, disruption of drainage systems, deforestation, excessive water drawdown, and lowering and contamination of the water table.
3. Processing, transportation, storage and consumption	Gas leaks, oil spills and pollution of the air, soil and water	Thermal body of waterways, increase in CO_2 and CO, ozone layer depletion, acidification of air, soil and water, weather modifications, toxicity hazard to plants and consumers, death of terrestrial and marine life, loss of crops and livestock, impairment of atmospheric visibility, vehicular accidents, damage to buildings and machinery, nervous disorder, respiratory diseases, cardiovascular illness, cancer and food poisoning.

Source: NEST (1991)

Chemical Soil Degradation

The chemistry of soil is also altered as a result of soil erosion on farmlands. It results in net decrease in soil carbon and nitrogen (Mainville et al. 2006) in addition to leaching, burning and volatilization (Roulet et al. 1999). Loss of organic matter results in soil structural instability since it is a major binding agent (Mikha and Rice 2004). It has been reported that humus, which has much greater capacity to hold water and nutrient ions compared to clay, is more easily eroded (Esu 1999).

***Soil Acidity*:** Soil acidity is generally regarded as one of the major limiting factors in crop production. Soil acidity is one manifestation of soil degradation that has physical, chemical and biological dimensions (Eswaran et al. 1997). It results in a complex change in the soil, such as increase in toxic levels of aluminium and manganese, inhibition of biological processes, reduction in the cation exchange capacity of soil, phosphorous reserves, and diminished solubility of molybdenum and boron. Consequently, acidic soils are in effect also stripped of key macronutrients such as calcium, magnesium and potassium. The decrease in root growth coupled with the inability of plants to utilize water effectively and take up sufficient amounts of plant nutrients is often the most visible problem of soil acidity. All these factors contribute to lower soil productivity, and lower crop yield.

In Nigeria, more than 70% of arable soils are acidic especially in areas where rainfall exceeds evapotranspiration, and there is high level of leaching of the soil nutrients. Most of the southern states soils experience acidic conditions. In some cases, soils are acidic due to the nature of the parent materials which are inherently acidic especially those derived from sedimentary and basement complex rocks.

The main reasons for low crop productivity on acid soils are nutrient deficiency and elemental toxicity. Application of appropriate and adequate rates of fertilizers and liming have led to optimum yields on acid soils. Other factors that cause soil acidity are climate (excess rainfall containing dissolved carbon dioxide and organic acid), vegetation, which influences the rate of acidification, and use of acidifying inputs in agriculture such as ammonium containing fertilizers which results in loss of bases from the soil and lowering of soil pH.

Nutrient Losses: The average nutrient loss in SSA soils was estimated to be 24kg nutrients/ha per year (10kg N; 4kg P2O5, 10kg K2O) in 1990 and 48kg nutrients/ha per year in 2000, i.e. a loss equivalent to 100kg fertilizers/ha per year (FAO 2000). Excessive cultivation of the soil, especially in the south-eastern states of Nigeria, leading to crop removal of basic soil nutrients (nutrient mining) from the soil is also an important contributing factor. Water and wind removal of rich topsoil are, in addition, key factors that enhance nutrient losses and soil acidity. Generally, soils in the southern states (e.g. Lagos, Ondo, Bayelsa, Rivers, Akwa Ibom, Cross River, Anambra, Imo) are mostly acidic due to leaching of nutrients during the wet season with heavy rainfall. In contrast, soils in the north-eastern states, with little or no leaching, are mostly alkaline in nature, while those of the central states are moderately leached and hence moderately acidic. In a grouping of SSA countries by degree of soil nutrient depletion (Stoorvogel and Smalling 1990), Nigeria was placed in the 'High' (21-40 kg/yr.) group.

Sodicity and Salinity: The preponderance of sodium ions in the soil is a common feature in the arid and semi-arid regions and results in high soil pH ($\geq$7.5). This is known as soil sodicity. It occurs mainly in arid and semi-arid regions and results from accumulation of sodium salts due to inadequate drainage. Salinity, the accumulation of salts due to capillary rise, also poses major management problems in many irrigated and non-irrigated areas of the semi-arid regions of northern Nigeria. Most of the soils show both features; hence they are saline-sodic soils. In semi-arid and arid areas of Nigeria, the scarcity, high variation and unreliability of rainfall and high evapotranspiration affect water and salt balance in the soil. Oftentimes, these salts accumulate in the topsoil and reduce the uptake of basic plant nutrients and water through osmosis.

These phenomena are experienced in major irrigation schemes. About 20% of the lands, mostly in semi-arid northern Guinea and Sudan savanna have been degraded as a result of salt accumulation in the soil (FAO/NPFS 2009). The states affected by various levels of salinity are Yobe, Bornu, Sokoto, Gombe, Kano, Kastina, Bauch, Kebbi, Jigawa and Adamawa. Crop production in these areas is highly limited by high pH, high exchangeable sodium percentage (ESP), poor water infiltration and inadequate distribution of plant roots, because of strong prismatic structure especially in vertisols. Some sites have been abandoned.

***Soil Pollution*:** The major soil pollution in Nigeria is the crude oil pollution in the oil producing areas and along the oil pipelines.The negative effects of crude oil on the growth and performance of plants have been reported in many researches. These effects have been due to the interference of the plant uptake of nutrients by crude oil and the unfavourable soil physical and biological conditions (Gudin and Syratt 1975; McGill and Rowell 1977). It has been reported that plants and soil microbes compete for the little nutrient available in soils when soil is polluted with crude oil thereby suppressing the growth of plants in such soils.

In a United Nation Environment Programme report (UNEP 2011) on environmental assessment in Ogoni land, southeastern Nigeria, released in 2011, drinking water, air and agricultural soil in 10 communities contain over 900 times the permissible levels of hydrocarbon and heavy metals resulting from crude oil spills. The report acknowledged that recovery after extensive compliance with recommendations may take 30 years. A cursory look at published research work shows that heavy metal pollution is a continental trend in SSA (UNEP 2007). The heavy metals detected include: Pb, Cd, Hg, Cu, Co, Zn, Cr, Ni and As (Fakayode and Onianwa 2002; Odai et al. 2008).

***Loss of Soil Biodiversity*:** Intense management practices that include application of pesticides and frequent cultivation, affect soil organisms, often altering community composition of soil fauna. Soil biological and physical properties (e.g., temperature, pH, and water-holding characteristics) and microhabitat are altered when natural habitat is converted to agricultural production (Crossley et al. 1992). Changes in these soil properties may be reflected in the distribution and diversity of soil meso-fauna. Organisms adapted to high levels of physical disturbance become dominant within agricultural communities, thereby reducing richness and diversity of soil fauna (Paoletti et al. 1993). The principal threats to soil biodiversity in SSA include land use and land cover change, mainly through conversion of natural ecosystems, particularly forests and grasslands, to agricultural land and urban areas. It is likely that land clearing and deforestation will continue, hence threatening genetic diversity as species losses occur (IAASTD 2009).

Reduction in biological diversity of soil macrofauna is one of the most profound ecological consequences of modern agriculture, for example, the number of earthworm species is largely decreased in agricultural soils. The biodiversity of the soil organisms lead to the control (natural biological suppression) of plant root diseases. The management practices used in many agro-ecosystems (e.g. monocultures, extensive use of tillage, chemical inputs) degrade the fragile web of community interactions between pests and their natural enemies and lead to increased pest and disease problems. Decline in soil biodiversity is expected to affect soil turnover, decrease natural soil aggregation, increase crusting, reduce infiltration rates, and thus exacerbate soil erosion. The major factors of loss of soil biodiversity in Nigerian soils are tillage, inorganic fertilizer application and oil pollution.

In a Press Release by the International Resource Panel of UNEP after its meeting in Beijing on June 17, 2016 (The Guardian, June 20, 2016), the Panel stated:

> Erosion, nutrient depletion, acidification, salinization, compaction and chemical pollution have left 33 percent of the world's soils either moderately

or highly degraded. If current conditions continue, then 320-849 million hectares of land will be converted to cropland by 2050 at the expense of the world's savannahs, grasslands and forests. As a result, greenhouse gas emissions from agriculture may increase from 24 per cent to 30 per cent. As the global population expands, climate change intensifies and more people move to urban areas, it will become increasingly difficult to sustainably produce enough food, fuel and fibre to meet demand without further depleting the world's finite land resources.

It concluded that the world needs to improve the way land is evaluated in order to unlock its true potential and reverse the alarming pace of land degradation, like the loss of 24 billion tonnes of fertile soil and 15 billion trees every year.

Summary of Challenges of Soil Resources Management in Nigeria

The information provided so far shows that efforts to manage the Nigerian soil resources are confronted by a number of challenges which include:

- High and ever increasing population growth and pressure;
- Increased demand for food;
- Stiff competition for land space from non-discriminatory, non-agricultural uses;
- Dependency of livelihoods, industry and even the service sector on agriculture, with 65-70% of the population depending directly on rainfed agriculture and natural resources;
- High sensitivity of agriculture to variability and change in climate, and markets/prices;
- Multiple severe impacts resulting from climate change including higher temperatures, water scarcity, unpredictable precipitation, higher rainfall intensities and environmental stresses;

- Fragile natural resources and ecosystems including dry lands, mountains, rainforests, and wetlands;
- High rates of land degradation (erosion and declining soil fertility, increasing water scarcity and loss of biodiversity);
- Low yields and high post-harvest losses due to poor land management and storage practices and limited availability of, and access to, inputs.

