LAND USE AND SLOPE POSITION EFFECT ON THE HYDROLOGICAL PROPERTIES OF SANDY LOAM SOILS OF KOUPENDRI CATCHMENT, NORTH-WEST OF BENIN †

[USO DE LA TIERRA Y EFECTO DE LA POSICIÓN DE LA PENDIENTE EN LAS PROPIEDADES HIDROLÓGICAS DE LOS SUELOS DE ARENA SUAVE DE LA CAPTURA DE KOUPENDRI, AL NOROESTE DE BENIN]

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SUMMARY

Background. Land use and landscape characteristics influence soil hydrological properties and catchment hydrology. **Objective.** To investigate the effect of land use and slope positions on soil hydrological properties. **Methodology.** The study was done in Koupendri catchment, northwest Benin. The experimental design was a 2x2 factorial scheme replicated ten times. The study considered two land use types and two slope positions. The soil texture was sandy loam with high gravel (50-71%) and low organic carbon (11-18.4 g/kg) contents. **Results.** The Ksat in-situ and steady state infiltration were significantly ($p<0.05$) influenced by land use. Higher Ksat values of 5.33-11.96 cm/h and steady state infiltration (13.53 cm/h) were obtained under fallow shrub-grassland (FSG) compared to 2.21-3.04 cm/h and 3.58 cm/h respectively under tilled maize-beans (MBT). At both daily and 30-minute timescales, the maximum in-situ soil moistures were 0.270cm^3/cm^3 and 0.393cm^3/cm^3, respectively under FSG compared to 0.221cm^3/cm^3 and 0.202cm^3/cm^3 recorded under MBT. The coefficient of variation (CV) of the soil hydrological properties was low (<10%) for BD and porosity, moderate (<30%) for θ_i,θ_f, and Ksat in-situ and very high (>50%) for Ksat-Lab. **Conclusion.** Land use significantly influenced soil hydrological properties and have more control over their variability. In-situ determination of soil hydrological properties significantly reduced their variability.

Keywords: Soil-water management; infiltrometer; hillslope; hydrology; landscape

RESUMEN

Antecedentes. El uso del suelo y las características del paisaje influyen en las propiedades hidrológicas del suelo y en la hidrología de la cuenca. **Objetivo.** Investigar el efecto del uso del suelo y las posiciones de las pendientes en las propiedades hidrológicas del suelo. **Metodología.** El estudio se realizó en la cuenca de Koupendri, al noroeste de Benin. El diseño experimental fue un esquema factorial 2x2 replicado diez veces. El estudio consideró dos tipos de uso del suelo y dos posiciones de pendiente. La textura del suelo era franco arenoso con alto contenido de grava (50-71%) y bajo contenido de carbono orgánico (11-18.4 g / kg). **Resultados.** La infiltración de Ksat in situ y en estado estacionario fue influenciada significativamente ($p <0.05$) por el uso de la tierra. Se obtuvieron mayores niveles de Ksat (5,33-11,96 cm/h) y de infiltración en estado estacionario (13,53 cm/h) en pastizales en barbecho (FSG) en comparación con 2,21-3,04 cm/h y 3,58 cm/h, respectivamente, en frijoles labrados (MBT). Tanto en las escalas de tiempo diarias como en las

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de 30 minutos, las humedades máximas in situ del suelo fueron de 0.270cm3 / cm3 y 0.393cm3 / cm3, respectivamente bajo FSG en comparación con 0.221cm3 / cm3 y 0.202cm3 / cm3 registradas bajo MBT. El coeficiente de variación (CV) de las propiedades hidrológicas del suelo fue bajo (<10%) para BD y porosidad, moderado (<30%) para θ_i, θ_f y Ksat in situ y muy alto (> 50%) para Ksat -Laboratorio. **Conclusiones.** El uso del suelo influyó significativamente en las propiedades hidrológicas del suelo y tiene más control sobre su variabilidad. La determinación in situ de las propiedades hidrológicas del suelo redujo significativamente su variabilidad.
Palabras Clave: Manejo del agua del suelo; infiltrómetro; ladera; hidrología; paisaje.

INTRODUCTION

Sustainable soil and water resources management, and the understanding of the hydrological processes of landscapes, especially hillslopes require measurement of soil hydrological properties. The soil hydrological properties especially hydraulic conductivity, infiltration and soil moisture influences the transport and flow of water, nutrients and pollutants through soils (Bagarello and Sgroi 2007; Kirkham 2005). It is important to note that characterizing catchment hydrological behaviour requires the knowledge of soil hydrological properties. Soil hydrological properties such as hydraulic conductivity and soil moisture vary significantly in space (Daniel et al. 2017; Zhu and Mohanty 2002) and they influence hydrological processes such as runoff generation, groundwater recharge and water retention. Soil moisture dynamics and water retention capacity are important soil hydrological properties that affect flow and transport processes, soil productivity and management. Watershed management commonly aims to enhance water infiltration rather than runoff mainly by improving the soils physical and hydro-physical properties (Brady and Weil 1999). This further ensures that water requirements for crop growth and development are met (Grayson and Western 1998).

