Chapter 10

Soil-Water-Crop Relationship: A Case Study of Cassava in the Tropics

Saurau O. Oshunsanya and Nkem J. Nwosu

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.71968

Abstract

Cassava is the most important food crop in Africa occupying about 6 million hectares (ha). Several factors have limited the continuous and sustainable production of cassava in tropical Africa. Some of these factors include (but not necessarily limited to) soil and water, which are the two basic fundamental resources for cassava production. The demand on soil and water resources is increasing, especially for new and conflicting soil functions like enhancing crop production, improving water quality and mitigating climate change. Soil–plant-water relations relate to the physical properties of soil and plants that affect the movement, retention and use of water. This chapter reviewed the soil, water and plant relationship for cassava production in tropical Nigeria. The study observed that understanding the effects of soil quality and water characteristics on cassava production and its management as well as the relationship between soil, water and crop for sustainable optimum cassava production is highly imperative now than ever before, especially in developing countries of Africa (like Nigeria) that are characterised by high risks of soil degradation, rising populations and pressure on agricultural lands juxtaposed with predominant resource—poor and small landholders.

Keywords: cassava, soil quality, water characteristics, sustainable production, tropics

1. Introduction

Soil is the Earth's fragile skin that anchors all life comprising countless species that create a dynamic and complex ecosystem. Soil is a major component of the environmental system. It is a major resource of the earth with a lot of potentials. Generally, soil has been described as the basis of human civilisation. This is because soil supports plants, which provide nutrition for man and his livestock [1]. The ability of the soil to continue providing essential services in the face of disturbance, whether natural or human induced, is essential to maintain or improve crop production overtime. Crop production is a function of the soil, management and the environment (of which water availability and quality are important indices). The quality of tropical soils, water quality and the synergy between them is highly imperative for optimum crop production. The availability of both water and plant nutrients is largely controlled by the physico-chemical properties, micro-environment of soils, the success and failure of any species of a particular area are, therefore, governed by the quality of soil characteristics [2].

Soil quality is the ability of a soil to perform functions that are essential to people and the environment [3]. It is the capacity of soil to perform specific functions of interest to human [4]. Soil quality has hitherto been equated with agricultural productivity. Soil conservation practices geared to maintain soil productivity are as old as agriculture itself. Soil quality is implied in many decisions farmers make about land purchases and management, and in the economic value rural assessors place on agricultural land for purposes of taxation. The concern of soil quality has challenged human kind for over 10,000 years; the definition and the basic concept remain a work in progress and keep evolving with every generation [3].

Similarly, the importance of water in any crop production cannot be overemphasised. Cassava requires a certain amount of water daily to meet its crop water requirements [5]. Water is regarded as an intrinsic factor in any crop production as their function in food production, nutrient mineralisation and distribution, as well as plant turgidity in every crop production cannot be extremely emphasised. Water is a major constituent of living plant tissues, which consist of about 90% water. Water is involved in most of the physical, chemical and biological processes that occur in soils. In addition, all biological processes within the living plants depend on water. The optimal moisture conditions for any crop vary depending on many factors, such as soil type, climate conditions, growth rate and habit [5]. The favourable soil moisture tension should be maintained throughout the entire growth period of plants due to the relationship between evapotranspiration and biomass production.

Cassava (Manihot esculenta Crantz) has been identified as one of the most important food crops in Africa. It derives its importance from the fact that it is starchy and thickened, with tuberous roots that serve as valuable sources of cheap calories, especially in developing countries with widespread calorie deficiency and malnutrition. In many parts of Africa, the leaves and tender shoots of cassava are also consumed as vegetables [6]. Over two-thirds of the total production of cassava is consumed in various forms by humans. The International Food Policy Research Institute (IFPRI) in 2014 noted that cassava is an insurance crop that increases food security because they can be left in the ground until needed [7]; and their usage as a source of ethanol for fuel, energy in animal feed and starch for industry is increasing. The crop is amenable to agronomic as well as genetic improvement juxtaposed with a high yield potential under good conditions and performs better than other crops under suboptimal conditions. It is grown widely in several countries in sub-Saharan Africa and Madagascar. Cassava was introduced into Africa in the latter half of the sixteenth century from South America and, perhaps, also from Central America, where it is believed to have originated. Globally, there has been widespread production of cassava across continents. Thailand, Vietnam, Indonesia and Costa Rica have been reported as the world leading exporters of cassava [8].

Although Nigeria is the world's largest producer of cassava (**Figure 1**), however, its exports have been progressively reduced by the brunt population increase in the nation, implying

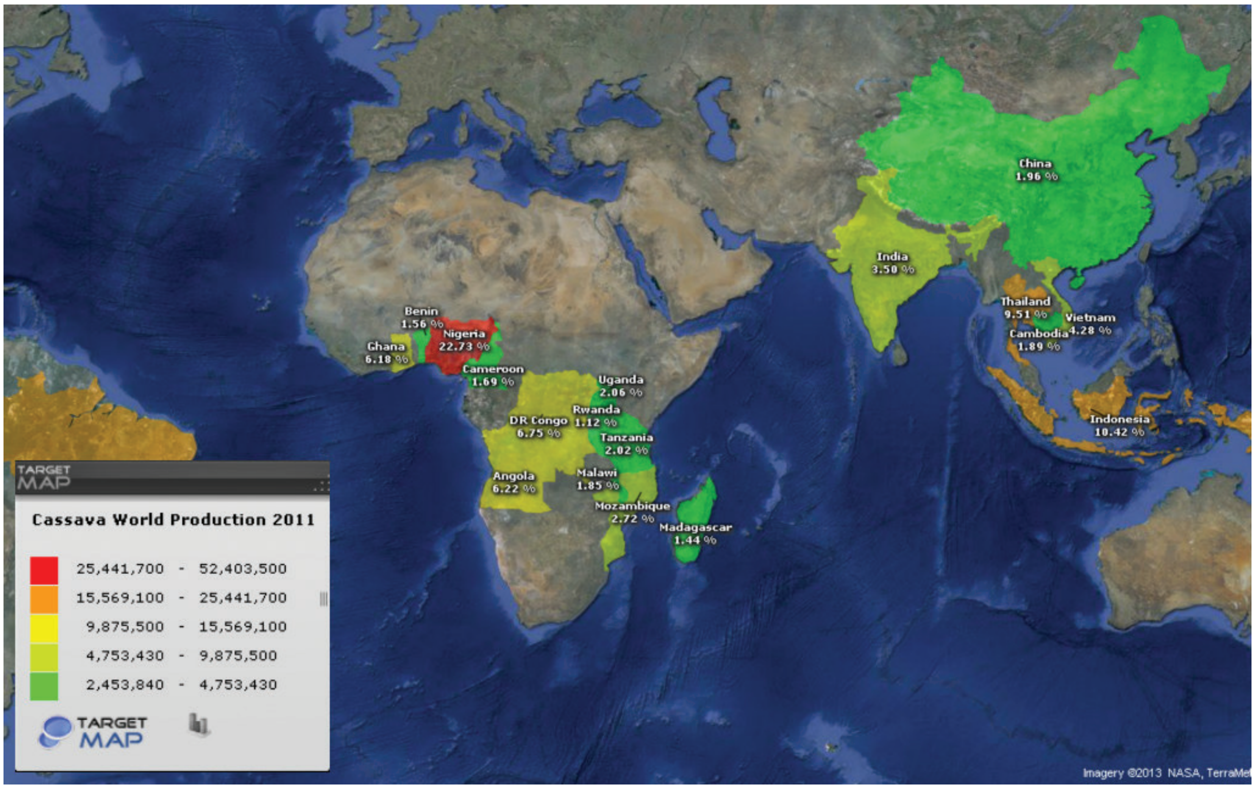

Figure 1. World cassava production in 2011 (source: www.targetmap.com).

