



Strength and hydraulics characteristics variations within a tropical Alfisol in Southwestern Nigeria under different land use management

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ABSTRACT

This study investigated the hydraulics and strength characteristics of an Alfisol under long-term land use in Akure, southwestern Nigeria. The three agricultural land uses under study are Cropland, Grazing land, and Oil palm plantation. Hydraulic conductivity tests were randomly conducted at 60 sampling points per location (10 m apart), to make a total of 180 samples from the three land uses, while the unconfined compressive strength (q_{uf}) and vane shear strength measurement were conducted in the laboratory and insitu, respectively on soil at depths up to 45 cm (i.e. 0–15, 15–30, and 30–45 cm). The hydraulic conductivity and soil water sorptivity were determined using mini disk infiltrometer at a steady-state flow of –0.5, –1 and –2 cm water suction rates. Land use and land cover change significantly affected the hydraulic and mechanical properties of the soil ($p \leq 0.001$, $p \leq 0.01$ and $p \leq 0.05$). The hydraulic conductivity value showed an increasing trend from the grazing land to cropland and oil palm plantation in the order: grazing land (4.72 cm h^{-1}) < cropland (10.80 cm h^{-1}) < oil palm plantation (13.21 cm h^{-1}). Grazing land recorded the highest mean soil water sorptivity value, while oil palm plantation had the least value. Grazing land had the highest average q_{uf} and shear strength among the land use types at depths 0–15 cm, 15–30 cm and 30–45 cm of soil. Depth-wise consideration showed that in all the land uses, unconfined compression strength (q_{uf}), shear strength and vane shear strength significantly increased with depth. Soil properties such as organic matter content, bulk density, and aggregate sizes influence the infiltration and strength characteristics of soils of the study area. Land uses influenced the hydraulic properties and strength characteristics of agricultural soils and therefore, assessment of changes in soil properties under land use types should be conducted periodically to effectively monitor the soil status over time. This will guide decisions on measures adoptable to ensure the sustainability of soil structure and texture for optimum crop productivity.

1. Introduction

Extensive land use changes and soil management practices throughout the world have resulted from rapidly increasing human populations and their needs/uses of the land for various agricultural activities (Cunningham et al., 2005). Human, animal activities, as well as use of machine for soil tillage purposes over the years, have affected soil biodiversity and its physical properties that control water movement and retention in the soils (Tilahun, 2007). Soil deformation and degradation by compaction and shearing, as well as erosion by water, are considered as the most harmful processes in agriculture and in forestry (Horn, 2003). Most of the soil compaction at the farm level is caused by the use of heavy-duty machinery, pressure from wheels, occasional vehicular traffic on the field especially during the movement of men and materials into and outside of the field during planting and harvesting operations, respectively, trampling

by animals, frequent use of chemical fertilizers and ploughing at the same depth for many years (Mulholland and Fullen, 1991; Davies et al., 1992; Milne and Haynes, 2004; Batey, 2009). Soil deformation by compaction and shearing as a result of intensive agriculture with heavy machinery alters soil structure, pore size distribution and the connectivity of the pore network (Vogeler et al., 2006; Batey, 2009). The mechanical impact of animal hooves on soil surface through the external forces applied by treading and trampling can also be a severe disturbance on topsoil structure (Gifford and Hawkins, 1978; Greenwood et al., 1997; Drewry, 2006), which changes the form and stability of soil aggregates, resulting in changes in bulk density and soil strength, among other properties (Taboada et al., 2011). Soil compaction also could lead to increased risk of surface runoff and erosion due to decreased rainwater infiltration in humid areas (Lipiec and Hatano, 2003). Furthermore, loss of porosity, loss of water and nutrient loss, increased soil bulk density and increased soil penetration resistance that

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impedes root growth are some of the characteristics of compacted soil (Lipiec and Hatano, 2003). As a result, reductions in rooting depth and reduced water and nutrient uptake may impair crop growth, yield and quality (Batey and McKenzie, 2006). All these occurrences explain the importance of the study of soil compaction considering its impacts on soil structure, strength and hydraulic properties.

Soil strength is a measure of soil compaction because it reflects soil resistance to root penetration (Hamza and Anderson, 2003). As soil strength increases, the plant roots must exert greater force to break all impediments to root growth, which often cause reduction to plant productivity. The strength of the soil can change in a systematic way with changes in its moisture content and density. Soil susceptibility to compaction can be measured on the basis of soil shear strength and mechanical impedance. Since the state of compactness is an important soil structural attribute, there is the need to find a measure for its characterization, such as relative bulk density, that gives directly comparable values for all soils (Hakansson and Lipiec, 2000). However, in all soils the bulk density should be determined at standardized moisture contents, to prevent problems caused by water content variations (Hakansson and Lipiec, 2000).