Soil hydrological properties especially infiltration capacity and soil water retention are influenced by land use change (Price et al. 2010; Zimmermann et al. 2006). For example, natural forest conversion to cultivated or grazing land has been shown to decrease soil moisture content, infiltration capacity and hydraulic conductivity (Bormann and Klaassen 2008; Schwärzel et al. 2011; Yu et al. 2015; Zimmermann et al. 2006). Research has also shown that agricultural land use and improper soil management practices can significantly reduce soil macro porosity, pore system geometry, infiltration and moisture content, and consequently result to increased surface runoff (Germer et al. 2010; Ndiaye et al. 2007).

Soil hydrological properties are commonly measured in-situ or in the laboratory using soil cores. Determination of soil hydrological properties from laboratory experiments on soil cores has been adjudged to be time consuming and costly (Oliver and Smettem 2005). Also, such determinations do not offer accurate representation of the effective soil hydrological properties that control hydrological processes at large spatial scales (Minasny and McBratney 2002). Thus, field or in-situ methods have received widespread acceptance or preference over laboratory or core methods, especially in soils with high macroporosity. For such soils, measured hydrological properties are usually poor due to the dissection of the continuous macropores by the core walls (Angulo-Jaramillo et al. 2000; Reynolds et al. 2000). Thus, evaluating the effect of land use and catchment configuration on soil hydrological properties requires in-situ measurement of these soil properties.

In situ measurements of infiltration and saturated hydraulic conductivity are typically made using various types of infiltrometers (Angulo-Jaramillo et al. 2000; Reynolds et al. 2002). Compared to other standard tension infiltrometers, the Hood infiltrometer requires little transportation effort, causes minimal soil disturbance during soil surface preparation, and minimizes the effect of contact layer or materials on measured soil hydrological properties (Schwärzel and Punzel 2007). This makes the result obtained with Hood infiltrometer more reliable in comparison to the results from other tension or pressure infiltrometers. For adequate soil water management on hillslopes, information on how slope positions and land management practices affect important soil hydrological properties is indispensable. This study therefore aims to assess the effect of land use and slope position on selected soil hydrological properties of local hillslope of Koupendri catchment using laboratory and field methods.

MATERIALS AND METHODS

Site description

This study was carried out at Koupendri catchment located between latitudes 10°44' to 10°46'N and longitudes 1°08' to 1°11'E (Fig. 1). The study catchment has a relatively flat physiography with few intermittent local hillslopes which influences the hydrology of the catchment. The catchment can be characterized as an undulating pediplain relief overlying a Precambrian crystalline basement. The soils are mostly plinthosol (Azuka et al. 2015) with plinthic horizons. It has a unimodal rainfall distribution pattern with distinct wet (rainy) seasons and dry seasons. The rainy season lasts for about five months, from June to October, with the peak in September while the dry season lasts for seven months, from November to May. Annual rainfall varies between 700 and 900 mm with a mean of 800 mm. Temperature varies between 25˚C and 30˚ C, during the rainy season with a relative humidity above 90 percent in August. However, between March and April, the temperature reaches a maximum of 42˚C. It has Sudanian vegetation dominated by a mixture of grassland and trees/shrubs of low density. The major land use is agriculture which focuses more on grain crops such as maize, sorghum, beans, rice etc., tuber crops such as yam; oil and cash crops such as cotton, and pastoralism (livestock production).

Soil sampling

Forty (40) core soil samples (10 from each of the two selected slope positions and two land use types) were randomly collected at 0-20 cm depth using soil core samplers of dimensions 8.0 cm x 7.5 cm. Also, 20 auger soil samples were also randomly collected downslope in both land use types (10 from each land use) at 0-20 cm depth because the soils have shallow depth (0-25 cm) while 40 auger soil samples were collected upslope in both land use types at 0-20 cm and 20-40 cm depths respectively. In all, a total of one hundred (100) soil samples (40 core samples and 60 auger samples) were collected for this study. The soil samples were carefully bagged and transported to the laboratory for analysis. The soil core samples were used for the determination of soil hydrological properties while the disturbed soil samples were used for the determination of soil particle size distribution and soil organic carbon.