that production is not enough to feed the current population in the country. The African Development Bank (AfDB) reported in 2015 that although Nigeria produces 20% of the world's cassava, the country exports less than 1% of its produce. It was concluded that cassava production in the tropical Nigeria needs to increase with the rising population and this has been significantly influenced by the changing climate and the poor soil quality conditions arising due to soil degradation [8]. This invariably laid credence to the pertinence of galvanising strategies for boosting cassava production and export in the tropical Africa. This review will however consider soil quality, water characteristics and their synergy for suitable and optimum production of cassava in tropical soils.

2. Soil quality and cassava production

The demand on soil resources in increasing, especially for new and conflicting soil functions like enhancing food security, improving water quality, disposing urban and industrial wastes and mitigating climate change. Thus, soil quality and its management are more important now than ever before, especially in developing countries that are characterised by high risks of soil degradation, predominantly resource—poor and small landholders [4].

Soil quality is the capacity of soil to perform specific functions of interest to human. Soil quality has historically been equated with agricultural productivity. Soil conservation practices to maintain soil productivity are as old as agriculture itself. Soil quality is implied in many decisions farmers make about land purchases and management and in the economic value rural assessors place on agricultural land for purposes of taxation. The concern of soil quality has challenged human kind for at least 10,000 years; the definition and the basic concept remain a work in progress and keep evolving with every generation.

Furthermore, soil quality is defined as the ability of a soil to perform functions that are essential to people and the environment [9]. Soil quality is not limited to agricultural soils. The first step in science of agriculture is the recognition of soils and of how to distinguish that which is of good quality and that which is of inferior quality. However, in spite of numerous definitions of soil quality, reviewed reports suggest that the widely accepted definition of the concept of soil quality was laid down by the Soil Science Society of America (SSSA) in 1996 which states that soil quality is the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation.

Soil functions keep changing with time and are different with developing compared with developed countries [4]. Although the definition of soil quality may be universal, the fact that its application is soil/society specific needs to be recognised for the concept to be useful in addressing the problems of resource-poor farmers in developing countries of the tropics. Larson and Pierce [10] defined soil quality as the capacity of a soil to function within the ecosystem boundaries and interact positively with the environment external to that ecosystem. Three soil functions are considered essential: provide a medium for plant growth, regulate and partition water flow through the environment and serve as an effective environmental filter. However, no soil is likely to successfully provide all these functions, some of which occur in natural ecosystems and some of which are the result of human modification. Hence, soil quality depends on the extent to which soil functions to benefit humans.

The qualities of tropical soils are imperative indices towards the sustainable production of cassava. Cassava is known to be a heavy feeder, and literatures have opined that more than average output is obtainable from cassava grown on marginal lands. However, in view of the ever-increasing population of the tropical Africa (most notably in Nigeria), and with the production rates seldom meeting the increasing market demands of the produce, production of cassava on quality soils is therefore an imperative factor which when juxtaposed with good management and adequate climatic conditions, the production of cassava can be improved.

More so, speaking in an interview in 2016, the Provost of the Federal College of Agriculture, Akure (FECA), Dr. Samson Odedina, while demonstrating the profitability of cassava production enterprise to young people and emerging farmers noted that farmers obtain an average yield of 8–10 tonnes of cassava per hectare, adding that the yield is far below the potentials of the crop. He further stressed that if the soil conditions are well managed, farmers can get up to 50–60 tonnes per hectare if they follow the recommended soil management practices. This increasingly justifies the pertinence of the quality of soils used for cassava production in tropical Nigeria.

In addition, the FAO in 2017 reported that cassava has the reputation of causing serious erosion when grown on sloppy soils [11]. Researchers have also argued that this reputation is undeserved, since cassava is often grown on already-eroded soils where few other crops can survive and be productive. Nevertheless, concise reviews of related literatures generally maintained that cassava production on slopes causes increased erosion on an annual basis than other crops grown under the same circumstances. Cassava, in conjunction with common bean (Phaseolus vulgaris), upland rice and cotton, tends to cause considerably more erosion than cereals (like maize), peanut, sugarcane, pineapple or sweet potato. This was predominantly attributed to the fact that cassava needs to be cultivated at a relatively wide spacing. The canopy formation and the initial growth phase are slow, leaving the soil exposed to the direct impact of rainfall during the first 3–4 months of the cropping season. Contrarily, once the crop canopy is closed, erosion is usually minimal during the remainder of the crop cycle (**Figure 2**).

The soil condition used for the production of cassava in Nigeria is of utmost importance if the demands for the produce are to be met before the year 2030 (**Figure 3**). For good growth of cassava, the soil used for production must have adequate room for water and air movement

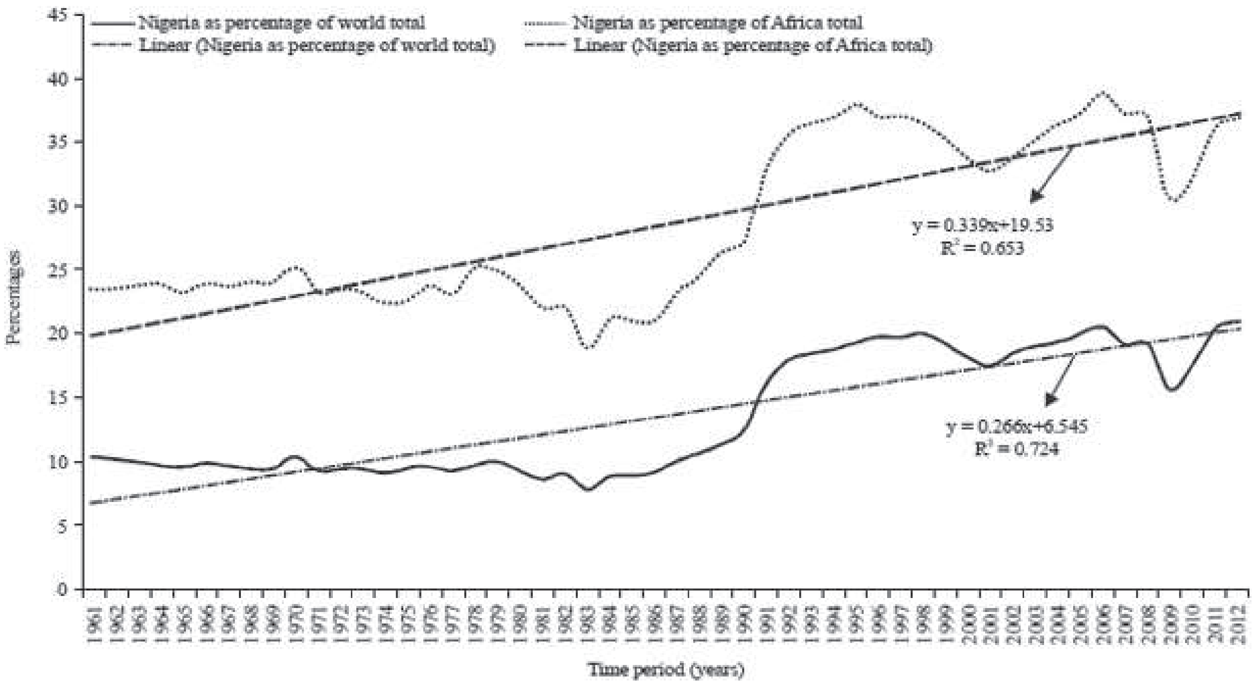

Figure 2. Nigeria's cassava production in the world and Africa totals, 1961–2012 [12].