Food Security

Crop production on fragile and highly degraded soils results in poor yield and consequently food insufficiency. The World Food Summit (WFS) of 1996 defined food security as existing "when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life" (FAO 1996). The Food and Agriculture Organization of the United Nations defines food security as "a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 2002). Commonly, the concept of food security is defined as including both physical and economic access to food that meets people's dietary needs as well as their food preferences. In many countries, health problems related to dietary access are an ever increasing threat. In fact, malnutrition and foodborne diarrhoea have become double burden.

Of the 39 countries worldwide that faced food emergencies at the beginning of 2003, 25 are found in Africa (Ojo and Adebayo 2012). Several factors were listed to be responsible for the low performance of African countries on the issue of food security. Apart from the very high rate of population expansion, all the others are soil or soil-related, particularly soil degradation/soil management.

Pillars of Food Security: From its definition, food security is built on three pillars:

- Food availability: sufficient quantities of food available on a consistent basis.
- Food access: having sufficient resources to obtain appropriate foods for a nutritious diet.
- Food quality/use: appropriate use based on knowledge of basic nutrition and care, as well as adequate water and sanitation.

Availability of Food is faced with challenges and risks. A major challenge is land degradation while two major risks are: (i) population growth and (ii) land use change. Thus, food availability is still a concern in some agriculture-based countries. Nigeria is one of the many countries that have declining domestic production per capita of food staples. The other countries are Burundi, Ethiopia, Kenya, Madagascar, Sudan, Tanzania, and Zambia; all had negative per capita annual growth rates in staple food of –1.0 to –1.7 percent from 1995 to 2004 (FAO 2014). In addition, staple food production in many agriculture-based countries is largely rain-fed and experiences large fluctuations caused by climatic variability.

Food access – This simply means having enough to eat. But for most of the malnourished, the lack of access to food is a greater problem than food availability. There is a difference between not having enough food to eat, and there being not enough food to eat. The irony is that most of the food insecure live in rural areas where food is produced, yet they are net food buyers rather than sellers. Poverty constrains their access to food in the marketplace. According to the UN Hunger Task Force, about half of the hungry are smallholders; a fifth are landless; and a tenth are agro-pastoralists, fisherfolk, and forest users; the remaining fifth live in urban areas (FAO 2014).

Food quality – Food use translates food security into nutrition security. Malnutrition has significant economic consequences, leading to estimated individual productivity losses equivalent to 10 percent of lifetime earnings, and gross domestic product (GDP) losses of 2 to 3 per cent in the worst-affected countries. But malnutrition is not merely a consequence of limited access to calories. Food must not only be available and accessible, but must also be of the right quality and diversity (in terms of energy and micronutrients), be safely prepared, and be consumed by a healthy body, as disease hinders the body's ability to turn food consumption into adequate nutrition

Food Security in Developing Countries

At the very centre of concern about development must be a concern about food, agriculture, and people. Combining these three elements into an objective that is fundamental to all else in development is the concept of sustainable food security. The challenge of food security is immense. The following statistics give the idea of the situation in the developing countries:

- An estimated 13 to 18 million people, mostly children, die from hunger, malnutrition, and poverty-related causes each year. That is about 40,000 people a day or 1,700 people an hour (UNDP 1993). The actual estimate is 12.6 million children per year.
- One billion people—20 percent of the global population—live in households too poor to obtain the food necessary for sustaining normal life. Half a billion live in households too poor to obtain the food needed for healthy growth of children and minimal activity of adults.
- One child in three is underweight by age five and more people are undernourished now than in 1950.
- 600 million people are seriously deficient in such micronutrients as iron and iodine, which can lead to long-term impairment or death.

- Most (85 to 90 percent) hunger arises from silent poverty, and only 10 to 15 percent stems from famine and similar emergencies.
- Moreover, the United Nations projects that the number of people in "absolute poverty" will increase by 300 million to 1.5 billion by 2025 unless urgent and positive action is taken.

Food Security in Nigeria

An old saying in Yoruba says that if hunger can be removed from poverty, poverty has ended. Among the developmental problems facing Nigeria, food insecurity ranks among the topmost (Babatunde et al. 2007). In Nigeria, the percentage of food insecure households was reported to be 18% in 1986 and over 40% in 2005 (Sanusi et al. 2006). Although figures released by the FAO in 2005 on the state of food insecurity in the world indicated that 9% of the Nigerian population was chronically undernourished between 2000 and 2002 (FAO 2005), this was less than the regional average of 33% for Sub-Saharan Africa.

Nigeria faces huge food security challenges. About 70 percent of the population live on less than ₦100 per day, suffering hunger and poverty. Despite a seven percent growth rate in agricultural production (2006-2008), Nigeria's food import bill has risen. The growing population is dependent on imported food staples, including rice, wheat and fish. In the 40s and early 50s, Nigeria did not have to contend with the problem of food insecurity. The system was able to feed her citizens and at the same time export the surplus food items. Every region of the country specialized in the production of one or two major crops, whether food or cash crops, and together the country was relatively self-sufficient in food production. Nigeria had the groundnut pyramids in the North, cocoa in the West, oil palm and kernel heaps in the East and rubber plantations in the Mid-West (*Tell*, August 3, 2009).

As mentioned earlier, when oil was discovered in 1956 and its exportation started in 1958, things started changing gradually, and later rapidly. As oil prices went up, interest in agriculture waned, which marked the beginning of decline in agricultural activities, including food production, resulting in the rising cost of food items, especially the rise in the prices of staple foods. In particular, the price of rice has increased by over 100 percent since 2006. Nigeria requires 2.5 million metric tonnes of rice annually while local rice production is less than half a million metric tonnes per year (*Tell*, May 5, 2008). Thus, Nigeria is short of two million tonnes of rice annually, which it has to source from other countries.

In 2006, Nigeria spent $2.85 billion on the importation of various food items. A breakdown of this figure showed that Nigeria imported 36 percent of its rice need costing $267 million, sugar, 99 percent costing $1 billion, wheat 99 percent totalling $1 billion and tomatoes 14 percent costing $50 million. Fish import was 66 percent per consumption costing $500 million (see *Newswatch*, May 5, 2008). In 2008, it was estimated that Nigeria spent a whopping $2 billion importing about six million tonnes of wheat, $750 million on rice, $700 million on sugar. $500 million on milk and other dairy products (*Tell*, May 5, 2008). In 2013, it was $4.5 billion (table 9) and on June 24, 2014, the Supervising Minister of Niger Delta Affairs (Arch. Darius Ishaku) disclosed that Nigeria was spending N 1.3 trillion annually on importation of food.

The President, Federal Republic of Nigeria, Muhamadu Buhari in a speech on November 19, 2015 stated that the ₦1 trillion food importation bill was no longer sustainable. With the global rise in food prices, the United Nations Food Security Information Note, (FOSIN 2007) showed that market tensions manifest, in part, through price increases and would be most acutely felt by vulnerable households, where difficulties in accessing cereals would lead to localized food security problems.

Table 9: Nigeria Top Ten commodities Import value 2011

S/No	Commodity	Value [1000 USD]
1	Wheat	1,475,304
2	Palm oil	1000,000
3	Sugar Raw Centrifugal	470,000
4	Milk Whole Dried	359,807
5	Flour, Malt Extract	301,368
6	Food Prep Nes	259,536
7	Sugar Refined	235,628
8	Paste of Tomatoes	162,279
9	Milk Skimmed Dry	126,109
10	Wine	86,064
11	Total	4,476,095

Food Security Land Availability and Soil Quality

Apart from the three pillars of food security (i.e. Availability, Access and Quality), other factors that have been identified to influence Food Security are: Population Explosion and Water Resources, Land/Soil Resources and Climate Change (Premanandh 2011; Babatunde et al. 2007; Stocking 2003). Out of 14 billion hectares of land on the planet, only 3 billion ha is arable and this area continues to dwindle. Rapid population growth has been suggested as the major cause of reduced land area. For instance, there were about 12 acres per person worldwide in 1959, and it reduced to about 6 acres per person in 2006. A further reduction to as low as 2.8 acres per person is estimated by 2040. Between 1960 and 2000 the ratio of arable land to population declined by up to 55% in the developing nations (FAO 2008; Smith et al. 2010). Moreover, unless soil management significantly improves, half of the current arable land will become unusable by the year 2050 (UNCCD 2008).

Globally, around 2–5 million hectares of arable land is estimated to be lost annually through degradation, in particular desertification and soil erosion. The rate of degradation is two to six times higher in Asia, Africa and Latin America than in Europe and North America. Land degradation in all its forms is a threat to food production and rural livelihoods, especially in the poorest areas of the developing world. Land demand for non-agricultural use, particularly urban use, has been increasing sharply in recent times, resulting in further reduction of land availability for food production (Kampman et al. 2008).