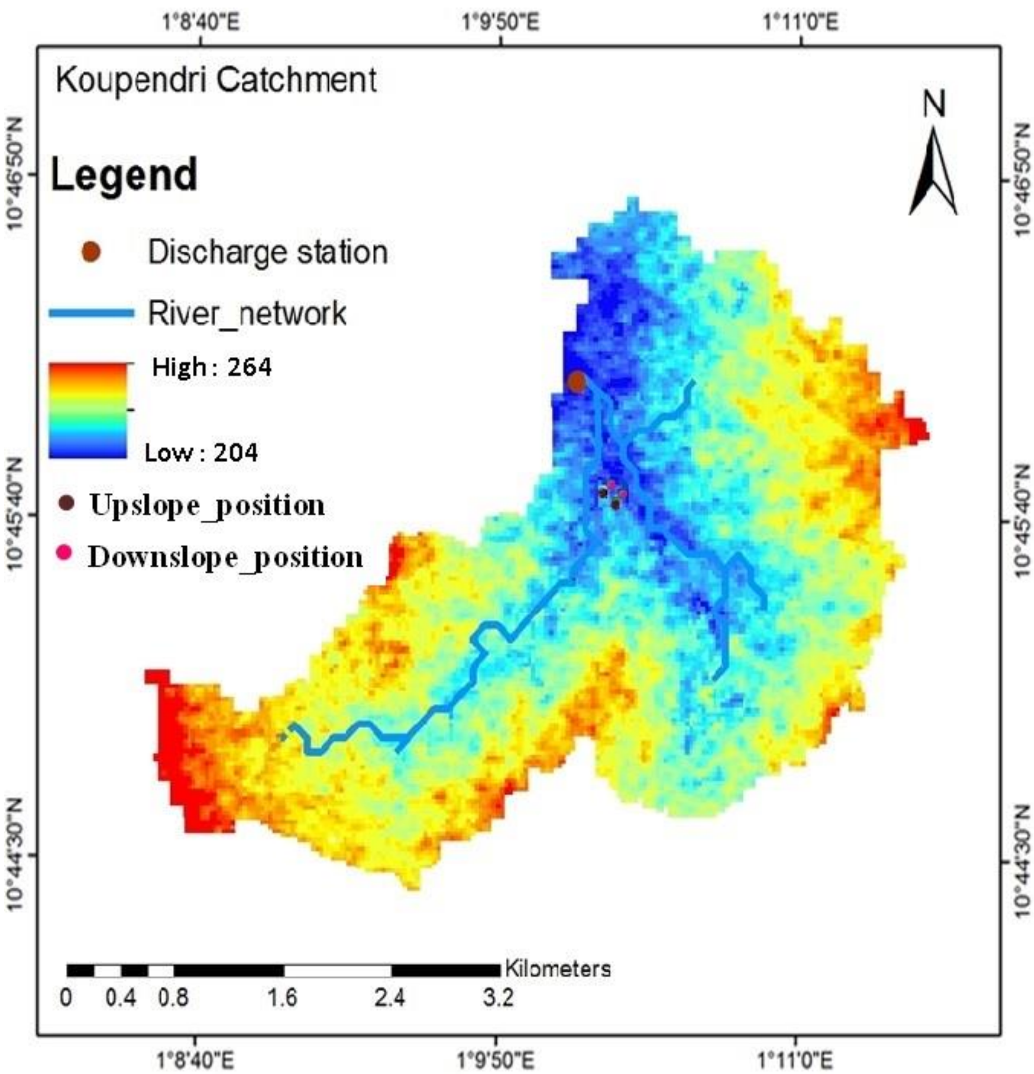

Figure 1. Location of Hillslopes or slope positions in Koupendri catchment**.**

Laboratory determination of saturated hydraulic conductivity

The core samples were saturated before the analysis. Saturated hydraulic conductivity (Ksat) was determined by the constant head method using Eijkelkamp laboratory permeameter. It operates on the basis or the principle of difference in water pressure on both ends of a saturated soil sample and the resulting flow of water is measured for hydraulic conductivity determination. Darcy's equation for analysis of constant head method, as described by Youngs (2001) was used for the computation of Ksat

$$Ksat = \frac{Q \, . \, L}{(A \, . \, T \, . \, \Delta H)} \quad \ldots\ldots(1)$$

Where Q is steady state volume of outflow from the entire soil column (cm^3), L is the length of soil column (cm), A is the interior cross-sectional area of the soil column (cm^2), T is the time of flow (sec), ΔH is the change in hydraulic head or the head pressure difference causing the flow (cm). The saturated weight of the core samples was taken before the analysis and weighed again after drying in the oven at a temperature of 105˚C. The result obtained was used to calculate the bulk density and porosity. Bulk density was determined by core method as described by Blake and Hartge (1986) while total porosity- TP (%) (assumed particle density p_s = 2.65 kg/m^3) was computed from bulk density (Bd), using the equation below:

$$TP = \left(1 - \frac{Bd}{Ps}\right) x \; 100 \quad \ldots\ldots(2)$$

Where TP = total porosity, Bd = bulk density, Ps = particle density

Determination of soil organic carbon and particle size distribution

The particle size distribution of the < 2 mm size fraction of soil samples was determined using the hydrometer method described by Gee and Or (2002). Soil organic carbon (SOC) was determined on the air dried, 2 mm sieved samples according to the Nelson and Sommers (1982) method.

***In-situ* measurement of soil moisture**

Soil moisture and water retention characteristics was monitored under each of the two selected land use or land cover types using three Hydra sonde moisture probes and three pF-meter probes (Fig. 2). The selected land use or land cover types are; maize-bean cropland + tillage (MBT) and Fallow Shrub-grassland (FSG). The soil moisture sensors were installed at the Ap horizon (0-20 cm) at the mid-slope in each of the selected land use or land cover from September 2014 – July 2015.