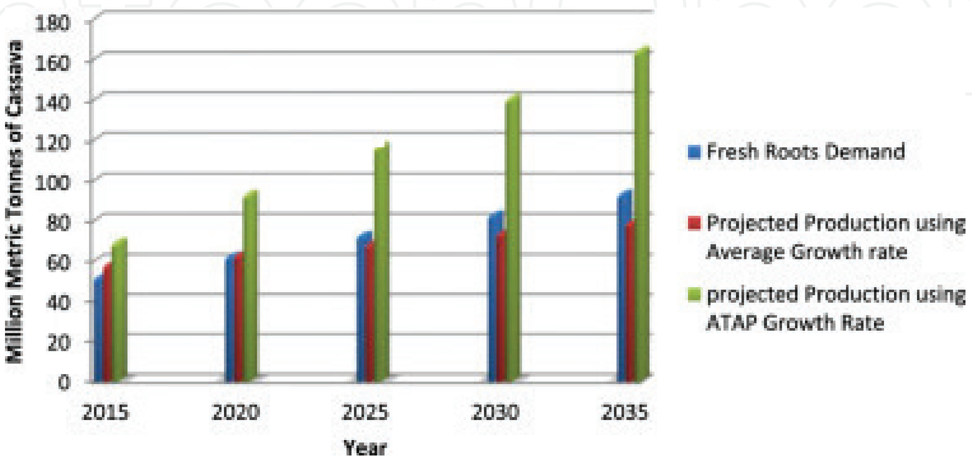

Figure 3. Cassava demand and supply projections in Nigeria [13].

and for root growth. Also, the rising pressure on agricultural lands has made it difficult to obtain high-quality lands for sustainable production of deep-rooted crops like cassava. The insurgence of climate change and its effects on tropical soils has also increased this malady. These, therefore, lay emphasis on the true need of establishing soil management techniques aimed at boosting soil physical, chemical and biological conditions—which are main indices for soil quality towards the optimum production of cassava in this high-demand region of West Africa. Hence, based on reviewed statistics, cassava production in Nigeria will increase greatly with optimum soil, environmental and management conditions.

3. Soil quality assessment for cassava production

Soil is likely to show great variability in their physical, chemical and biological properties because the soil is a heterogeneous unit. Knowledge of variability of soil properties is highly indispensable as this can affect crop yield. A study of the variability trends of soils is essential in order to highlight the soil potentials and enhance their management and productivity [14].

Anikwe et al. [15] noted that the spatial variability of soil properties has effects on crop production across an agricultural field. They emphasised that it is important to be aware of the effect of spatial variability of soil properties when choosing indicator variables of soil quality for crop production. Although when, how and where to collect soil samples for soil quality determination may differ according to the objective of the assessment being made, management history and current inputs should also be considered to ensure valid interpretation of the information.

Soil quality assessment for agricultural production is an important operation towards sustainable crop and livestock production in tropical Africa. Owing to the high degree of variability that is characteristic of tropical soils, there is a need for the assessment of soil condition and capability to offer suitable crop outputs. Fundamentally, soil productivity for cassava production is a function of soil quality and management. Soil quality assessment is the process of measuring the management-induced changes in soil as we attempt to get soil to do what we want it to do. The ultimate purpose of assessing soil quality is to provide the information necessary to protect and improve long-term agricultural productivity, water quality and habitats of all organisms including people [16].

Basically, Soil Science Society of America [3] reported that soil quality is an inherent attribute of a soil that is inferred from soil characteristics or indirect observations. Papendick et al. [17] suggested that a minimum data set (MDS) of soil characteristics representing soil quality must be selected and quantified. The MDS may include biological, physical or chemical soil characteristics otherwise known as soil quality indicators (**Figure 4**).

Furthermore, the US Department of Agriculture [19] defined soil quality indicators as physical, chemical or biological properties, processes and characteristics that can be measured to monitor changes in the soil. The types of indicators that are the most useful depend on the function of soil for which soil quality is being evaluated. Sojka and Upchurch [20] highlighted that while recognising some controversies about the basic concept of soil quality, considerable

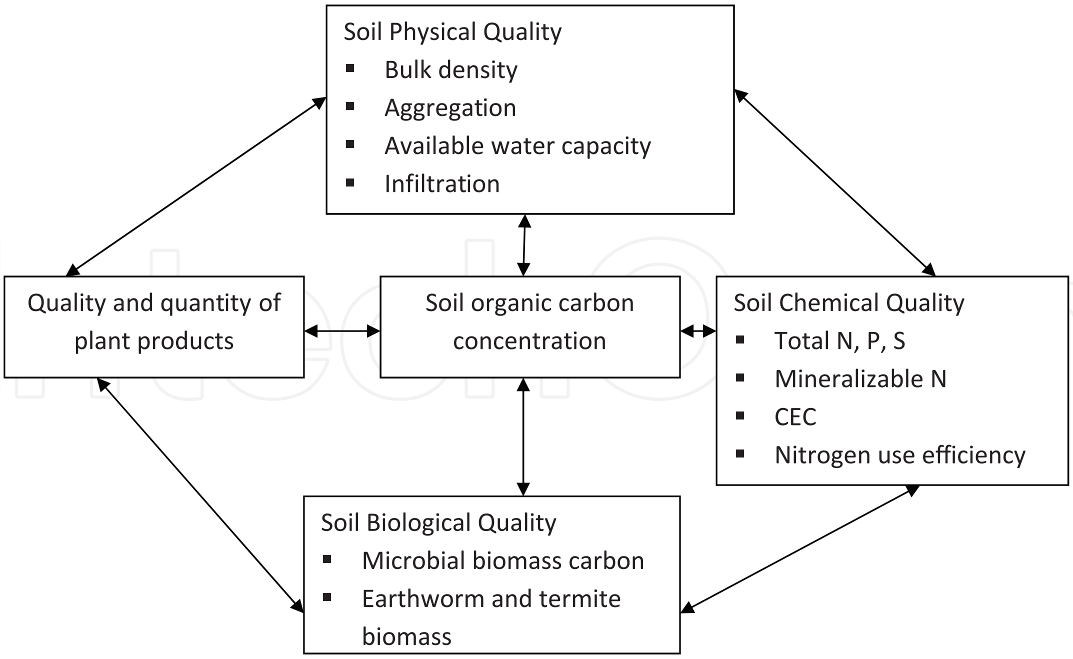

Figure 4. Showing key indicators of soil quality [18].

progress had been made in the 1990s in identifying the indicators of soil quality. However, indicators of soil quality can be generally categorised into four groups: visual, physical, chemical and biological quality indicators [19].