Soil quality is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen et al. 1997; Doran and Zeiss 2000; Karlen et al. 2001). Soil quality is more than the sustained capability of a soil to accept, store, and recycle water, nutrients, and energy. It is the capacity of soil to sustain *ecological productivity*, maintain *environmental quality*, and *promote plant and animal health*. Ecological productivity minimizes both non-renewable inputs and polluting outputs, while ensuring optimal production over the long term. Farmers face an important challenge in their attempts to maintain soil quality and productivity. This is not an easy or straight-forward task, particularly when faced with an uncertain climate, sloping topography, shallow soils, and/or narrow economic margins, as is frequently the case in Nigeria. In order to achieve genuine progress in agriculture, society as a whole must ensure that soil quality is maintained and improved according to a set of proposed indicators. Soil quality should be tracked over time to achieve optimal long-term ecological productivity.

Erosion is an important factor adversely affecting soil quality and sustainability of cropping and farming systems. It is more serious in the tropics than in temperate climates because of the prevalence of fragile soils of high erodibility, harsh climates of high erosivity, and predominately resource-poor farmers who cannot afford to adopt conservation-effective measures. Erosion affects crop yields and agronomic productivity both directly and indirectly. Directly, it reduces the effective rooting depth and available water and nutrient retention capacities. Indirectly, it decreases use efficiency of inputs and increases the amount of fertilizers, water and energy needed to produce the same yield (Lal 2009).

Depletion of soil nutrients—just one indicator of declining soil quality—is a major cause of low per capita food production, especially in Africa. Over the past four decades, annual nutrient depletion rates for sub-Saharan Africa have amounted to a fertilizer equivalent value of US$4 billion (Dreschel 1999). However, ascribing a decline in food production unambiguously to the effects of changing soil quality is difficult because of the complex interactions involved. Yields decline for many reasons, such as deficiency or excessive uptake of nutrients in crops without replenishment, pests and diseases, weed infestations, and increasing prevalence of climate change–induced drought (Stocking 2003).

There is an emerging understanding of the importance of microbial communities for soil health through the use of DNA and RNA methods to determine physical and chemical changes in soil (Girvan et al. 2003). Many soil factors are involved, including soil depth and rooting, available water capacity, soil organic carbon, soil bio-diversity, salinity and sodicity, aluminum toxicity, and general acidification. The Soil Quality Institute has suggested several indicators that relate to yields, from which indexing approaches to measure soil quality have been devised (Andrews 2001). One of the main factors that integrate the effects of others is reduction in soil organic carbon (Lal 2009). But these indicators do not offer a comprehensive measure of the spatial and temporal variability of soils. This lack has led to calls for interdisciplinary studies to understand how soil properties and processes interact within ecosystems (Karlen et al. 2003); how economic utility is affected (Boardman et al. 2003); and how society, culture, and local knowledge are influenced (Prain et al. 1999).

In general, application of fertilizers and soil amendments masks the adverse impacts of accelerated soil erosion. In Nigeria, Salako et al. (2007) reported 65–75% reduction in crop yield with the removal of 25cm of topsoil when no fertilizers or manure were applied. However, productivity of eroded soils was restored more effectively by the application of manure than by use of chemical fertilizers. Similar experiments by Oyedele and Aina (2006), also conducted on Alfisols in Western Nigeria, indicated that grain yield of maize (*Zea mays*) decreased from 3.2 Mg/ha under control to 0.1 Mg/ha where 20 cm of topsoil was removed. Maize yield decreased exponentially with decrease in the depth/thickness of the remaining topsoil. Drastic reduction in maize grain yield on eroded soil was attributed to the low physical and chemical quality of the exposed sub-soil. Field experiments conducted in the West African Sahel indicated that the grain yields of pearl millet (*Pennisetum glaucum*) were severely reduced on eroded and unmulched compared with uneroded and mulched soils (Michels and Bielders 2006).

It is therefore important to make these inputs available to minimize the adverse impacts of weather and soil degradation, and advance food security. There is no reliable substitute for the judicious use of inputs. Improved germplasm cannot extract water and nutrients from degraded/depleted soils. Therefore, making water and nutrients available at the critical time and in appropriate forms is essential to obtaining high yields. Growing improved varieties can help, but these are not substitutes for the essential inputs. Thus the challenge lies in: (i) understanding soil processes, (ii) characterizing and mapping soil resources, and (iii) predicting soil behaviour under a variety of land uses and management scenarios (Miller and Mail 1995). The strategy is to make economic-agricultural development congruent with ecological, social and political realities, use and conserve indigenous genetic resources, and restore degraded soils and ecosystems (Miller and Mail 1995).

Using the ecological footprint, Kitzes et al. (2007) and Hazell and Wood (2007) proposed two scenarios to balance human demands and ecosystem supply: (i) managing the consumption of food, fiber and energy, and (ii) maintaining and increasing the productivity of agricultural ecosystems. It is important to understand the linkages between human needs, agriculture and the environment. The strategy is to develop agricultural systems which balance the positives and negatives of farming to protect the production capacity and wellbeing of the land/soil resources (Pollock et al. 2007). There are several technological options relevant to achieving these goals including agro-biodiversity (Thrupp 2000), conservation agriculture (Hobbs et al. 2007), and social/political factors which determine farmers' interest in adopting recommended practices (Shriar 2007). Recommended practices should be those that enhance eco-efficiency or the sustainable use of resources in farm production and land management (Wilkins 2007).

Soil Management and Sustainable Development

What is Sustainable Development?

Sustainable development (SD) simply refers to the existence of environmental, economic and social well-being for today and tomorrow. More than one hundred definitions of sustainable development exist, but the most widely used one is from the World Commission on Environment and Development, presented in 1987. The concept of sustainable development is most closely associated with the 1987 report of the United Nations World Commission on Environment and Development, better known as the Brundtland Commission, after its chairperson, Gro Harlem Brundtland of Norway (World Commission on Environment and Development 1987). The report popularized a compelling definition of sustainability: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

Sustainable development promotes the idea that social, environmental, and economic progress are all attainable within the limits of our earth's natural resources. Sustainable development approaches everything in the world as being connected through space, time and quality of life. Thus, the concept of sustainability has since been widely applied to many aspects of human society, including wide application in soil science and land management. The concept of sustainable land/soil management is firmly entrenched in policy tools, and is central to Pillar 1 of the recently formed Global Soil Partnership (GSP) i.e. "Promote sustainable management of soil resources for soil protection, conservation, and sustainable production".

Agricultural Sustainability

Agricultural Sustainable Development concept is derived from the Sustainable Development Goals (SDGs), an offshoot of the Millennium Development Goals (MDGs), put together in 2000 and signed by 189 countries including Nigeria (MDG-Nigeria 2010). By the end of 2015, MDG was replaced with SDG with 17 goals each with its targets and indicators.

In March 2015, an international expert workshop convened by the European Environment Agency (EEA) and the Institute for Advanced Sustainability Studies (IASS) to develop a set of indicators to contribute to the Global Land Indicators Initiative (GLII) and the post-2015 Development Agenda, proposed a "shortlist" of three land and soil management indicators. The indicators aim to support the achievement of multiple Sustainable Development Goals (SDGs).

The workshop's outcome document, titled 'Proposal for Land and Soil Indicators to Monitor the Achievement of the SDGs,' identifies three "tiered" global indicators—land cover/land use change, land productivity change and soil organic carbon change—all of which can be further enriched at the national and sub-national levels. The proposal asserts that land and soil resources underpin key services, such as the production of food, feed, fibre and fuel, the sequestration of carbon, nutrient cycling, protection of biodiversity, and water regulation. It supports targets on land and soil quality and land degradation neutrality, as proposed by the Open Working Group (OWG) on the SDGs. It also highlights the links between good governance of land and soil resources, and the proposed SDG on peaceful and inclusive societies.

Noting the workshop built on on-going efforts by the UN Convention to Combat Desertification (UNCCD) Secretariat to explore common land indicators across the Rio

Conventions, the experts' document describes their three shortlisted indicators as "measurable and essential in capturing a minimum of land characteristics that are globally comparable," and calls for their inclusion in the list of proposed SDG indicators being developed by the UN Statistical Commission (UNSC).

Sustainable development is made of three components: (i) economic development, (ii) social development and (iii) environmental development. The aspect of Sustainable Development in which the land is key is the environmental-ecosystem services and preservation, and food security. This involves the combination of sustainable soil/land management, sustainable agriculture and sustainable resource management.

From this perspective, the goal of achieving sustainable food security in the decades ahead emerges as one of the greatest challenges humanity has ever faced (Sanchez and Swaminathan 2005). Agricultural output must be tripled, and people must have the income to buy it. The erosion of the resource base must be halted and reversed. Failure on any of these fronts will result in unpleasant national and international consequences. Sustain-able food security must be seen as a fundamental aspect of global human security. The world needs to recognize the right to food as a universal human right. This goes well beyond the mere endorsement of this right in principle, beyond the ringing denunciations of the use of food as a weapon, beyond the emerging idea that civilians in zones of armed conflict are entitled to food for survival, and beyond humanitarian food supply measures to prevent famine. It requires continuous practical action at all levels—international and national, household and individual—on the basic social responsibility to ensure that everyone is adequately fed under all circumstances. It requires the adoption of concrete international goals such as reducing world hunger by half over the coming decade (Speth 1993).

Farmers' Soil Management Strategies

Soil management is the sum total of all tillage operations, cropping practices and treatments conducted on or applied to a given kind of soil for the production of crops (Landon 1991). It is an integral part of land management and may focus on differences in soil types and soil characteristics to define specific interventions that are aimed to enhance the soil quality for the land use selected. Specific soil management practices are needed to protect and conserve the soil resources.