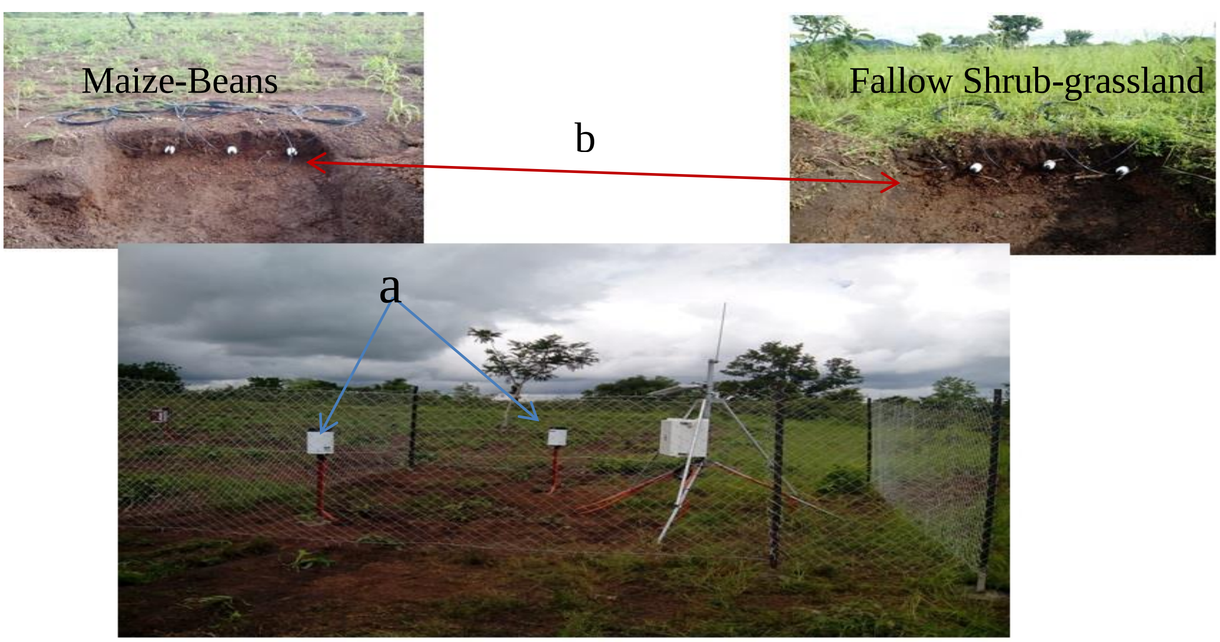

Figure 2. Installation of (a) tipping bucket rain gauge and (b) soil moisture sensors at the soil-moisture stations at Wanteou in Koupendri catchment. (Picture was taken during field work by one of the authors, Azuka, Chukwuebuka Vincent)

In-situ measurement of hydrological properties using Hood infiltrometer

In-situ measurement of infiltration characteristics until steady state was done using Hood infiltrometer (Fig. 3) (UGT, Müncheberg, Germany), as described by Schwärzel and Punzel (2007). The infiltration measurement was replicated thrice in each of the selected land use and slope positions. Soil samples were collected before and after each infiltration for determination of initial (θ_i) and final soil moisture (θ_f) contents. The soil samples were weighed before and after oven drying in the oven at a temperature of 105^0 C for gravimetric soil moisture (θ_g) determination;

Soil moisture (θ_g) = $\frac{\text{Moist weight}_{soil} - \text{Dry weight}_{soil}}{\text{Dry weight}_{soil}}$ ……...(3)

The soil moisture obtained here is gravimetric soil moisture in grams. To convert to volumetric moisture, we multiplied the gravimetric moisture content with the soil bulk density.

Determination of in-situ saturated hydraulic conductivity

The steady state values obtained during the infiltration test at different tensions or pressures were converted to the saturated hydraulic conductivity using the underlying theoretical principles stated below;
Unsaturated hydraulic conductivity k_u (cm/hr) as a function of water tension h in soils or other open-pored materials near saturation can be described according to Gardner (1958):

$$k_u = k_f . e^{(\alpha.h)} \quad \text{.............................(4)}$$

k_f – field saturated hydraulic conductivity (cm/hr).
h – Hydraulic pressure head (cm) - positive in overpressure range.
α = inverse capillary length scale (cm^{-1}).
Such approach allows an analytical solution for a large number of two- and three dimensional flow processes. It is the regular basis for the interpretation of test results with the infiltrometer systems common so far.

According to Wooding (1968), the following applies to the steady-state flow Q (volume/time) from a circular infiltration area (radius α) into the infinite soil:

$$Q = \pi . r^2 . k_u . (1 + \frac{4}{\pi . r . \alpha .}) \text{....... .(5)}$$

Where Q= steady-state infiltration rate (cm/hr), r = radius of the disc (cm), K_u = unsaturated hydraulic conductivity (cm/hr). For experimental determination of $\mathbf{k_f}$ and $\boldsymbol{\alpha}$ above, the infiltration test can be run with different water tensions (hydraulic pressure heads) or the infiltration gets fed from source areas with different radii for equal water tensions (Wang and Qi, 1998). However, infiltration from different source areas makes sense only in largely homogeneous soils.
For the infiltration test at different water tensions up to the bubble point of the soil, the chosen water tensions (h_1, h_2) apply according to equations (4), (5):

$$\frac{Q_1}{\pi . r^2} = k_f . e^{(\alpha.h_1)} . (1 + \frac{4}{\pi . r . \alpha}) \text{......(6)}$$

$$\frac{Q_2}{\pi . r^2} = k_f . e^{(\alpha.h_2)} . (1 + \frac{4}{\pi . r . \alpha}) \text{.......(7)}$$

By way of division we get:

$$\alpha = \frac{In\left(\frac{Q_1}{Q_2}\right)}{(h_1 - h_2)} \qquad (h_1, h_2 < 0) \text{ ...... (8).}$$

Statistical Analysis

The data set obtained from this study were checked and corrected for possible outliers by performing normality test using skewness, kurtosis and Shapiro-Wilk test (Shapiro and Wilk 1965) before subjecting them to statistical analysis. Afterwards, data on soil hydrological properties were subjected to a two-way analysis of variance (ANOVA) appropriate for a 2x2 factorial experiment using Genstat Discovery Edition 10.3. The factors considered were; land use (Tilled maize-beans (TMB) and Fallow shrub-grassland (FSG)) and Slope (Upslope and Downslope) replicated ten (10) times. The mean effects of land use and slope position on soil hydrological properties were compared using the Fischer's least significant difference (F-$LSD_{0.05}$) as described by Obi (2002).