3.1. Visual indicators

This may be obtained from observation or photographic interpretation. Exposure of subsoil, change in colour, ephemeral gullies, ponding, run off, plant response, weed species, blowing soil and deposition are only a few examples of potential locally determined indicators. Visual evidence can be a clear indication that soil quality is threatened or changing [21]. Adeoye and Agboola [22] maintained that for sustainable cassava (or any other crop) production, the presence of spear grass on the field to be cultivated is a good indication of a soil with good fertility conditions. In addition, the presence of Chromolaena odorata suggests that the soil possesses good hydrological properties, which is a necessity for cassava production in the early 3–4 months of the growth period.

3.2. Physical indicators

These are related to the arrangement of solid particles and pores. The soil physical characteristics are necessary part of soil quality assessment for cassava production because they often cannot be easily improved [23] during the course of the cropping season. Lal [18] reported that important soil physical parameters to be assessed include soil aggregation, available water capacity, texture, saturated hydraulic conductivity, bulk density, infiltration rate and rooting depth. Researchers have further stressed the need for establishing a quantitative assessment of these soil physical parameters in order to predict biomass productivity, soil organic carbon dynamics, transport processes of water and solutes, etc.

3.3. Chemical indicators

Assessment of soil quality based on soil chemistry, whether the property is a contaminant or part of a healthy system requires a sampling protocol, a method of chemical analysis and an understanding of how its chemistry affects biological systems and interacts with mineral forms and standards for soil characterisation and suitability classification for cassava production in tropical soils. In light of these, Larson and Pierce [10] laid emphasis on those chemical properties that either inhibit the root growth or affect nutrient supply due to the quantity present or the availability. Also, Reganold and Palmer [24] suggested chemical parameters related to nutrient availability as measures of soil quality, including cation exchange capacity (CEC), total nitrogen and phosphorus, soil pH and extractable phosphorus, sulphur, exchangeable calcium, magnesium and potassium, while Karlen et al. [25] opined that total and available plant nutrients and nutrient cycling rates should be included in soil quality assessments for optimum crop productivity. Nevertheless, Abua [26] highlighted the importance of maintaining high levels of nitrogen and phosphorus in the soils as chemical indices for quality soils to be used for cassava production in southern Nigeria.

3.4. Biological indicators

Basically, microorganisms and microbial communities are dynamic and diverse, making them sensitive to changes in soil conditions [27]. Their populations include fungi, bacteria including actinomycetes, protozoa and algae. However, some soil organisms such as nematodes and bacterial and fungal pathogens reduce plant productivity. Visser and Parkinson [28] reported that diverse soil microbiological criteria may be used to indicate deteriorating or improving soil quality, and measurement of one or more components of the nitrogen cycle including ammonification, nitrification and nitrogen fixation may be used to assess soil fertility and soil quality.

Nevertheless, USDA [19] devised biological indicators of soil quality to include measurement of micro- and macro-organisms, their activity, or by-products; and also suggested measurement of decomposition rates of plant residue in bags or measurement of weed seed numbers, or pathogen population can also serve as biological indicators of soil quality.

4. Soil-water characteristics for cassava production

Water is a major constituent of living plant tissues, which consist of about 90% water, and all biological processes within the living plants depend on it [5]. Water is regarded as the most important of the four soil physical factors that affect plant growth (mechanical impedance, water, aeration and temperature) [29]. The optimal moisture conditions for any crop vary depending on many factors such as soil type, climate conditions, growth rate and habit, etc. [30]. The water movement in soils for any given crop production (a case study of cassava) is defined by the soil water characteristic curve.

The soil-water characteristic curve (SWCC) defines the relationship between (pore water suction) matric suctions (ψ) and water content [gravimetric (w) or volumetric (θ) or degree of saturation (S)] [31]. The soil-water characteristics (also known as the soil-water retention or desorption curve) can be described as a measure of the water holding capacity (i.e. storage capacity) of the soil as the water content changes when subjected to various values of suction. SWCC is an indication of the ability of the soil to release water for plants use. The soil-water characteristics are a conceptual and interpretative tool through which the behaviour of unsaturated soils can be understood. As the soil moves from the saturated state to drier states (unsaturated states), the distribution of the soil, water and air phases changes as the stress state changes. The relationships between these phases take on different forms and influence the engineering properties of unsaturated soils [32–34].

Generally, the curve is a function of soil texture and soil structure. The graph of SWCC can be used to obtain the field capacity (FC) and the permanent wilting point (PWP). The curve also explains how different soil structures will hold and release water. From the SWCC curve (**Figure 5**), it can be deduced that a fine-textured soil (like peats) will hold more water at FC and PWP than a coarse-textured soil (sand). The relationship between pore water suction and water content, as presented in a SWCC, is one fundamental relationship used to describe unsaturated behaviour of a soil. Suction is inversely proportional to the water content in a soil. Suction generally increases as the soil desaturates. Increasing suction generally results in high resistance to flow and increase in effective stress. Desiccation is a by-product of the increased effective stress [36]. Increasing suction in compacted clays due to decrease in water content modifies the flow behaviour of covers. During desiccation, the saturation of a liner is reduced and the remaining pore water is held at increasingly large suction.

The relationship between saturation and suction during desiccation is described using the SWCCs. Knowledge of suction and corresponding water content in the soil can be used to predict cracking potentials of liners. The onset and resulting amount of cracking can be correlated to a soil-specific critical suction level [31]. Hence, the SWCC provides critical input to the design of a compacted clay cover liner due to its potential impact on flow rates and the desiccation

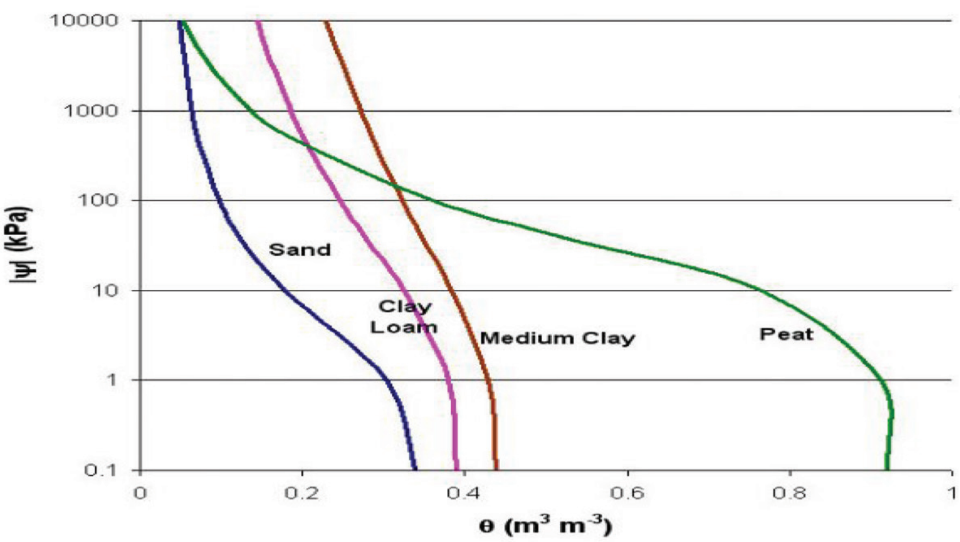

Figure 5. Soil moisture retention curve [35].

process. More so, Hillel [37] reported that the shape of the SWCC is a function of the soil type. Soils with smaller pores have higher air entry pressure (ψa). Soils with wider ranges of pore sizes exhibit greater changes in matric suction with water content. The SWCCs of compacted clay soils depend on the compaction water content, compactive effort and plasticity index [31].