The distinct climatic difference between the northern and southern parts of Nigeria necessitates different requirements for soil/land management to sustain crop production in the two regions. In the moist and humid south, population explosion and the resulting urbanization has made the old traditional shifting cultivation/bush fallow system unsustainable. It has been virtually replaced by 'modern' systems including: use of short-fallow crops (e.g. *Sesbania sesban*, use of leguminous cover crops, pigeon pea), farm yard manure (FYM), compost, animal manure (poultry, cow dung), municipal waste, sewage sludge, organic and organo-mineral fertilizers, etc. In the south-east, due to the sandy nature of the soils and associated characteristics, there is additional emphasis on conservation practices. These include: 'the traditional stone wall terracing', normal terracing, use of earth bunds, stone pitching, Vetiver grass technology, cross ties/tie ridges. In the drier northern part, mixed farming is the practice with the livestock providing manure while they feed on crop residues (in addition to normal grazing). Soil management practices include: the traditional kraaling (occupation of field by livestock for manuring some months before cropping season), use of composted manure and termatarium in planting holes, use of municipal wastes, entrapped harmattan dust, and shelterbelt/wind break plantation. Considerable yield increases have been obtained.

Thus, some of the soil management practices in Nigeria hold promise. However, they cannot be applied on a large-scale basis because they are based on trial-and-error approach rather than scientific data, and they cannot handle the overwhelming soil degradation problem at hand. Besides, increases in productivity that have been witnessed are not commensurate with increasing demands on land resources, and for the most part, the imminent impacts expected as a result of climate change have yet to be taken into account (Ogunkunle 2015b). All concerned stakeholders at different levels as well as development partners seem to agree that there is need for a soil management approach that is simultaneously integrative, synergistic and encompassing; capable of ensuring and sustaining food security for the ever-increasing population (Ogunkunle 2015a; The (Nigerian) Guardian 2016).

Sustainable Land/Soil Management

Sustainable Land Management (SLM) has been defined as the adoption of land use systems that, through appropriate management practices, enable land users to maximize the economic and social benefits from the land while maintaining or enhancing the ecological support functions of the land resources (IFAD 2009; TerrAfrica 2006). In the 21st century, food and fiber production systems will need to meet three major requirements:

(1) Adequately supply safe, nutritious, and sufficient food for the world's growing population.

(2) Significantly reduce rural poverty by sustaining the farming-derived component of rural household incomes.

(3) Reduce and reverse the degradation of natural resources and the ecosystem services essential to sustaining healthy societies and land productivity.

SLM requires balancing the needs for human purposes with those for environmental conservation and functioning. It includes management of soil, water, vegetation and animal resources. SLM is a knowledge-based procedure that helps integrate land, water, biodiversity, and environmental management (including input and output externalities) to meet rising food and fiber demands while sustaining ecosystem services and livelihoods. SLM is necessary to meet the requirements of a growing population. Improper land management leads to land degradation and a significant reduction in the productive and service functions (World Bank 2006). It involves processes and actions to stop and/or reverse degradation—or at least to mitigate the adverse effects of earlier misuse. Such actions are increasingly important in uplands and watersheds—especially those where pressures from the resident populations are severe and where the destructive consequences of upland degradation are being felt in far more densely populated areas downstream. SLM can take various forms such as:

- Preserving and enhancing the productive capabilities of cropland, forestland, and grazing land (such as upland areas, down-slope areas, flatlands, and bottomlands);
- Sustaining productive forest areas and potentially commercial and non-commercial forest reserves;
- Maintaining the integrity of watersheds for water supply and hydropower-generation needs and water conservation zones;
- Maintaining the ability of aquifers to serve the needs of farm and other productive activities.

The ultimate aim of SLM is Agroecosystem Sustainability which results from a nested relationship/interaction among soil quality functions, environmental characteristics, agronomic sustainability and socio-economic viability of the land use (fig. 6).

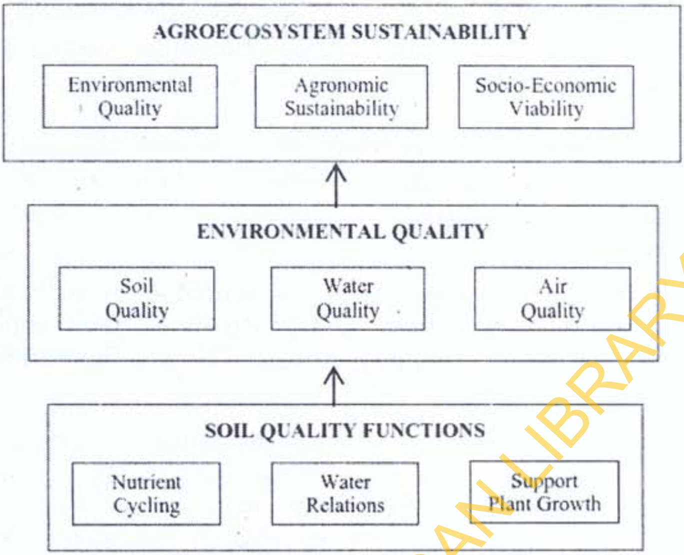

Fig. 6: Nested relationship among agroecosystem sustainability, soil quality and soil functions (After Rakesh et al. 2012).

Human activities now appropriate nearly one-third to one-half of global ecosystem production, and as development and population pressures continue to mount, so could the pressures on the biosphere. As a result, the scientific community is increasingly concerned about the condition of global ecosystems and ecosystem services. Thus, land use presents a dilemma. On one hand, many land-use practices are absolutely essential for humanity because they provide critical natural resources and ecosystem services, such as food, fiber, shelter, and freshwater. On the other hand, some forms of land use are degrading the ecosystems and services on which we depend. So, the challenge is how to reduce the negative environmental impacts of land use while maintaining economic and social benefits (IFAD 2013).

Dimensions of SLM

SLM also includes ecological, economic and socio-cultural dimensions (Hurni 1997). These three are functionally related—they are interconnected in the process of sustainable food production (fig. 7). They are also referred to as the '3 Es' of sustainable management—Equality, Economy, and Ecology (UNESCO 2006).

Ecologically, SLM technologies, in all their diversity, effectively combat land degradation. This becomes very crucial, since majority of agricultural land is not sufficiently protected.

Socially, SLM helps secure sustainable livelihoods by maintaining or increasing soil productivity, thus improving food security and reducing poverty, both at household and national levels.

Economically, SLM pays back investments made by land users, communities or governments. Agricultural production is safeguarded and enhanced for small-scale subsistence and large-scale commercial farmers alike, as well as for livestock keepers. Furthermore, the considerable offsite benefits from SLM can often be an economic justification in themselves.

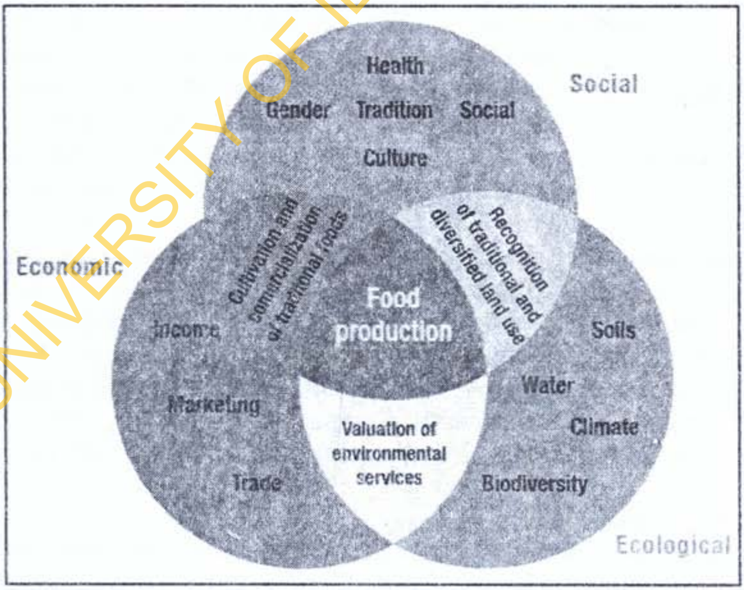

Fig. 7: The three dimensions of sustainability (After IAASTD 2009).

Principles of Sustainable Land Management (SLM)

The primary target of SLM is to increase land productivity, improve food security and also provide for other goods and services. There are three ways to achieve this: (1) expansion, (2) intensification, and (3) diversification of land use.

***Expansion*:** Since 1960, agricultural production in Sub-Saharan Africa has been increased mainly by expanding the area of land under farming (Lal 2009; Blum 2013). Limited access and affordability of fertilizers and other inputs (e.g. improved planting material) have forced African farmers to cultivate less fertile soils on marginal lands; these in turn are generally more susceptible to degradation and have poor potential for production. There is very limited scope for further expansion without highly detrimental impacts on natural resources (e.g. deforestation).

***Intensification*:** Globally, the last 50 years have witnessed major successes in agriculture, and food production largely as a result of the 'Green Revolution' which was based on improved crop varieties, synthetic fertilizers, pesticides, irrigation, and mechanization (The Montpellier Panel 2013). However, this has not been the case for SSA countries.

