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# Land use management effects on soil hydrophobicity and hydraulic properties in Ekiti State, forest vegetative zone of Nigeria

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ABSTRACT

This study was conducted to characterize soil hydrophobicity, unsaturated hydraulic conductivity and sorptivity under different land uses (i.e croplands, plantation agriculture and natural forests) and soil types in southwestern Nigeria. In this study, a total of 105 different points in 35 different locations comprising of the 3 land uses were sampled in the study areas. Random sampling pattern of 3 sampling points per sample location were carried out and undisturbed soil samples were collected at depths up to 15 cm from the different locations. Handheld mini disk infiltrometer at a steady-state flow of −2 cm water suction rate was used to determine the unsaturated hydraulic conductivity, water and ethanol sorptivity at each land use site. In addition, the effects of antecedent soil moisture contents (MC), soil bulk density (BD), total porosity (PT), soil water holding capacity (WHC), organic matter content (SOM), and cation exchange capacity (CEC) on soil hydrophobicity, unsaturated hydraulic conductivity and sorptivity were determined. The mean hydrophobicity index, R, showed a decreasing trend in the order: natural forest ˃ plantation agriculture ˃ croplands, whereas, mean hydraulic conductivity values showed an increasing trend in the order: natural forest < plantation agriculture < croplands. Hydraulic conductivity resulted to a negative correlation with hydrophobicity among all sampled soils. In all the sampled soils, index of soil hydrophobicity (R) correlated significantly ($p \le 0.01$) with organic matter content, organic carbon and cation exchange capacity (CEC). Soil sorptivity to water correlated negatively with moisture content among all samples at $p \le 0.05$. Soil ethanol sorptivity showed significantly positive correlation with organic carbon, organic matter content and cation exchange capacity among all the soil samples at a $p \le 0.05$. Soil properties such as organic matter content, bulk density, and aggregate sizes influence the infiltration characteristics of soils of the study areas. Findings from this research has provided a better understanding of soil characteristics and water management under different land uses, which will be of utmost usefulness to land managers, growers, hydrologist and soil scientists.



## 1. Introduction

Soil hydrophobicty (water repellency) has become a subject of global concern, with substantial effects on plant production, land use and management (Müller and Deurer, 2011; Vogelmann et al., 2013). Soil hydrophobicity is caused through the production of complex organic acids during the decomposition of organic matter and these complex organic acids are wax-like substances derived from plant material during organic matter decomposition or burning during a hot fire that form a coating over particles of soil (Franco et al., 2000). It is a phenomenon documented in several countries around the world, and can be responsible for enhanced surface runoff, erosion and preferential flow (Vogelmann et al., 2013). Soil hydrophobicity has been documented in cultivated lands, pastures, forests (Doerr et al., 2006) and wildlands (Crockford et al., 1991; Doerr et al., 1996; Lin et al., 1996; Scott, 2000; DeBano, 2000).

Several soil factors affect the origin and severity of soil hydrophobicity one way or another (Cesarano et al., 2016). Some of these factors include organic matter content, soil texture, aggregation state, soil moisture content, fire intensity, and soil pH etc. (Vogelmann et al., 2010; Olorunfemi et al., 2014; Cesarano et al., 2016). The occurrence of soil water repellency or hydrophobicity is not limited to any particular soil type as numerous researches have reported that soil texture i.e. the proportion of different particle sizes (sand, silt and clay) in a soil influences the degree of hydrophobicity (Wallis et al., 1991; Dekker et al., 2005, Lellamanei et al., 2010). Though coarse-textured, sandy soils are most likely to become hydrophobic because of their relatively small surface area per unit of volume (Karnok and Tucker, 2002). The ease of coating of sand by hydrophobic substances (Wallis and Horne, 1992),

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and their susceptibility to acidification favour soil hydrophobicity (Deurer et al., 2011; Schwen et al., 2015). Similar results were found and documented in loamy, peaty clay and clayey peat soils (McGhie and Posner, 1980; Dekker and Ritsema, 1996a, 1996b), as well as in heavy clay soils with grass covers (Dekker and Ritsema, 1996c). Organic matter content has also been shown to have positive correlation with soil water repellency in range of studies (e.g. Berglund and Persson, 1996; Taumer et al., 2005), while others reported little or no relationship (Jungerius and de Jong, 1989; Doerr et al., 2005; Doerr et al., 2006). Soil pH is another static site-dependent controlling factor for the degree of soil hydrophobicity. Steenhuis et al. (2001); Woche et al. (2005); and Schwen et al. (2015) reported an inverse relationship between soil hydrophobicity and soil pH. The soil moisture is also an important component that can prevent or lead to the formation and persistence of a hydrophobic layer (Olorunfemi et al., 2014). It is the main risk factor responsible for the high variability of this phenomenon in the soil (Hallett, 2008). Subedi et al. (2013) reported that the coating of mineral soil particles or aggregates with partly hydrophobic soil organic matter caused the dependence between soil hydrophobicity and the soil water content. Prolong exposure to critically low water contents causes the arrangement of organic matter in the soil to change (i.e shape of the polar compound changes) so that the hydrophobic surface is exposed to the air/water in soil pores. Whereas under moist conditions, the hydrophilic surface of amphiphilic soil organic matter molecules is exposed to the air/water in soil pores (Olorunfemi et al., 2014; Schwen et al., 2015).