5. Classification of soil water

Water occurs in the soil pores in varying proportions. Some of the definitions related to the water held in the soil pores are as follows:

1. *Gravitational water*: A soil sample saturated with water and left to drain the excess out by gravity holds on to a certain amount of water. The volume of water that could easily drain off is termed as the gravitational water (**Figure 6**). This water is not available for plant use as it drains off rapidly from the root zone.
2. *Capillary water*: The water content retained in the soil after the gravitational water has drained off from the soil is known as the capillary water. This water is held in the soil by

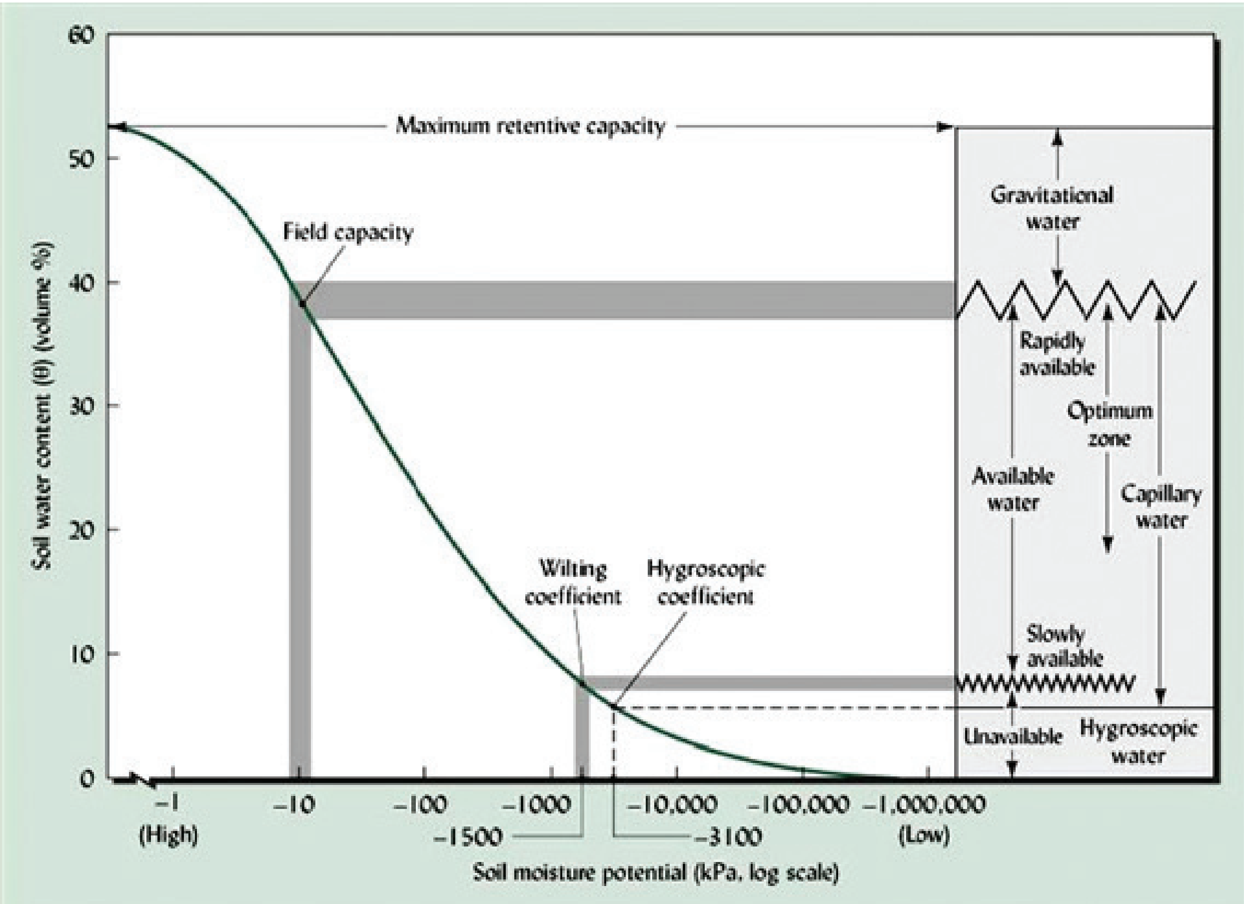

Figure 6. Soil-water movement [39].

http://dx.doi.org/10.5772/intechopen.71968

surface tension. Plant roots gradually absorb the capillary water and thus constitute the principle source of water for plant growth.

3. *Hygroscopic water*: The water that an oven dry sample of soil absorbs when exposed to moist air is termed as hygroscopic water. It is held as a very thin film over the surface of the soil particles and is under tremendous negative (gauge) pressure. This water is not available to plants.

The above definitions of the soil water are based on physical factors. Some properties of soil water are not directly related to the above significance to plant growth. These are discussed next.

6. Soil-water constants

For a particular soil, certain soil-water proportions are defined which dictate whether the water is available or not for plant growth. These are called the soil-water constants. The soil-water constants refer to the different stages of moisture in the soil as one moves from a wet soil to a dry soil (i.e. from saturated to unsaturated soil condition). These constants are described below:

A. *Saturation capacity*: This is the total water content of the soil when all the pores of the soil are filled with water. It is also termed as the maximum water holding capacity of the soil. At saturation capacity, the soil moisture tension is almost equal to zero.

B. *Field capacity*: This is defined as the maximum amount of water that a soil will hold against the influence of gravity or gravitational force, when downward movement of water has ceased completely. It is the water retained by an initially saturated soil against the force of gravity. Hence, as the gravitational water gets drained off from the soil, it is said to reach the field capacity. At field capacity, the macropores of the soil are drained off, but water is retained in the micropores. Though the soil moisture tension at field capacity varies from soil to soil, it is normally between 0.1 (for clayey soils) and 0.3 (for sandy soils) atmospheres. Field capacity is the upper limit of soil available water.

C. *Temporary wilting point*: This denotes the soil water content at which the plant wilts at day time but recovers during night or when water is added to the soil. It is also referred to as *incipient wilting* or *partial wilting*. At this wilting point, the cassava plants fold their stomata through which water is lost to the atmosphere. This folding is pronounced in the day during periods of active solar radiation. Temporary wilting also denotes that the amount if water the plant is losing to the atmosphere (transpiration demand) is higher than the amount of water the plant roots are able to tap from the soil.

D. *Permanent wilting point*: This refers to the amount of water present in the soil when the soils can no longer supply water at fast sufficient rates to prevent the plants or crops from wilting permanently. Moisture under this condition is not available for the plant roots because the water is present in the latex and not the pores through which the roots elongate. The amount of water a soil at permanent wilting point is a function of soil texture (**Figure 5**). A fine-textured soil (like clay) will hold more water than sand (coarse textured) at this moisture condition. However, soil matric potential at permanent wilting point ranges from −10 bars to −20 bars with an average of −15 bars. A highly coarse-textured soil will have −10 bars, while a fine-textured soil will have −20 bars at the same moisture condition.