***Diversification*:** This implies an enrichment of the production system related to species and varieties, land use types, and management practices. It includes an adjustment in farm enterprises in order to increase farm income or reduce income variability. This is achieved by exploiting new market opportunities and existing market niches, diversifying not only production, but also on-farm processing and other farm-based, income-generating activities (Dixon et al. 2001). It involves diversified farming systems such as crop-livestock integration, agroforestry, intercropping, crop rotation, etc., assisting farmers to broaden the base of agriculture, reduce the risk of production failure, attain a better balanced diet, use labour more efficiently, procure cash for purchasing farm inputs, and add value to produce.

Soil Quality as an Indicator of Sustainable Management

Developing sustainable agricultural management systems is complicated by the need to consider their utility to humans, their efficiency of resource use, and their ability to maintain a balance with the environment that is favourable both to humans and most other species (Harwood 1990). More simply stated by Tom Franzen, a mid-western farmer in the USA, who says: "Sustainable agriculture sustains the people and preserves the land". We are challenged to develop management systems that balance the needs and priorities for production of food and fiber with those for a safe and clean environment. Assessment of soil quality or health is invaluable in determining the sustainability of land management systems (Karlen et al. 1997).

Soil quality is conceptualized as the major linkage between the strategies of conservation management practices and achievement of the major goals of sustainable agriculture (Acton and Gregorich 1995; Parr et al. 1992). In short, the assessment of soil quality or health, and direction of change with time, is the primary indicator of sustainable land management (fig. 8). Scientists make a significant contribution to sustainable land management by translating scientific knowledge and information on soil function into practical tools and approaches by which land managers can assess the sustainability of their management practices (Bouma 1997; Dumanski et al. 1991).

Specifically, assessment of soil quality/health is needed to identify problem production areas, make realistic estimates of food production, monitor changes in sustainability and environmental quality as related to agricultural management, and to assist government agencies in formulating and evaluating sustainable agricultural land-use policies (Granatstein and Bezdicek 1992). Use of one given approach for assessing or indexing soil quality is fraught with complexity and precludes its practical or meaningful use by land managers or policy makers (Harris et al. 1996). However, the use of simple indicators of soil quality and health which have meaning to farmers and other land managers will likely be the most fruitful means of linking science with practice in assessing the sustainability of management practices (Romig et al. 1995, 1996).

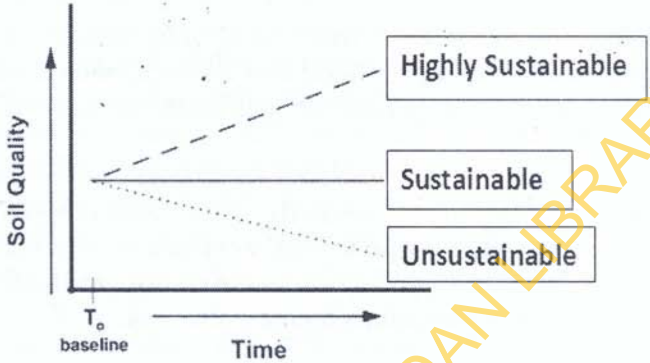

Fig. 8: Effect of soil quality sustainability of land use with time (After Karlen et al. 2003 - modified)

Pillars of SLM

Recognizing that a clear objective is essential to successful evaluation, the Framework for the Evaluation of Sustainable Land Management (FESLM) Working Party, in Nairobi in 1991, laid a foundation for the following definition of SLM:

> Sustainable land management combines technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns so as to simultaneously:
> - maintain or enhance production/services (**Productivity**),
> - reduce the level of production risk (**Security**),
> - protect the potential of natural resources and prevent degradation of soil and water quality (**Protection**),
> - be economically viable (**Viability**),
> - and be socially acceptable (**Acceptability**).

These five objectives of Productivity; Security; Protection; Viability and Acceptability are seen to be the basic '***pillars***' on which the SLM edifice must be constructed and against which its findings must be tested and monitored (Smyth and Dumanski 1993).

Each pillar is complex, and requires further brief examination:

Productivity**:** The returns from SLM may extend beyond material yields from agricultural and non-agricultural uses to include benefits from protective and aesthetic aims of land use.

Security**:** Management methods that promote balance between a land use and prevailing environmental conditions reduce the risks of production; conversely, methods that destabilize local relationships increase that risk.

Protection**:** The quantity and quality of soil and water resources must be safeguarded, in equity for future generations. Locally, there may be additional conservation priorities such as the need to maintain genetic diversity or preserve individual plant or animal species.

Viability**:** If the land uses being considered are not locally viable, the use will not survive.

Acceptability**:** Land use systems can be expected to fail, in time, if their social impact is unacceptable. The populations most directly affected by social and economic impact are not necessarily the same.

Strategies for Sustainability

In defining sustainable agricultural management practices, Doran et al. (1994) stressed the importance of holistic management approaches that optimize the multiple functions of soil, conserve soil resources, and support strategies for promoting soil quality and health. They initially proposed use of a basic set of indicators to assess soil quality and health in various agricultural management systems. Experience has shown that while many of these key indicators are extremely useful to specialists (i.e. researchers, consultants, extension staff, and conservationists), many of them are beyond the expertise of the producer to measure (Hamblin 1991). Also, the measurement of soil quality and health does nothing to improve the sustainability of the system under which the soil is managed. In response to this dilemma, Doran et al. (1996) and Doran and Safley (1997) presented strategies for ensuring sustainable management which included generic indicators of soil quality and health which are measurable by and accessible to producers within the time constraints imposed by their normally hectic and unpredictable schedules, as given in table 10.

It is noteworthy that soil organic matter serves as a primary indicator of soil quality and health for both scientists and farmers (Romig et al. 1995). Strategies for sustainable management, such as those shown in table 10, maximize the benefits of natural cycles, reduce dependence on non-renewable resources, and help producers identify long-term goals for sustainability that also meet short-term needs for production. However, successful development and implementation of standards for assessment of soil health and sustainability can only be accomplished in partnership with agricultural producers, who are the primary stewards of the land.

Table 9: Sustainability Strategies and Proposed Indicators of Crop Performance and Soil Health

Sustainability Strategy	Indicators for Land Users/Producers
Conserve soil organic matter by maintaining soil C & N levels through reduction in tillage, recycling plant and animal manures and/or increasing plant diversity where C inputs > C outputs	Change in organic matter levels through color (visual) or chemical analysis; specific OM potential for climate, soil and vegetation, soil water storage
Minimize soil erosion through conservation tillage and increased protective cover (residue stable aggregates, cover crops, green fallow)	Visual (gullies, rills, dust etc.); Surface soil properties (topsoil depth, organic matter content/ texture, water infiltration, runoff, ponding, % cover)
Balanced production & environment through conservation and integrated management systems (optimizing tillage, residue, water and chemical use) and by synchronizing available N and P levels with crop needs	Crop characteristics (visual or remote sensing of yield, colour, nutrient status, plant vigour and rooting characteristics); Soil physical conditions/compaction Soil and water nitrate levels Amount and toxicity of pesticides used
Better use of renewable resources through relying less on fossyl fuels and petrochemicals and more on renewable resources and biodiversity (crop rotation, legumes, manures IPM etc.)	Input/output ratios of costs and energy Leaching losses/soil acidification Crop characteristics (as listed above) Soil and water nitrate levels

Source: Doran et al. (1996)

Some Established Systems of SLM

About 46% of Nigeria's vast cultivable land area (71.2 million ha) is currently in agricultural use (NLUP 2012). Expanding this area to boost the food supply for ensuring food security is not an acceptable option, rather the emerging paradigm of sustainable intensification (The Montpellier Panel 2013), is more desirable and can be adopted for building resilience in Nigerian agriculture. The old practice of bush burning in the dry season still persists with the resultant soil nutrient depletion due to the destruction of the organic matter in the soil surface and addition to the problem of climate change. Indiscriminate soil excavation to obtain sand and/or gravel for building or road construction is another major practice that affects the Nigerian soil resources adversely. The major soil management systems considered sustainable are: Integrated Soil Fertility Management (ISFM), Conservation Agriculture (CA) and Organic Agriculture (OA). Precision Agriculture (PA), the application of Computer Technology to enhance efficiency and economic performance, can be integrated with any of these systems.

Integrated Soil Fertility Management (ISFM)

Integrated Soil Fertility Management (ISFM) has been defined as a set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at optimizing agronomic use efficiency of the applied nutrients and improving crop productivity (Vanlauwe et al. 2015; Fairhurst 2012). All inputs need to be managed following sound agronomic and economic principles.

This definition combines all the agronomic components necessary to make crops grow and yield well, including the use of high yielding and healthy planting material, plant nutrients, whether supplied as organic materials or mineral fertilizers, and other soil amendments. The ISFM approach embraces the principles of plant production ecology where yield is a function of the interaction between genotype, environment and management:

Yield = G (genotype) + E (environment) + M (management),

Where:

- Genotype is the seed or plants used in the farming system, local or improved varieties.
- Environment refers to the soils and climate in the particular location.
- Management refers to the farmer's ability and skill in managing crops and the farming system.

A model can be used to illustrate the impact of moving towards more complete implementation of ISFM. However, it has been established that:

(1) The more complete the implementation of ISFM, with all the necessary inputs/interventions (fig. 6), the greater the value for agronomic efficiency.
(2) It shows the distinction between responsive soils and less responsive soils—the response to seed and fertilizer and other inputs is large in responsive soils, but small in non-responsive 'degraded' soils.
(3) Organic resources are required to make efficient use of fertilizer and improved seeds.
(4) Full implementation of ISFM requires knowledge on how to adapt practices to each farm's peculiarities (Fairhurst 2012).