Figure 3. Set-up of Hood infiltrometer in the field during the field measurement**. (**Picture was taken during field work by one of the authors, Azuka, Chukwuebuka Vincent).

RESULTS

Soil properties at 0-20 cm and 20-40 cm depths on two slope position and land use types

The soil textural characteristics within the root zone (0-40 cm) of the selected slope positions and land use types are shown in Table 1. The results showed that sand is the dominant particle size (560-620 g/kg), followed by silt (280-310 g/kg) and the least is clay (60-160 g/kg). The soils were mostly sandy loam in all depths and the clay content increased with increasing depth. Soil organic carbon (SOC) decreased with increasing depth with higher values recorded upslope irrespective of land use. The values of SOC at 0-20 cm are 18.4 g/kg (FSG) and 13.3 g/kg (MBT) upslope, and 16.3 g/kg (FSG) and 14.1 g/kg (MBT) downslope. The results also showed that at 0-20 cm irrespective of slope position, SOC was highest 18.4 g/kg (upslope) and 16.3 g/kg (downslope) under FSG compared to 13.3 g/kg (upslope) and 14.1 g/kg (downslope) under MBT. The gravel content of the soil was highest (71%) under FSG (0-20 cm) downslope and lowest (52.8) under FSG (0-20 cm) upslope and MBT (0-20) downslope.

Soil hydrological properties of Koupendri catchment hillslope

The hydrological properties of hillslope soil of Koupendri catchment under two slope positions and land use types are shown in Table 2. The results showed that land use has significant ($p < 0.01$) effect on saturated hydraulic conductivity (Ksat) determined in-situ and the steady state infiltration rate. Ksat values determined in-situ and the steady state infiltration recorded high values of 11.96 cm/hr and 13.53 cm/hr respectively under FSG when compared to 2.21 cm/hr and 3.61 cm/hr recorded under MBT. However, Ksat in-lab and other soil hydrological properties such as bulk density (BD), porosity, initial (θ_i) and final soil moisture (θ_f) contents were not significantly ($p < 0.05$) influenced by land use. The results showed that the slope position had no significant ($p < 0.05$) effect on the soil hydrological properties (Table 2). Also, slope and land use interaction had no significant ($p < 0.05$) effect on soil hydrological properties (Table 3). The coefficient of variation (CV) of the soil hydrological properties was low (< 10 %) for BD and porosity, moderate (< 30 %) for θ_i, θ_f, and Ksat in-situ and very high (> 55 %) for Ksat in-labacross land uses and slopes, and their interaction (Tables 2 and 3). Generally, the variability in soil hydrological properties was higher under the land use compared to the slopes.

Table 1. Soil properties at the two slope positions and land use types.

Landuse	Depth (cm)	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	Textural class	SOC (g/kg)	Gravel (%)
FSG Upslope	0-20	610	310	80	SL	18.4	52.8
FSG Upslope	20-40	560	280	160	SL	11.5	56.5
FSG Downslope	0-20	600	290	100	SL	16.3	61.0
MBT Upslope	0-20	620	320	60	SL	13.3	53.4
MBT Upslope	20-40	590	300	110	SL	12.3	58.9
MBT Downslope	0-20	610	300	90	SL	14.1	59.8

SOC= soil organic carbon, FSG= fallow-shrub-grassland, MBT= tilled maize-bean, SL=sandy loam

Table 2. Main effect of land use and slope on soil hydrological properties of Koupendri hillslope at 0-20 cm depth.

Treatment	Ksat_in-situ (cm/hr)	Ksat_in-lab (cm/hr)	θ_i (cm^3/cm^3)	θ_f (cm^3/cm^3)	BD (gcm^{-3})	Porosity[b] (%)	Infiltration (cm/hr)
Land use							
FSG	11.96	5.33	0.065	0.183	1.37	48.5	13.53
MBT	2.21	3.04	0.048	0.169	1.34	49.5	3.61
CV %	16.8	62.8	21.8	12.8	2.9	3.2	13.6
$LSD_{0.05}$	2.72	NS	NS	NS	NS	NS	4.10
Slope							
Upslope	6.68	5.13	0.065	0.158	1.33	49.8	8.34
Downslope	7.46	3.29	0.047	0.194	1.37	48.3	8.81
CV %	12.3	50.9	18.6	10.4	2.3	3.1	12.8
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS

MBT= tilled maize-bean, FSG= fallow shrub-grassland, NS = not significant, K_{sat} = saturated hydraulic conductivity, θ_v = volumetric moisture content, BD = bulk density, [b]Estimated from bulk density values, assuming particle density of 2.65 g cm^{-3}.