NB: For cassava (or any crop) production, it is imperative that for sustainable increase in production levels, the soil condition should never be allowed to reach the permanent wilting point, as this will be very detrimental to output returns. In addition, depending on the prevailing soil and climatic conditions, there may be need to incorporate organic matter and irrigation operations in order to raise the water table of the soil to the root depth of the crop and consequently meet the crop water requirement of the crop for optimum growth and development.

E. *Soil available water*: This is the zone at which water is made available to plant roots. It is the amount of water a soil holds between field capacity and permanent wilting point. The soil available water is the zone that is targeted during irrigation. As earlier maintained under field capacity and permanent wilting point, the soil texture influences greatly the amount of water available to plants at this moisture condition (**Figure 5**). Fine-textured soils will possess more soil available water than coarse-textured soils.

7. How soil holds water

Soil holds water in two ways: (1) as a thin film on individual soil particles and (2) as water stored in the pores of the soil. Water stored as a thin film on individual soil particles is held in place by adsorption forces. Adsorption involves complex chemical and physical reactions, but in simple terms, a thin film of water adheres to the outside layers of soil particle molecules. Water stored in the pores of the soil is stored by capillary forces. An example of the capillary force phenomenon would be to place one end of a glass capillary tube in a pan of water. Water in the tube will rise to a certain height, which depends on the diameter of the capillary tube. This phenomenon can act in any direction and is the key to water being stored in soil pores.

8. Soil-water tension

The soil-water tension simply refers to the amount of water retained [38]. The availability of soil moisture is now frequently described in terms of soil moisture tension, which is dependent upon surface forces, and in terms of total soil moisture stress, which includes surface and other forces arising from the presence of solutes in the soil solution. Soil-water tension (also known as soil-water potential) determines the ease by which water can be extracted from the soil. These are equivalent values, except for the sign (negative vs. positive), which might be thought of as either a push or a pull on the water. Water being held in pores by the capillary storage is held in the soil at a certain tension. The same is true for water held with the adsorption phenomenon.

http://dx.doi.org/10.5772/intechopen.71968

As the soil dries, these tensions become larger. It is easier for a plant to extract water being held at lower tensions. Plants develop the tension, or potential, to move water from the soil into the roots and distribute the water through the plant by adjusting the water potential, or tension, within their plant cells. For water to move from soil, into roots, into stems, into leaves and finally into air, the water potential must always be decreasing.

Under waterlogged condition, the soil matric potential is zero ($\psi = 0$). This waterlogged condition is not favourable for cassava production. This is due to the inability of the crop to absorb nutrients from the soil as a result of poor respiration which tends to limit the crop energy potentials. Also the cassava plant cannot carry out other physiological processes like photosynthesis. At saturation, the soil-water tension is approximately 0.001 bars; it would therefore be easy for a cassava plant to extract water from a saturated soil [40]. Also, the dividing point between the available soil-water content and readily available soil-water content is named the *maximum allowable depletion*, or MAD, soil-water content. For most field crops like cassava, yam, etc., the MAD level is usually defined as about 50% available water. In some water-sensitive crops, such as vegetables and flowers, the MAD level may be less, such as 30% available water.

The water requirements of cassava at each developmental stage known as the *crop water requirement* greatly influence the need to adjust the water characteristics of the soil in order to ensure optimum growth and productivity of the crop. It has been already established that different soil types pose different soil-water properties, hence, ensuring that the adequate soil type which presents the best soil-water content at field capacity and wilting points is used for cassava production, if yield of the crop is to be improved upon, as water plays a major part in the first 4 months of the crop's development. Majumdar [41] reported that the optimum soil moisture requirement for tall wheat is from the field capacity to 50% of availability; the optimum soil moisture for barley ranges from the field capacity to 40% of availability; the optimum soil moisture for maize range is from 100 to 60% of availability in the maximum root zone depth which extends from 0.4 to 0.6 on different soil types, while for cassava, it ranges from field capacity to 50% of water availability in the maximum root zone, which extends to about 0.5–0.75 m in depth.

9. Soil, water and cassava production in tropical soils of Nigeria

Soil–plant-water relations refer to the physical properties of soil and plants that affect the movement, retention and use of water. These relations must be considered in designing an operation system. Soil is a store house of plant nutrients, a habitat for bacteria, an anchorage for plant and a reservoir that holds the water needed for plant growth. The amount of water a soil can hold in available form for plant use is determined by its physical properties. This amount determines the length of time a plant can survive without water being added. It determines both the frequency of irrigation and the capacity of irrigation system needed to ensure continuous crop growth. Soil is a three-phase system comprising the solid phase (made of mineral and organic matter and various chemical compounds), the liquid phase (called soil moisture) and the gaseous phase (called the soil air). They also contain variety of living an organisms.

Plant growth depends on two important natural resources—soil and water [38, 40]. The soil provides the mechanical support and nutrient reservoir necessary for plant growth. Water is essential for plant life processes. Soil acts like a reservoir that holds water and nutrients that plants need to grow. Some soils are large reservoirs with more holding capacity that releases water and nutrients easily to plants, while other soils have limited reservoirs (**Figure 5**). Effective management of these resources for cassava production in Nigeria necessitates a detailed understanding of the synergy between soils, water and plants by the crop producer. Knowledge of the soil physical and hydrological properties can influence the decision-making process, such as determining what crops to plant and when to irrigate. Cassava (like most other arable crops) has varying water needs at different stages of growth. While the plant is young, it requires less water than when it is in the reproductive stage. As a plant approaches maturity, its water needs drops.

Two important physical properties of soil, which differ the supply of water and air in soil, are texture and structure. Soil texture refers to the relative proportion of sand, silt and clay in a given volume of soil. The texture of the soil delineates the degree of fineness or coarseness of a soil as determined by the percentage of sand, silt and clay contained in the soil. The arrangement of these soil separates (sand, silt and clay) determines the size of pores in the soil. This lays credence to the reason why clay soil will hold more water than sandy soil in the same period. Soil structure on the other hand refers to the arrangement of soil separates into units called aggregates (which contain solids and pore spaces).

The arrangements of the soil separates into aggregates (known as soil structure) will determine the proportion of the macropores (large pores, non-capillary pores and/or air pores) and micropores (small pores, capillary pores and/or water pores) in the soil. Sandy soils with larger soil particle sizes will tend to have more preponderance of large or macropores due to the coarseness of the soil. This limits the amount of water it can hold. Conversely, clay soils that are characterised by high proportion of micropores which serve as pathways for water movements will tend to hold more water at the same period (**Figure 5**). Nevertheless, in tropical regions of sub-Saharan Africa, where the soils are highly heterogenous, the prevailing soil and environmental conditions will determine the amount of water available for cassava or any crop production. Cassava as a root crop requires a substantial amount of moisture in the first 3–4 months of its growth; hence, soils with high water holding capacity culminating in high water table for the root absorption are highly essential for optimum production. However, waterlogged conditions must be avoided.

Nigeria is a nation comprising various vegetation zones that differ in their soil and climatic characteristics. Cultivation of cassava in these diverse agro-ecologies has yielded varying quantities of cassava in different geopolitical zones in nation. The FAO statistics [8] noted that on a per capita basis, North-Central was the highest producing state at 0.72 tonnes per person, followed by South-East (0.56), South–South (0.47), South-West (0.34), North-West (0.10) and North-East (0.01).