ISFM involves the combined use of appropriate interventions on soil management, fertilizer use and crop agronomy to drive the main outputs of increased yield and productivity. The introduction of interventions is affected by market economics and government policy. When introduced successfully, productivity is increased and less land is required to achieve a given level of production. The impact is the sustainable improvement of food security, increased farm incomes and lower food prices, which benefit the urban population (fig. 9).

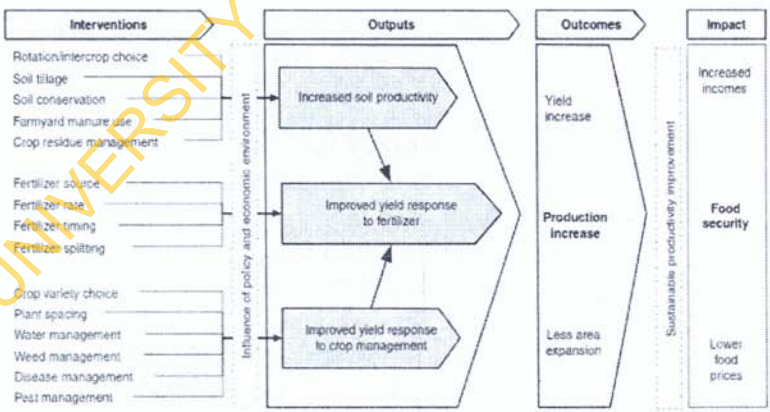

Fig. 9: ISFM as an integral process for SLM and food security. *Source:* Fairhurst (2012)

Conservation Agriculture (CA)

CA is an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment (FAO 2015).

The predominant form of agriculture is based on the 'interventionist approach', in which most aspects of the production system are controlled by human technological interventions, such as soil tilling, curative pest and weed control with agrochemicals, and the application of synthetic mineral fertilizers for plant nutrition. Most of these crop production systems are both economically and environmentally vulnerable and unsustainable (MEA 2005; WDR 2008; McIntyre et al. 2008; Foresight 2011). However, there are now a growing number of production systems with the 'ecosystem approach', underpinned by healthy soils, and designated as Conservation Agriculture (CA), that are not only effective in producing food and other raw materials economically, but also more sustainable in terms of land management and environmental services and impacts. Their further development and spread merit deeper support with the development of suitable policies, funding, research, technologies, knowledge diffusion, and institutional arrangements.

Principles of CA in relation to Sustainability

The production systems which follow a predominantly *ecosystem approach* offer a range of productivity, socio-economic and environmental benefits to producers and to society at large on a sustainable basis. They are based on five overall objectives:

(i) Simultaneous achievement of increased agricultural productivity and enhanced ecosystem services;
(ii) Enhanced input-use efficiency, including water, nutrients, pesticides, energy, land and labour;
(iii) Judicious use of external inputs derived from fossil fuels (such as mineral fertilizers and pesticides) and preference for alternatives (such as recycled organic matter, biological nitrogen fixation and integrated pest management);

(iv) Protection of soil, water and biodiversity through use of 'minimum soil disturbance' and maintaining organic matter cover on the soil surface to protect the soil and enhance soil organic matter and soil biodiversity; and

(v) Use of managed and natural biodiversity of species to build systems' resilience to abiotic, biotic and economic stresses, with an underlying emphasis on improving soils' content of organic matter as a substrate essential for the activity of the soil biota.

The farming practices required to implement these objectives will differ according to local conditions and needs, but will have the following necessary characteristics:

(i) ***Minimum soil disturbance by mechanical tillage*** - Physical soil problems such as compaction are rectified and, as much as possible, seeding or planting is directly into untilled soil in order to maintain soil organic matter, soil structure and overall soil health;

(ii) ***Maintenance of organic matter cover on the soil surface,*** using crops, cover crops or crop residues. This protects the soil surface, conserves water and nutrients, promotes soil biological activity and contributes to integrated weed and pest management; and

(iii) ***Diversification of species*** – both annuals and perennials—in associations, sequences and rotations that can include trees, shrubs, pastures and crops, all contributing to enhanced crop nutrition and improved system resilience.

The practices described above are those generally associated with CA, now widely used in all continents—over 117 million hectares (Kassam et al. 2010). However, for production intensification, these CA practices should be strengthened by the following additional best management practices:

(i) Use of well adapted, high yielding varieties and good quality seeds;
(ii) Enhanced crop nutrition, based on healthy soils;
(iii) Integrated management of pests, diseases and weeds; and
(iv) efficient water management.

Sustainable crop production intensification is the combination of all seven of these improved practices applied in a timely and efficient manner. Such sustainable production systems are knowledge and management intensive and relatively complex to learn and implement. They offer farmers many possible combinations of practices to choose from and adapt, according to their local production conditions and constraints (Pretty 2008; Kassam et al. 2009; FAO 2010, 2011; Pretty et al. 2011).

Uniqueness of CA for Sustainable Land Management

Sustainable agricultural land management and production intensification is facilitated with CA because biological optimization of soil conditions is continuous, and repeated soil-recuperative breaks (essential in tillage-based systems) are unnecessary. A main criterion for ecologically sustainable production systems or sustainable land management is the maintenance of an environment in the root-zone to optimize soil biota, including healthy root functions, to the maximum possible depth. Roots are thus able to function effectively and without restrictions to capture plant nutrients and water as well as interact with a range of soil microorganisms beneficial for soil health and crop performance (Shaxson 2006; Uphoff et al. 2006; Shaxson et al. 2008; Kassam et al. 2009). Maintenance or improvement of soil organic matter content and biotic activity, soil structure, and associated porosity, are critical indicators for sustainable production and other ecosystem services.

A key factor for maintaining soil structure and organic matter is to limit mechanical soil disturbance in the process of crop management. This is because it provokes accelerated oxidation of organic matter and loss of the resulting CO back into the atmosphere. In so doing, it depletes soil organic matter, the energy-rich substrate for the life processes of the soil biota which are essential for developing and maintaining any soil in a healthy and productive condition. Nevertheless, for any agricultural system to be sustainable in the long term, the rate of soil formation—from the surface downwards—must exceed the rate of any degradation due to loss of organic matter (living and/or non-living), and of soil porosity, evidenced by consequent soil erosion. In the majority of agroecosystems, this is not possible if the soil is mechanically disturbed (Montgomery 2007). For this reason the avoidance of unwarranted mechanical soil disturbance is a starting point for sustainable production. Not tilling the soil is therefore a necessary condition for sustainability, but not a sufficient condition: other complementary techniques including mulch cover, crop rotations and legume crops are also required.

The sustainable crop production principles of CA described above can be readily integrated into other ecosystem-based approaches to generate greater benefits. For example, *System for Rice Intensification* (SRI) has proven to be successful as a basis for sustainable intensification in all continents under a wide range of circumstances. Trained farmers have shown that SRI embodies CA principles to offer higher factor productivities and income, and requires less seeds, water, energy, fertilizer and labour compared with conventional irrigated or rainfed flooded rice production systems (Kassam et al. 2011).

Organic Agriculture (Farming)

Organic agriculture is defined by International Federation of Organic Movements (IFOAM) as, "a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and good quality of life for all involved" (IFOAM 1998).

One of the primary objectives of organic agriculture is to increase the sustainability of agricultural systems. Organic agriculture uses a whole system approach based upon a set of processes resulting in sustainable ecosystems, safe food, good nutrition, animal welfare and social justice. It is more than just a system of production that includes or excludes certain inputs, particularly agro-chemicals, because it builds on and enhances the ecological management skills of farmers, fisher folk and pastoralists. Practising organic or agro-ecological agriculture requires ecological knowledge, planning and commitment to work with natural systems, rather than trying to change them. Industrial agriculture uses an opposite approach; it provides inputs and technologies to substitute and thus reduces or destroys the inherent diversity of natural systems (Sombrock et al. 2003). It contributes to both land degradation and climate change. This is vividly portrayed in the books *The Fatal Harvest: The Tragedy of Industrial Agriculture* and *The Fatal Harvest Reader: The Tragedy of Industrial Agriculture* (Kimbrell 2002).

In 2004, IFOAM published a scoping study on "The Role of Organic Agriculture in Mitigating Climate Change" (Kotschi and Müller-Sämann 2004). The study looked at how organic agriculture could contribute to reducing greenhouse gas (GHG) emissions and mitigate the impacts of climate change. Specifically, organic agriculture;

- encourages and enhances biological cycles within the farming system;
- Maintains and increases long-term fertility in soils;
- Uses, as far as possible, locally available renewable resources in locally organized production systems; and
- Minimizes all forms of pollution (IFOAM 1998).

Organic Agriculture's Contribution to Carbon Sequestration

The emphasis on strengthening the internal nutrient and energy cycles inherent in organic agriculture offers a means to sequester carbon dioxide in the soil and in the vegetation. Kotschi and Müller-Sämann (2004) reported the results of a study that compared carbon sequestration by organic and conventional agricultural systems. Organic agriculture showed a clear advantage with an efficiency of 41.5% compared to 21.3% for conventional farming. The study also showed the much higher contribution to sequestration of root biomass as compared with above ground biomass.