Table 3. Interaction effect of land use and slope on soil hydrological properties of Koupendri hillslope.

Land use	Slope	Ksat_insitu (cm/hr)	Ksat in-lab (cm/hr)	θ_i (cm^3/cm^3)	θ_f (cm^3/cm^3)	BD (gcm^{-3})	Porosity[b] (%)	Infiltration (cm/hr)
FSG	Upslope	10.31	6.46	0.066	0.165	1.36	48.6	11.97
	Downslope	13.58	4.25	0.064	0.202	1.37	48.4	15.09
MBT	Upslope	3.05	3.75	0.065	0.152	1.30	50.1	4.7
	Downslope	1.35	2.33	0.031	0.187	1.38	48.9	2.53
	CV %	18.7	64.5	24.5	17.4	3.4	3.6	15.8
	$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS

MBT= tilled maize-bean, FSG= fallow shrub-grassland, K_{sat} = saturated hydraulic conductivity, θ_v = volumetric moisture content, BD = bulk density, [b]Estimated from bulk density values, assuming particle density of 2.65 g cm^{-3}, NS = not significant, CV= coefficient of variation.

Temporal soil moisture dynamics at two timescales under different land use types

The temporal variability of soil moisture or soil moisture dynamics at 30-minutes and daily timescale for a sandy loam soil under different land use is shown below (Figs 4 and 5). The results of the measurement showed that the soil moisture is higher on FSG land use than on MBT land use. Generally, soil moisture under FSG land use was higher throughout the studied period evaluated with daily maximum and minimum values of 0.270 cm^3/cm^3 and 0.100 cm^3/cm^3, respectively at daily time scale, and 0.392 cm^3/cm^3 and 0.096 cm^3/cm^3, respectively at 30-minutes timescale. A similar trend was observed in the laboratory measurements (Table 3) where both initial and final soil moisture contents were higher under FSG land use on both slope positions. The dynamics of soil moisture depicted the dynamics of the rainfall distribution, an indication that rainfall characteristics contributed to driving soil moisture dynamics under the two land use types.

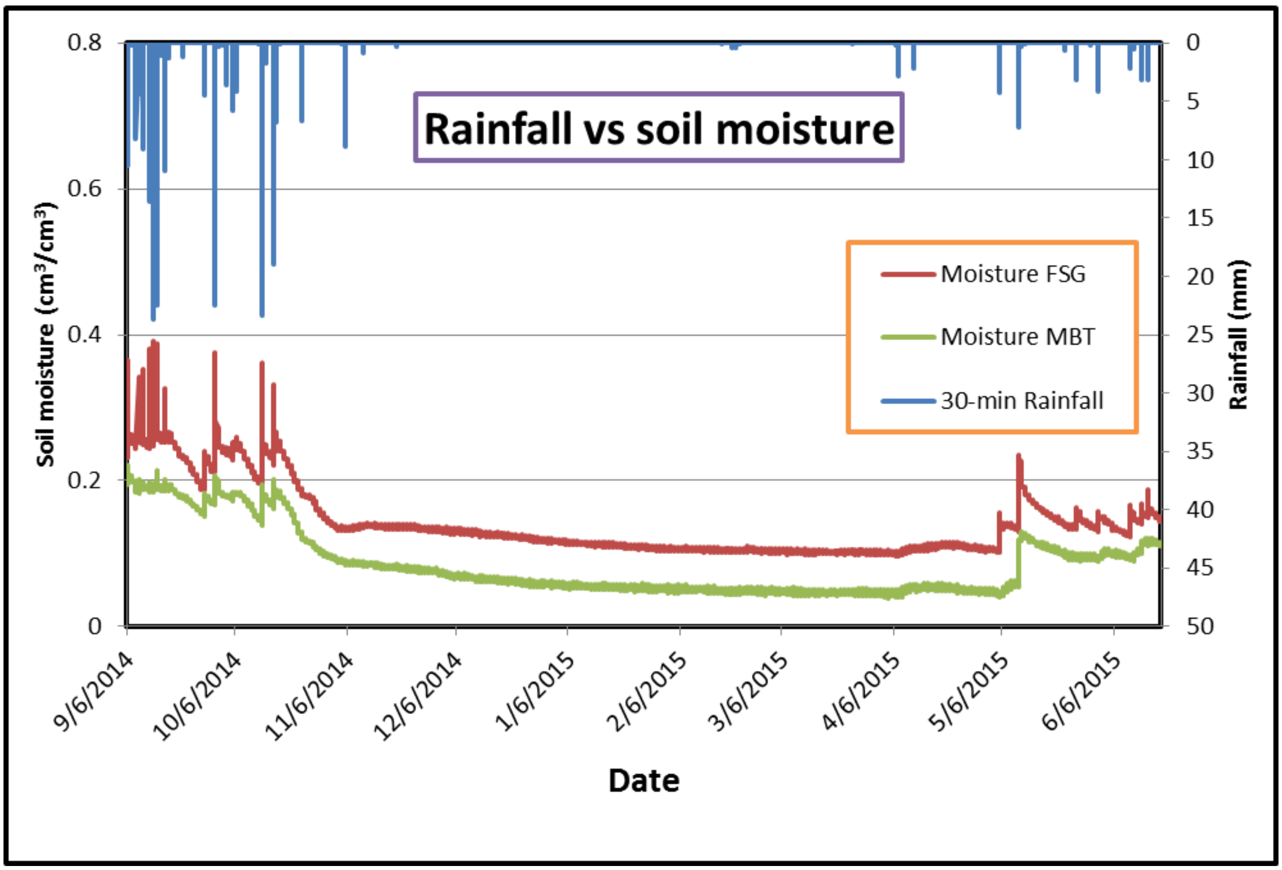

Figure 4. Temporal variability of rainfall and soil moisture dynamics under different land use at 30-minutes timescale.