Dekker and Ritsema (1994) established a transition zone or a critical soil moisture zone, defined by two water content thresholds. When soil moisture is above this critical value (which varies for every soil), the water repellency effect is temporarily eliminated but when it falls below this critical value, the soil returns to a hydrophobic condition. In general, the degree of soil hydrophobicity depends mainly on soil texture, quantity and quality of soil organic matter and the soil water content (Keck et al., 2016). These findings revealed that hydrophobicity is not an isolated curiosity as it has been found in soils all over the world (Dekker et al., 1999; Franco et al., 2000; Scott, 2000; Doerr et al., 2003). Wallis and Horne (1992) equally reported soil hydrophobicity under a range of crops and cropping systems (Wallis and Horne, 1992). Thus, it should be a point of concern in the rain forest region of Nigeria.

Hydrophobic soils repel water, thus, reducing water infiltration into soil. Decreased infiltration into the soil results in damaging flows in stream channels. Erosion increases with greater amounts of runoff, and much of the fertile topsoil layer is lost. Increased runoff carries large amounts of sediment that can spread over lower lying areas, clog stream channels, and lower water quality (Olorunfemi et al., 2014). Few studies have investigated the impacts of soil hydrophobicity on soil hydraulic properties. Bauters et al. (2000) and Lamparter et al. (2010) found a linear relationship between contact angle (quantitative measure of the wetting of a solid by a Liquid) and the air-entry value (inverse of the van Genuchten $\alpha$ parameter) in controlled laboratory investigations on sand and glass beads with different degrees of soil water repellency. Laboratory studies by Arye et al. (2007) and Subedi et al. (2013) also confirmed this relationship. A contact angle of zero represents complete wetting (hydrophilic) while a contact angle $> 90°$ is said to be non-wetting (hydrophobic/water repellent) (van Genuchten and Leij, 1992; Olorunfemi et al., 2014). However, most soils have a certain level of water resistance, where water will infiltrate but at a slower rate than expected as demonstrated by Tillman et al. (1989). These soils have contact angles between 0° and 90°. Schwen et al. (2015) studied the impacts of soil water repellency on effective soil hydraulic characteristics with the perspective to include water repellency effects into advanced soil hydrological models in a beech forest under simulated rainfall. Their findings confirm that the postulated linear relationship between contact angle and the air-entry value is applicable to natural field soils. They also affirmed that increased soil water repellency (SWR) levels strongly reduced near-saturated hydraulic conductivity. Studies by Hallett et al. (2001, 2004); Lamparter et al. (2006) and Orfánus et al. (2008) suggested that the impact of subcritical water repellency (WR) on water sorptivity, conductivity and infiltration rates is underestimated and Lamparter et al. (2006) found subcritically water repellent soils to reduce infiltration rates by a factor of 3 to 170. All these findings explain why the study of hydrophobicity is very important considering its impacts on soil hydraulic properties i.e. soil water sorptivity and unsaturated hydraulic conductivity.

Assessment of the hydraulic properties of soil, such as infiltration and sorptivity, is very important component for the interpretation of the physical characteristics of soil and the management of agricultural practices (Green et al., 2003; Vogelmann et al., 2010). It is an important step in understanding the water dynamic and solution transport in the soil matrix. Soil hydraulic properties reflect the ability of a soil to retain or transmit water and its dissolved constituents (van Genuchten and Leij, 1992). Soil hydraulic properties are also important for modelling hydrological processes and related contamination transport (Xu et al., 2009). Soil hydraulic properties are active and changing, this is due to factors such as rainfall, irrigation, wetting and drying cycles and most especially cropping systems (Mapa et al., 1986). Lekamalage (2003) further reported that soil, soil surface and agricultural management are the three categories of factors affecting hydraulic properties. As human activities, such as agricultural practices (ploughing and sowing) change, land use related to deforestation or reforestation of abandoned agricultural land can significantly affect topsoil and first layers soil properties and consequently hydraulic (Gonzalez-Sosa et al., 2010) and soil water repellency properties. Therefore, research dealing with soil hydrophobicity and hydraulic properties under different land uses 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.

In the literature of tropical soils, large areas in the humid tropics have been subjected to dramatic land use (LU) and land cover (LC) changes over the last few decades (Chang and Lau, 1993; Bonell et al., 2010). Giertz and Diekkruger (2003) and Giertz et al. (2005) assessed the effects of land use change on soil physical properties and hydrological processes in the sub-humid tropical environment of West Africa. Also, the effect of land use on saturated hydraulic conductivity and hydrological flow paths has been the focus of many studies in the last decades (Hanson et al., 2004; Zimmermann et al., 2006; Chaves et al., 2008; Germer et al., 2010; Hassler et al., 2011). Previous studies have also been carried out and documented on soil hydrophobicity in the humid tropical climates (Vogelmann et al., 2010; Cambronero et al., 2011). Vogelmann et al., 2013 reviewed the correlation between origin of soil hydrophobicity and hydro-physical processes and soil properties. Despite these research efforts, there is scarcity of data, typical for tropical soils especially on the soil hydrophobicity and hydraulic characteristics under cropland, plantations and natural forest in the forest vegetative zone of Nigeria. Beyond the above studies, little is known about the effects of soil water repellency on soil hydraulic characteristics and there is generally poor understanding of the soil parameters that affect water repellency, the prediction of its occurrence and severity in the humid tropical region of Nigeria and Africa. The increasing dry climate and reductions in the availability of irrigation water has led to a situation where soil water repellency has emerged as an issue facing gardeners, farmers, land managers, hydrologists, and soil scientists. Given the extensive researches on the prevalence of soil water repellency in the humid temperate regions of the world, and its effects on crop performance or soil erosion, one might expect a higher degree of soil hydrophobicity in terms of prevalence and severity in the tropical regions of Nigeria owing to increasing dry climate. We also expect the degrees of soil hydrophobicity to be very different among the different land uses depending on the various soil factors affecting the occurrence