Also, earlier reports from the International Institute of Tropical Agriculture in 2004 noted Cross River in the South–South geo-political zone as well as Benue and Kogi state in the North-Central zone were the largest producers of cassava in Nigeria (**Figure 7**). The study attributed the results to the management techniques and prevailing soil and climatic conditions. Cassava

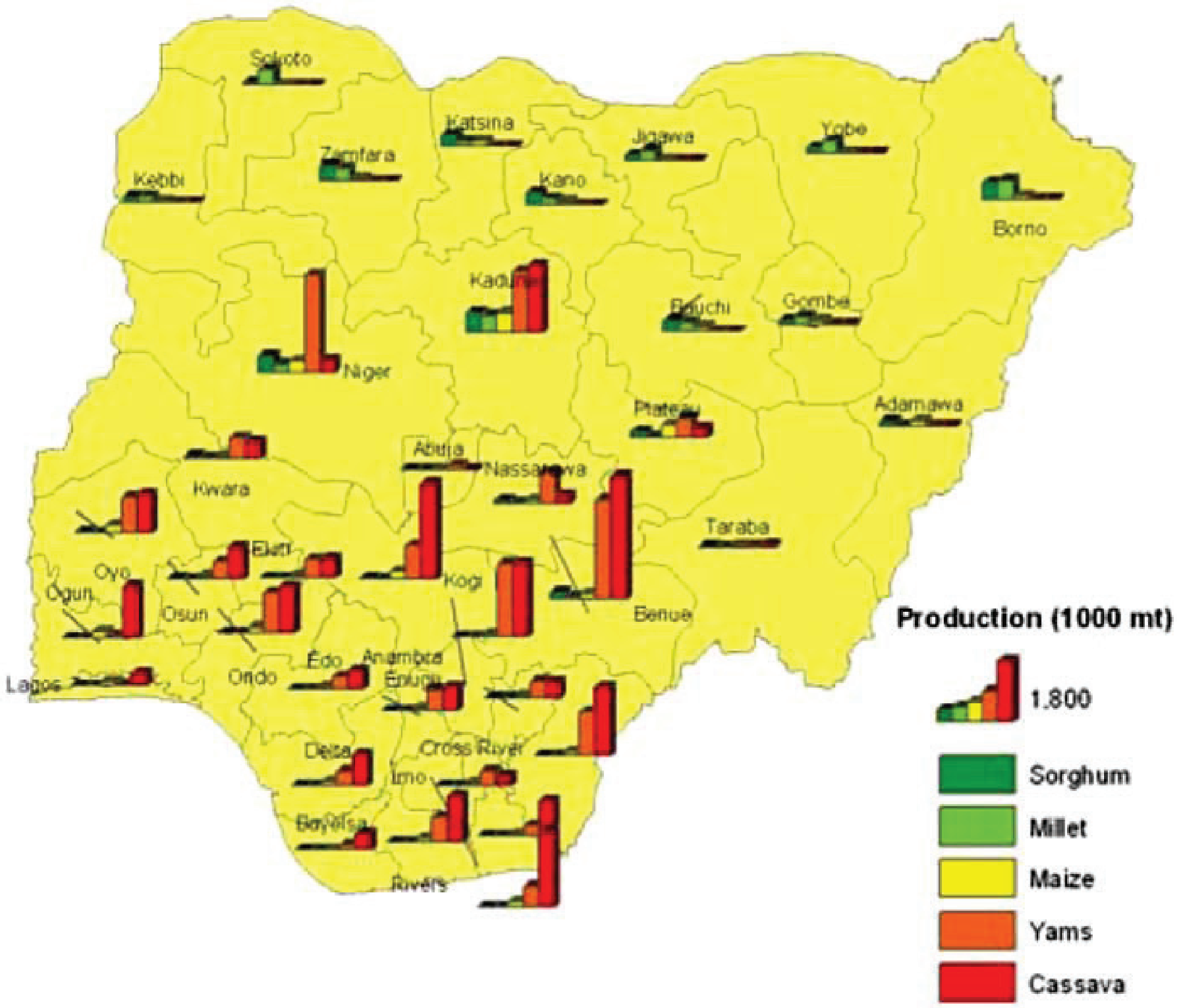

Figure 7. Crop production by Nigerian states [42].

Figure 8. Harvested cassava roots in sub-Sahara Africa [44].

yields favourably in acidic soils with high organic matter content. Hillel [43] maintained that soils with high organic matter content tend to hold more water with good aeration and contain more nutrients and beneficial microbial population, culminating in a good soil structure. This entails that such soils which are predominantly medium-textured soils are of high quality and presents the best inherent soil physical condition for cassava production in view meeting the food demands of the rising population in Nigeria. Hence, to combat the rising issues of food security in sub-Saharan Africa (particularly in Nigeria), the use of soils with good quality and water characteristics, juxtaposed with adequate soil management, are essential in obtaining sustainable cassava production (**Figure 8**) in this region of the world in light of the increasing scores of persons and animal population.

10. Summary

Soil-plant-water relation entails the physical properties of soil and plants that affect the movement, retention and use of water. Two important physical properties of soil, which influence the supply of water and air in soil for crop production, are soil texture and soil structure. Increasing cassava production outputs is extremely important in the face of a growing global population, but equally essential is ensuring that the correct quantity and quality are produced and distributed and in an environmentally sustainable manner with improved soil and water conditions. Cassava production in the wake of the brunt population increase in tropical regions of sub-Saharan Africa like Nigeria has been greatly affected by poor soil and water quality, which are intrinsic properties for sustainable optimum crop production. The varying effects of soil and water quality as well as the synergy of soil-water and crop play an important role in the lifecycle of cassava and ensure optimum production on a sustained basis. This chapter reviewed and discussed soil quality and its assessment methods, soil-water characteristics and the relationship between the soil, water and crop for soil quality management and the sustainable optimum production of cassava in tropical Nigeria.

Author details

Saurau O. Oshunsanya* and Nkem J. Nwosu

*Address all correspondence to: soshunsanya@yahoo.com

Department of Agronomy, University of Ibadan, Ibadan, Oyo State, Nigeria

References

[1] Gbadegesin AS. Variation in soil properties on cassava production in the coastal area of Southern Cross River State, Nigeria. Journal of Geography and Geology. 2010;**3**:94-103

[2] Oniya OO, Opadijo OO, Odedare KO, Oduyemi AT. Soil Suitability Analysis for Cultivation of Cassava in Ibarapa Central LGA: A GIS Approach. Japan: CIGR International Commission of Agricultural and BioSystems Engineering. 2009. p. 8

[3] Soil Science Society of America (SSSA). Glossary of Soil Science Terms. Madison, WI: Soil Science Society of America; 1996

[4] Lal R. Basic concept and global issues: Soil quality and agricultural sustainability. In: Lal R, editor. Soil Quality and Agricultural Sustainability. Chelsea, MI, USA: Ann Arbor Science; 1998. pp. 3-12

[5] El-Shal ZS, Soad ME. Response of cassava plant to water requirements and the levels of organic manure. Journal of Plant Production. 2012;**3**(7):2211-2222