Assessment of soil hydraulic properties is an important step in understanding the water dynamics and solution transport in the soil matrix (Olorunfemi and Fasinmirin, 2017) and thus a range of key biogeochemical processes in the earth's critical zone should be studied (Lin, 2010; Jarvis et al., 2013). The soil water dynamics are of fundamental importance for many applied questions in the fields of crop production and agronomy (Schwen et al., 2011a). The fundamental importance of soil hydraulic conductivity is reflected in its effects on soil fertility, soil aeration, soil temperature, drainage, irrigation and cultivability (Várallyay, 2005). As such, increased infiltration and water retention especially within the vadoze zone are important factors that determine crop productivity and soil loss (Haruna et al., 2018). Soil hydraulic properties are equally important for modelling hydrological processes and related contamination transport (Xu et al., 2009; Olorunfemi and Fasinmirin, 2017). Thus, knowledge of soil hydraulic conductivity (k) is a key element in many applications dealing with environmental studies by indicating how quickly water will infiltrate when applied to a given field or soil type. However, soil hydraulic properties are active and changing, this is due to cultivation practices affecting its processes dynamically in space and time with consequences for the storage and movement of water, nutrients, and pollutants, and for plant growth (Strudley et al., 2008; Schwen et al., 2011b). The three categories of factors affecting hydraulic properties are soil, soil surface and agricultural management (Lekamalage, 2003). Soil hydraulic conductivity depends on a number of factors such as soil moisture content, texture, number of pores and pore continuity (Das Gupta et al., 2006). Likewise, human activities such as agricultural practices (ploughing and sowing), land use related to deforestation or reforestation of abandoned agricultural land can significantly affect topsoil and first layers soil properties and so hydraulic properties (Gonzalez Sosa et al., 2010). In addition, factors such as rainfall, irrigation, wetting/drying cycles, biological activity, and most especially agricultural operations and cropping systems change the structure of soil top layers over time (Leij et al., 2002; Mubarak et al., 2009). Agricultural sustainability requires periodic evaluation of soil hydraulic and compaction status, which is important in understanding factors that impose serious constraints to increased crop production under different land use types and guide the adoption of suitable land management practices. Therefore, research dealing with soil hydraulic properties under various land use management is of great interest as the evaluation of the soil properties affecting them is essential for understanding the influences of human activities on soil water movement and possible implications for livelihoods.

Many studies have assessed the impacts of loadings and machinery passes (Hakansson et al., 1987, 1988; Okhitin et al., 1991; Slowin'ska-Jurkiewicz and Domzal, 1991; Defosse and Richard, 2002; Horn and

Fleige, 2003; Horn, 2003; Pytko, 2005; Botta et al., 2006; Peth et al., 2010; Fasinmirin and Adesigbin, 2012), animal trampling and treading (Chanasyk and Naeth, 1995; Singleton and Addison, 1999; Franzluebbers and Stuedemann, 2008; Fernández et al., 2010; Taboada et al., 2011) and tillage operations on soil compaction and strength (e.g., Ra'tonyi, 1998; Osunbitan et al., 2005; Vogeler et al., 2006). Likewise, land use management effects on saturated hydraulic conductivity and hydrological flow paths has been the focus of many researches in the last decades (Hanson et al., 2004; Zimmermann et al., 2006; Chaves et al., 2008; Germer et al., 2010; Hassler et al., 2011). Studies by Giertz and Diekkruger (2003) and Giertz et al. (2005) on the effects of land use change on soil physical properties and hydrological processes were carried out in the sub-humid tropical environment of West Africa. However, the literature clearly shows that the impact of different land use practices on soil strength and hydraulic properties is not consistent across locations, soils, and experiment designs. Understanding the soil compaction process has posed a great challenge to scientists, engineers, and farmers because of the complex character and infinite variability of soils. Moreso, long term land use change effects on soil strength and hydraulic characteristics under croplands, plantations and grazing lands are still not well documented and there is also generally a need for insitu measurements of various land uses induced-changes in soil hydraulic properties and strength in the humid rainforest of Nigeria in the Tropical Africa. Despite the emphasized importance of the study of land use and land cover changes, basic information on soil hydraulic conductivity status in relation to the strengths of the soil of different agricultural land use needs to be investigated. This is particularly needed in agricultural soils since the penetration of plant roots into soils for water and nutrients uptake depend on the strength of the soils.

Therefore, the aims of this research were to:

- i quantify and compare the effects of different land use management (cropland, plantation, and grazing land) on strength and hydraulic characteristics of soil;
- ii examine the relationship between soil strength, hydraulic characteristics and soil physicochemical properties for a better understanding of which soil parameters affect soil strength and hydraulic characteristics;
- iii identify the impacts of soil compaction on the hydraulic characteristics of the soils (i.e. unsaturated hydraulic conductivity and soil water sorptivity).

2. Materials and methods

2.1. Study Area

The research was conducted at the commercial Farm Site of the Federal University of Technology, Akure, Nigeria, which covers a total land area of approximately 25 ha. The site lies within the humid region of Nigeria at latitude 7°16'N; longitude 5°13'N. Akure has a land area of about 2303 sq km. Akure lies in the rain forest zone of Nigeria with a mean annual rainfall of between 1300–1600 mm and with an average temperature of 27 °C. The relative humidity ranges between 85 and 100% during the rainy season and less than 60% during the dry season period. The soil of the site is predominantly sandy clay loam and belongs to the Alfisol (Soil Survey Staff, 1999) or Ferric Luvisol (FAO, 2006).

2.2. Experimental procedure and soil sampling

Three agricultural land uses (treatments) were chosen for the experiment which include Cropland (latitude 7°30'08"N and longitude 5°15'04"E), Grazing land (latitude 7°30'31"N and longitude 5°12'44"E) and Oil palm (*Elaeis guineensis*) plantation (latitude 7°30'06"N and longitude 5°13'15"E). The cropland (2.5 ha) has been put under conventional tillage operation

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