The relationship between organic agriculture, traditional agriculture and sustainable agriculture is illustrated in figure 10. Organic agriculture is often equated with the use of organic fertilization techniques, systematic application of manure and compost from animal and crop residues, crop-legume rotations, green manuring with legumes, and agroforestry with multipurpose leguminous trees. Much expertise has been developed in these techniques and the use of these practices has produced outstanding improvements in productivity and environmental health, as the case study from Tigray, northern Ethiopia, demonstrates. In Switzerland, a long-term comparison between organic and conventional agricultural systems was carried out. After 18 years, soils treated with organic manures were found to contain 3-8 t ha^{-} more carbon than those that had had chemical fertilizer treatment (Kotschi and Müller-Sämann 2004).

In 2003, IFOAM commissioned a study to provide an overview of the status of the organic movement in Africa (IFOAM 2003). The survey covered both the formal (certified) and non-formal sectors for 22 of Africa's 54 countries. This represented 40% of the land area of the continent. Certified organic agriculture covers both large commercial and small-holder farmers. In global terms, only 1% of land under certified organic agriculture is found in Africa, but, because most of the farms are small (1-3 ha) the continent accounts for almost 10% of the farmers growing certified organic crops worldwide. The principles behind organic agriculture are also used in programmes and projects focused on overcoming food insecurity, rural poverty and environmental degradation. In 2003, IFOAM reported that over 40,000 farms covering 235,000 ha of land were growing certified organic products in Africa (IFOAM 2003).

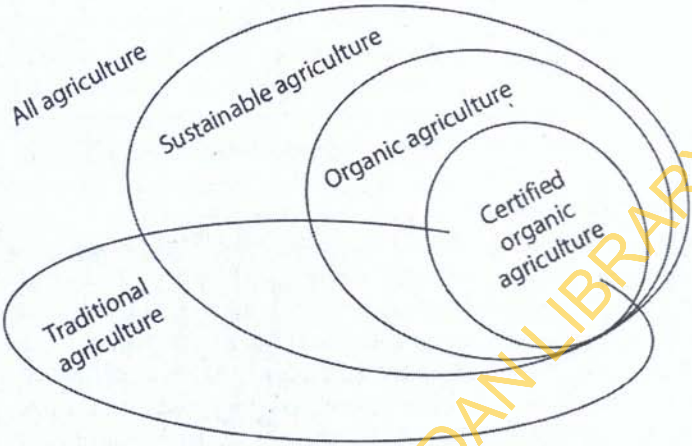

Fig. 7: Conceptual relationship between traditional agriculture, organic agriculture, certified organic agriculture and sustainable agriculture in the context of all agriculture.

Source: Twarog 2006, in UNCTAD Trade and Environment Review 2006: 144

Organic Agriculture in Nigeria

Organic Agriculture in Nigeria is very young, within the last two decades, although use of manure or decomposed organic materials from dump sites is an age-old practice. The practice of modern organic farming is at a relatively low level in Nigeria compared with developed countries. It is mainly at the research and awareness stage, production is very low and limited to the universities, research institutes and a few farmers. The awareness is concentrated in the south, particularly, South-West (table 11). It is being coordinated by the Nigerian Organic Agriculture Network (NOAN). Land area under Organic Agriculture in Nigeria was 3,134 ha in 2007 and 11,979 ha in 2010 (Global Agric. Information Network 2014).

Table 10: Awareness of Organic Agriculture in Nigeria

Geo-Political Region	% Awareness
North - East	1.35
North - West	2.7
North - Central	4.95
South - East	2.19
South - West	76.57
South - South	12.16

Source: Global Agric. Inform. Network 2014

Biochar Technology

There is a growing interest in using biochar (charcoal or black C) as a soil amendment and for sequestering C and improving soil quality. It has been acclaimed as a sustainable way to improve soils and decrease the use of chemical fertilizers (Lima et al. 2002). Biochar is a solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment—which creates a fine-grained, highly porous charcoal (Renwick et al. 2002; Rumpel et al. 2006). Application of biochar to soil can improve soil fertility. Application of biochar can enhance soil quality in many ways, including: (i) increase in soil's cation exchange capacity; (ii) decrease in loss of nutrients; (iii) increase in soil's microbial activity; (iv) improvement of soil structure and water retention capacity; and (v) increase in buffering against soil acidification (Fowles, 2007). In addition, biochar can also be used for remediation and/or protection against particular environmental pollution and as an avenue for greenhouse gas (GHG) mitigation (Marris 2006). This is thus an area of great potential in OA for food security and climate sustainability (IPCC 2007; Stern 2007).

Precision Agriculture

Precision agriculture (PA) (satellite farming or site specific crop management (SSCM), is a farming management concept based on observing, measuring and responding to inter and intra-field variability in crops. Precision agriculture is one of many modern farming practices that make production more efficient. With precision agriculture, farmers and soils work better, not harder. The term first came into popular use with the introduction of GPS (global positioning satellites) and GNSS (global navigation satellite systems) as well as other methods of ***remote sensing*** which allowed farm operators to create ***precision maps*** of their fields that provide detailed information on their exact location while in-field, thus making possible accurate prediction of soil conditions and/or crop performance at any location in the farm. Advancements in technology have enabled the practice of precision agriculture to expand, providing even greater advantages for farmers and agricultural operations, including ***yield monitoring*** and ***crop scouting***. With precision agriculture, control centers collect and process data in real time to help farmers make the best decisions with regard to planting, fertilizing and harvesting crops. Sensors placed throughout the fields are used to measure temperature and humidity of the soil and surrounding air.

There are several aspects of precision agriculture that can be applied to various types of farming operations, but they all share a common feature—the use of ***technology*** to enhance economic performance, better use of inputs and help to mitigate environmental damage.

Recent Development: "The Green Alternative''

Just at the completion of the preparation of this lecture, specifically on Wednesday, 20th of July, 2016, the Federal Executive Council approved the Agricultural Policy of the Government tagged 'The Green Alternative' for implementation. The Minister of Agriculture in his presentation called it the "Roadmap for agricultural operation for the next three years," outlining the policy and objectives to make agriculture "the next and biggest alternative" to oil in the nation's drive to diversify the economy of this country. The Minister went further: "We are fully aware that there is a major concern in the country for food self-sufficiency and that there is crisis in many families as a result of serious shortage of food." The policy reveals Government's plan for "a huge investment in soil mapping/testing" One can only pray and hope that 'The Green Alternative' has truly recognized the key role of soil resources management in the successful programme on food security and sustainable development.

Conclusion

The importance of soil resources in agricultural (food) production has been trivialized in Nigeria over the years. Thus, serious attention is not given to soil problems. In spite of the high degree of soil loss and depletion of soil quality through degradation in the country, little effort is made to redress it. There is no authentic national soil classification and map based on accurate soil data. Apart from inorganic fertilizer application and the old shifting cultivation/bush fallow system, all other management systems being adopted by farmers were acquired by trial-and-error. Consequently, yields of most of Nigerian arable crops are very low compared with their potentials. Food security, an indicator of sustainable development, cannot be achieved under such a system.

In addition, inherent characteristics of the Nigerian soil resources show that the soils are of marginal to average quality and the same is true of their capacity for supporting arable crops. For the quality and capacity of the soils to be improved and/or sustained, soil degradation must be minimized. This requires adequate knowledge of the characteristics of the soils so that the appropriate combinations of soil management and land use can be adopted. The fragile nature of the soils makes them highly susceptible to soil degradation of various types, water erosion being the most devastating. Several factors are responsible for the degradation, but the ones that stand out are deforestation, overgrazing and excavation/quarrying, excessive cultivation, and oil pollution in the oil-producing regions. Climate change has introduced further complications to exacerbate the effects of these factors. In addition, the relatively high rate of population expansion and the resultant demand for more food has forced the expansion of areas under cultivation to marginal lands, thus leading to more degradation.

This lecture therefore, has attempted to create a special awareness that the major problem militating against food security in Nigeria is the poor quality, highly degraded and poorly managed soil resources. It has emphasized the need for more information on the characteristics of the soils, avoidance of activities that lead to soil degradation, and encouragement of practices that enhance organic matter conservation in the top soil. Thus, the lecture calls for the adoption of appropriate sustainable management and conservation of the nation's agricultural soil resources to achieve food security for sustainable development in the country.

Sustainable land/soil management (SLM), a system that preserves the land and sustains the people seems to be the way out. From its dimensions, characteristics (Pillars) and strategies, SLM has the capacity to preserve the land resources to meet human needs and development. It is a knowledge-based procedure that integrates land, water, biodiversity, and environmental management in order to meet rising food demands while sustaining ecosystem services and livelihoods. SLM is necessary to meet the requirements of a growing population. The soil management strategies presently in use by Nigerian farmers cannot sustain soil quality and capacity for food security or self-sufficiency in food production for the Nigerian population.

Soils must not be taken for granted in any meaningful agricultural policy. While adoption of improved crop varieties is important, agronomic production can neither be improved nor sustained unless soil quality is restored and maintained. Maintaining soil quality and water resources at optimal levels is essential for realizing the potential of improved varieties. Degraded soils do not respond to other inputs unless their physical, chemical and biological quality is restored.