[6] International Institute for Tropical Agriculture. Cassava in Tropical Africa: A Reference Manual. Wisbech, UK: Balding and Mansell International; 1990. 184 pp

[7] International Food Policy Research Institute. In: Sebastian K, editor. Atlas of African Agriculture Research and Development: Revealing Agriculture's Place in Africa. Washington, DC, USA: A Peer-Reviewed Publication of the International Food Policy Research Institute; 2014. 90 pp

[8] FAO. FAOSTATS—World Production of Cassava. Rome, Italy: Food and Agricultural Organisation of the United Nations; 2014

[9] Doran JW, Coleman DC, Bezdicek DF, Stewart BA. Defining soil quality for a sustainable environment. Soil Science Society of America Special (SSSA) Publication, No. 35. Madison, WI: Soil Science Society of America Incorporation and American Society of Agronomy Incorporated; 1994

[10] Larson WE, Pierce FJ. The dynamics of soil quality as a measure of sustainable management. In: Doran JW, Coleman DC, Bezdicek DF, Stewart BA, editors. Defining Soil Quality for a Sustainable Environment, SSSA Special Publication 35. Madison, WI, USA: Soil Science Society of America; 1994. pp. 37-51

[11] FAO. Strategic Environmental Assessment. Food and Agriculture Organisation Corporate Document Repository. Rome, Italy: FAO; 2017

[12] Ojiako IA, Tarawali G, Nze L, Ogundijo D, Edtet M, Audu B, Adenekan S. Root's supply response for smallholder farmers supplying cassava to commercial starch processors in Nigeria. Asian Journal of Rural Development. 2017;**7**:1-14

[13] Anyanwu CN, Ibeto CN, Ezeoha SL, Ogbuagu NJ. Sustainability of cassava (*Manihot esculenta Crantz*) as industrial feedstock, energy and food crop in Nigeria; 2015

[14] Gbadegesin AS, Abua MA, Atu JE. Variation in soil properties on cassava production in the coastal are of southern Cross River state. Nigerian Journal of Geographical Geology. 2011;**1**:94-103

[15] Anikwe MAN, Obi ME. Evaluation of an index model for quantifying the productivity of soils in southeastern Nigeria using maize as a test crop. Journal of Agriculture and Environment. 1999;**1**:80-89

[16] United State Department of Agriculture. Soil Quality Glossary. Washington, DC: USDA National Resource Conservation Service; 2006

[17] Papendick RI, Parr JF, van Schnilfgaarde J. Soil Quality: New Perspective for a Sustainable Agriculture. In Proceeding International Soil Conservation Organization. New Delhi, India; 1995

[18] Nwosu NJ, Okon PB. Impacts of climate change on soil quality of tropical acid-sands [Unpublished B.Sc project]. Nigeria: Department of Soil Science, University of Calabar; 2016. pp. 44-52

[19] United State Department of Agriculture. Indicators for Soil Quality Evaluation. Soil Quality Information Sheet. USDA National Resource Conservation Service. Washington, DC: USDA – NRC; 1996. 2 pp

[20] Sojka RE, Upchurch DR. Reservations regarding the soil quality concept. Soil Science Society of America Journal. 1999;**63**:1039-1054

[21] Anikwe MAN. Soil Quality Assessment and Monitoring: A Review of Current Research Efforts. Enugu, Nigeria: New Generation Books; 2006

[22] Adeoye GO, Agboola AA. Critical levels for soil pH, available P, K, Zn and Mn and maize ear-leaf content of P, Cu and Mn in sedimentary soils of South-West Nigeria. Fertilizer Research. 1985;**6**:65-75

[23] Wagenet RJ, Hutson JL. Soil quality and its dependence on dynamic physical processes. Journal of Environmental Quality. 1997;**26**:41-48

[24] Reganold JP, Palmer AS. Significance of gravimetric versus volumetric measurements of soil quality under biodynamic, conventional, and continuous grass management. Journal of Soil and Water Conservation. 1995;**50**:298-305

[25] Karlen DL, Eash NS, Unger PW. Soil and crop management effects on soil quality indicators. American Journal of Alternative Agriculture. 1992;**7**:48-55

[26] Abua MA. Suitability assessment of soils for cassava production in the coastal and hinterland areas of southern Cross River state—Nigeria. Journal of Science and Environmental Management. 2015;**6**(5):108-115

[27] Kennedy AC, Papendick RI. Microbial characteristics of soil quality. Journal of Soil Water Conservation. 1995;**50**:243-248

[28] Visser S, Parkinson D. Soil biological criteria as indicators of soil quality: Soil microorganisms. American Journal of Alternative Agriculture. 1992;**7**:33-37

[29] Kirkham MB. Principles of Soil and Plant Water Relations. USA: Elsevier Academic Press; 2005. pp. 1-39

[30] Singh R, Alderfer RB. Effects of soil—Moisture stress at different periods of growth of some vegetable crops. Soil Science. 1966;**1**(1):69

[31] Osinubi KJ, Bello AA. Soil-water characteristics curves for reddish Brown tropical soils. Electronic Journal of Geotechnical Engineering. 2011;**16**:1-25

[32] Fredlund DG, Rahardjo H. Soil Mechanics for Unsaturated Soils. New York: John Wiley and Sons; 1993. 560 pp

[33] Fredlund DG. The emergence of unsaturated soil mechanics. The Fourth Spencer Buchanan Lecture. College Station, Texas: Texas A and M University; 1996. 39 pp

[34] Vanapalli SK, Fredlund DG, Pufahl DE. The influence of soil structure and stress history on the soil-water characteristics of a compacted till. Geotechnique. 1999;**49**(2):143-159

[35] Hob D. Soil porosity and water retention. An e-publication of cactiguide.com. 2006. http://cactiguide.com/forum Yesiller /viewtopic.php?t=13438. [Accessed: 21 July 2017]

[36] Miller CJ, Yesiller N, Yaldo K, Merayyand S. Impact of soil type and compaction conditions on soil water characteristic. Journal of Geotechnical and Geoenvironmental Engineering, ASCE. 2002;**128**(9):733-742

[37] Hillel D. Fundamentals of Soil Physics. San Diego, CA: Academic Press Inc; 1980

[38] Oshunsanya SO. Soil Physics. Ibadan: Debank Publishers; 2011. 161 pp

[39] Lajos B. Soil Moisture Retention Curve. 2008. E-page: http://www.tankonyvtar.hu/en/tartalom/tamop425/0032_talajtan/ch07s05.html. [Accessed: 21 July 2017]

[40] Rogers DH, Aguilar J, Kisekka I, Barnes PI, Lamm FR. Soil, water and plant relationships. Kansas State University Research and Extension. Irrigation Management Series, L904; Kansas State, USA: Kansas State University Agricultural Experiment Station and Cooperative Extension Service; 2014. 8 pp

[41] Majumdar DK. Irrigation Water Management. India: Prentice Hall; 2000. 18 pp

[42] FAO. FAOSTATS. Rome, Italy: Food and Agricultural Organisation of the United Nations; 2002

[43] Hillel D. Introduction to Environmental Soil Physics. Amsterdam: Elsevier Academic Press; 2004. 494 pp

[44] FAO. FAOSTAT. Rome, Italy: Food and Agriculture Organisation of the United Nations; 2012