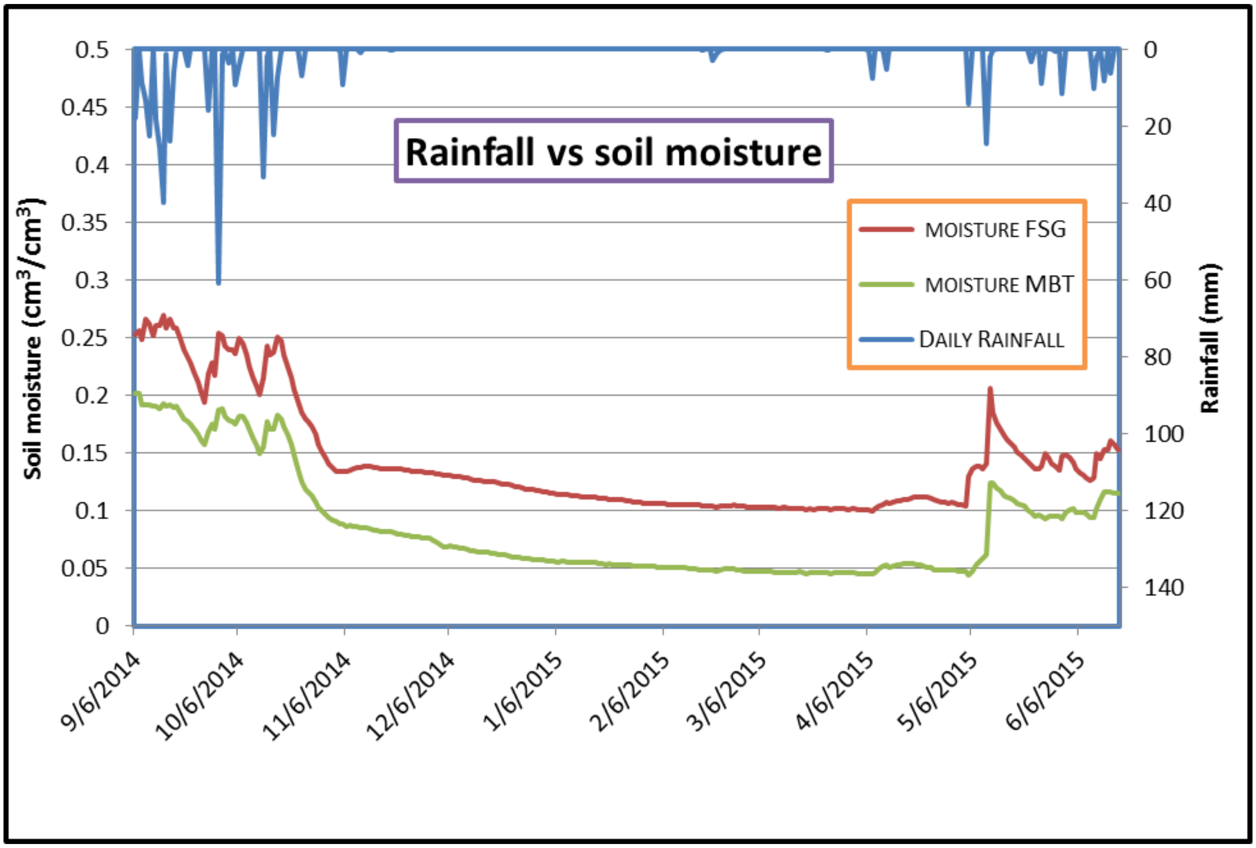

Figure 5. Temporal variability of rainfall and soil moisture dynamics under different land use at daily timescale.

DISCUSSIONS

Sustainable soil and water management require information on soil hydrological properties. The result obviously showed an effect of land use on the soil hydrological properties ($p<0.05$) especially Ksat in-situ, steady state infiltration and soil moisture dynamics. The Ksat is one important hydrological property associated with soil types, land uses, positions on landscape, instruments, and methods of measurement and experimental errors. The Ksat was adjudged a sensitive indicator of soil disturbance mainly by tillage practices (Ziegler et al. 2004, Zimmermann et al. 2006). This result also supports the findings that tropical forest conversions to pasture affects surface soil hydrological properties (Zimmermann et al. 2006). Similarly, Abaci and Papanicolaou (2009) reported that hydraulic conductivity may also be affected by vegetation cover, bio- and human activities. The present study showed that in-situ Ksat, in-lab Ksat and steady state infiltration was higher under FSG than under MBT on both slope positions. This may be attributed to the effect of soil tillage which destroys macropores and its network continuity and thus prevents formation of larger pores. Numerous soil stable macropore structures, connectivity and continuity as a result of high biological activity can be linked to the observed high soil hydrological properties on both slope positions under the FSG compared to MBT. Thus, transport and flow processes (both nutrient and contaminant), water balance and the hydrology of the hillslope are influenced by the effect of soil management and land use on soil hydrological properties. Contrary to the findings of other researchers (Schwarzel and Punzel 2007; Reynolds et al. 2000), it was observed that Ksat determined in-situ recorded higher values than Ksat determined in the laboratory using soil cores. However, the result of this study agrees with the findings of Fallico et al. (2006) who reported lowest Ksat values using soil cores in comparison to tension and pressure infiltrometers. The differences observed between the Ksat determined in-situ and in the laboratory could be attributed to the differences in coverage or sample size between the tension disc of the Hood infiltrometer and the soil cores (Reynolds et al. 2000). This could also be attributed to the destruction or creation of artificial macropores in the core determined Ksat resulting to either higher or lower values unlike the in-situ determination that ensure minimal disturbance of soil macropores. Basile (2003) further stated or argued that the differences observed between the laboratory and in-situ measured soil hydrological properties was due to differences in the hysteretic paths taken during wetting procedures.