The adoption of a number of science-based SLM systems that have been developed which have been adjudged to be effective for sustaining agricultural land use is very crucial to our success in food production. They are: Integrated Soil Fertility Management (ISFM), Organic Agriculture (OA), and Conservation Agriculture (CA). A detailed analysis of these systems shows that each of them is specialized in terms of approach, emphasis and area of impact (e.g. ISFM for chemical soil fertility, CA for conservation against soil loss/erosion). Therefore, a combination of any two or even the three of these systems (or some aspects of each) may be required for optimum sustainable management of the soil resources. Relevant type(s) of Precision Agriculture (PA) can be combined with any of the options selected to take advantage of modern technological advancement for greater and faster accomplishment.

Obviously, food security cannot be attained with the present attitude towards an essential resource as the soil. There is urgent need for agricultural transformation in which soil resources will be given their rightful place so that food security and hence, sustainable development will be a reality even with the ever increasing population in Nigeria. It is hoped that the current fall in oil price in the world market will force Nigeria to get its priorities right by wisely investing in agricultural production and research. If this can be done, the present suffering from the low price of oil will turn out to be a blessing in disguise.

Recommendations

On the premise of this lecture, I wish to make the following recommendations:

- Soil Resource Inventory: There is urgent need for characterization, classification and mapping of the soil resources in the country, with mapping at semi-detailed scale at the national level and detailed scale at the State level. This will enhance accurate prediction of the most appropriate land use and management for any area of interest in the country.
- Resuscitation of Federal Department of Agricultural Land Resources (FDALR) with adequate funding and review of its mandate to meet the demands of sustainable agriculture, food security, and minimal land degradation.

- Establishment of a functional National Soil Information System (NISIS) to produce a data bank (of the major soils, their characteristics and appropriate land use and management) which can be made available to farmers and land users on request in all the Geo-political regions in the country.
- Benchmark Soils Programme for continuous research on Sustainable Soil Management for the Major Kinds of Soils in the country, evaluation of sustainable management systems for their performance on the benchmark soils, and necessary adjustments/modifications before they are recommended to farmers.
- Establishment of a National Institute of Soil Science for the overall monitoring and supervision of activities/practices on soil resources in the country and standardization of the practice of soil science. (This has been pushed by the Soil Science Society of Nigeria, has been passed by the Senate, and is awaiting endorsement by the House of Representatives.)
- Legislation (and enforcement) against all forms of soil abuse e.g. bush burning, indiscriminate soil excavation, overgrazing, indiscriminate deforestation, etc.
- A review of the Federal Government's Department or Unit in charge of Sustainable Development Goals (SDGs) and its activities to establish professional sub-committees for relevance and performance. Alternatively, SDG committees can be formed based on grouping of similar goals in terms of professions (e.g. agriculture and environment, etc.).

Acknowledgement
I give all thanks, praises and glory to God Almighty my Father, to Jesus, my Lord and Saviour and the Holy Spirit, my guide and enabler—for sustenance, favour and grace to make this humble but crucial contribution towards the progress of my nation, Nigeria.

I wish to thank all my teachers from the elementary school to the University for their investments in my life. In

particular, I wish to remember Late Professor P.H.T. Beckett who supervised my D.Phil. project.

I very much appreciate my Colleagues and other members of staff of the Department of Agronomy, where I have spent over three decades of my life. I have enjoyed a very friendly atmosphere in my interactions with both staff and students. I pray that this progress and unity will increase and continue to produce ground-breaking research in Jesus' name. My Head of Department, Professor Victor Adetimirin and my Dean, Professor E.A. Iyayi who nominated me and the Vice-Chancellor and the Management of the University who approved my nomination for this Lecture, I appreciate you very much. My current Head of Department, Professor E.A. Akinrinde and Dean, Professor B.O. Omitoyin, I appreciate you both for your support. Dr. Julius Orimoloye, Professors Akin Oluwatosin and Gabriel Akinbola assisted me in the preparation of this lecture. I very much appreciate all of you. Several people have played one role or the other to get me to the stage of being qualified to give the 2016 University Lecture, I thank you all and pray that you will continue to enjoy the favour of God in Jesus' name.

I wish to appreciate members of my family, my children, Oluwanbe, Ife and his wife Kemi and children; my late parents, my siblings, uncles, aunties and in-laws; my Church (Pastor, Deacons and other members); thank you for your love, support, and prayers, May you never miss the love and support of the Lord in Jesus' name. Lastly, my darling wife, Dr. Oluwatoyin Ogunkunle, you have been wonderful. I very much appreciate your care, love, patience and encouragement through thick and thin, hence I dedicate this Lecture to you.

Let us listen to the counsel of the Wise in the Holy Scriptures: "And further, by these, my son, be admonished: of making many books there is no end; and much study is a weariness of the flesh". Let us hear the conclusion of the matter: "Fear God and keep His Commandments: for this is the whole duty of man".

To God be the Glory, Honour and Adoration. Amen.

Thank you for your attention.

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BIODATA OF
PROFESSOR AYOADE OLAYIWOLA OGUNKUNLE

Professor Ayoade Olayiwola Ogunkunle was born on the 10th of August 1947 to Mr. Amos Ogunwole and Mrs. Abigail Faderera Ogunkunle, both of blessed memory.

He attended Ishokun Baptist Day School (1954-1960), Oranyan Grammar School, Oyo (1962-1967); University of Ife (1968-1972) and University of Oxford, England (1975-79).

Professor Ogunkunle taught briefly in St. David's Anglican Modern School, Odeomu in 1968 after his School Certificate. He entered the University of Ife the same year to study Agriculture. He graduated in 1972 and taught briefly in Ila Grammar School, Ila-Orangun. He joined the Nigerian Institute for Oil Palm Research (NIFOR) as Research Officer-in-Training in 1973. He left NIFOR in 1975 to study for the D.Phil. degree in Pedology and Soil Survey at Oxford University and returned to NIFOR in 1979 after completing his study. He was a recipient of the Western Nigeria Government and Federal Government Scholarships for the undergraduate and postgraduate degrees respectively.

Professor Ogunkunle joined the Department of Agronomy as Lecturer Grade I in April 1983. He was promoted Senior Lecturer in 1988, Reader in 1993 and Professor in 1996.

He was the Departmental Coordinator of Consultancy, Departmental Coordinator of PG and Undergraduate Seminars, and Member of Ile-Ogbo land Acquisition Committee.

Professor Ogunkunle has conducted researches on soil survey techniques, soil variability and land use/cropping pattern, quantitative and conventional techniques of land evaluation, application of numerical classification to soil correlation, quality control in soil survey, soil quality and land use.

He has published 117 academic articles, single or co-authored, made up of 2 chapters in books, 90 journal articles, 8 proceedings and 14 technical reports. He was a recipient of research grants from University of Ibadan Senate, West African Rice Development Authority (WARDA), Belgian Govt., Dutch Govt., and British Royal Society. He was Visiting Scholar to University of Benin, University of Ghana, Legon; University of Stirling, Scotland; Obafemi Awolowo University, and Ekiti State University. He has been External Examiner/Assessor of professorial candidates in many universities within and outside Nigeria. He has successfully supervised 13 Ph.D. Projects.

Professor Ogunkunle was Dean, Student Affairs (1999-2006) and Deputy Vice-Chancellor, Administration (2006-2008).

Outside the University, Professor Ogunkunle was Consultant to Food and Agriculture Organization (FAO) on Integrated Soil Management (1998) and Application of Framework for the Evaluation of Sustainable Land Management (FESLM); Consultant to the Federal Department of Agricultural Land Resources on Land Evaluation (1985-1990); Collaborator, RCMD, IITA (1983-2000); Coordinator, UI/IITA Ayepe OFR Project (1990-1993); Chairman, Visitation Committee, Bowen University, Iwo (2011); Member of Governing Council, Bowen University (2012 to date); Member, AGRA Committee for Ph.D. Soil Science Curriculum in West African Universities (2009); Member of West Africa Agricultural Productivity Programme (WAAPP) Committee for Strategic Document for a Road Map for Improving Soil Fertility in Nigeria (2014).

He is a member of the International Soil Science Society, Soil Science Society of Nigeria, Agricultural Society of Nigeria and Remote Sensing Society of Nigeria; He is a Fellow of the Soil Science Society of Nigeria (2009).

Professor Ogunkunle is happily married to Dr. Oluwatoyin Ogunkunle and the marriage is blessed with two sons and two grandsons.

NATIONAL ANTHEM

Arise, O compatriots
Nigeria's call obey
To serve our fatherland
With love and strength and faith
The labour of our heroes' past
Shall never be in vain
To serve with heart and might
One nation bound in freedom
Peace and unity

O God of creation
Direct our noble cause
Guide thou our leaders right
Help our youths the truth to know
In love and honesty to grow
And living just and true
Great lofty heights attain
To build a nation where peace
And justice shall reign

UNIVERSITY OF IBADAN ANTHEM

Unibadan, Fountainhead
Of true learning, deep and sound
Soothing spring for all who thirst
Bounds of knowledge to advance
Pledge to serve our cherished goals!
Self-reliance, unity
That our nation may with pride
Help to build a world that is truly free

Unibadan, first and best
Raise true minds for a noble cause
Social justice, equal chance
Greatness won with honest toil
Guide our people this to know
Wisdom's best to service turned
Help enshrine the right to learn
For a mind that knows is a mind that's free