It is important to note that bulk density is one important soil hydrological property that influences soil water movement and retention. The bulk density values (1.33 g/cm^3 - 1.37 g/cm^3) obtained in this study were within the range considered good for agricultural activities because it allows for optimum movement of air and water through the soil (Hunt and Gilkes 1992). It has also been shown to be a good indicator of soil permeability and suitability for root growth (Cresswell and Hamilton, 2002, McKenzie et al. 2004). McKenzie et al. (2002) reported that soils with bulk densities higher than 1.6 g/cm^3 tend to restrict root growth and interferes with the ability of the plant to absorb water and nutrients. Both in-situ and laboratory determined saturated hydraulic conductivity, initial or antecedent soil moisture contents and steady-state infiltration rates were found to increase with increasing slope gradient. However, bulk density values and final soil moisture contents of the soil decreased with increase in slope, thus the increasing infiltration rate upslope can be interpreted. Tilahum et al. (2013) found that increased saturation of the watershed at the downslope reduced infiltration and resulted to increased runoff coefficient in the downslope compared to its upslope.

The gravel contents of the soils were high and may have influenced the soil hydrological properties. The high gravel contents could explain the high value of Ksat in-situ obtained downslope of FSG. Water tends to move faster through large pores than through small pores. It has been mentioned that saturated hydraulic conductivity of soil is a function of pore size (Jury et al. 1991). Coarser textured soils have larger pores hence they have higher saturated hydraulic conductivity than finer textured soils. This explains the high hydraulic conductivity and steady state infiltration rate recorded in this study. The infiltration rate was 9-88% higher upslope compared to downslope of the hillslope under the two land use types. The present result corroborates that of Brown et al. (1988) who observed 50-100 % higher infiltration rates for a silt loam soils upstream compared to the downstream furrow.

Soil texture, vegetation and soil organic matter content are known to have significant effect on soil water holding capacity or retention characteristics and storage (Joshi et al. 2011). The study showed that the difference between the maximum and minimum daily soil moisture (Figure 3) i.e. available water capacity (0.16-0.17) of the hillslope soil is within the range for sandy loam soils (Jensen et al. 1990). This information is vital for the determination of irrigation water requirements especially for effective daily irrigation scheduling and efficient irrigation management in the catchment. The low soil moisture storage observed especially in the dry period (October, 2014-April, 2015) could be due to the coarser soil texture including the gravel contents. At higher soil water potentials, coarse-textured soils are known to lose more water and plants growing on such soils tend to exhaust their water supply faster than plants growing in fine-textured soils (Hultine et al. 2005).

In this study, since the texture (sandy loam) and soil particle size distribution (sand, silt and clay percent) under the two land use types were similar (Table 1), the differences in the actual soil water or moisture content could be attributed to the differences in land use or land cover type, and soil management practices. Soil management practices such as tillage operation reduces the amount of residue, enhance rapid breakdown of soil structure or aggregates and organic matter, increases BD, and reduces hydraulic conductivity and infiltration, and consequently the soil-water storage capacity and quantity of soil water conserved in the soil. This was corroborated in the findings of some researchers (Gicheru et al. 2004, Mulebeke et al. 2013) who reported that soil management practices like tillage, have significant effect on soil physical properties, particularly on soil moisture content. The soil moisture content was significantly influenced by land use and soil management practices, which remained higher throughout the period of study under the FSG compared to MBT. This further confirms the above result of the volumetric soil moisture content obtained under the two land use types.

The results also showed that the temporal dynamics of the soil moisture is driven by the precipitation characteristics. The height and pattern of the peaks were dependent on rainfall amount, duration and intensity. A high amount of rainfall of low intensity at longer duration leads to high amount of soil moisture compared to a high amount of rainfall of high intensity at short duration. Anwar (2014) also found that moisture content was controlled by the amount of rainfall within a year. The soil moisture dynamics peaks during rain events and the responses were quick but descended during cessation of rain. The peaks of the soil moisture dynamics were captured better at 30-minutes timescale when compared to daily timescale mainly due to differences in timescale.

CONCLUSION

This study evaluated the effect of land use and slope positions on soil hydrological properties that influence flow and transport processes in the soil. The soil hydrological properties were determined using both in-situ and laboratory methods. The texture of the soil is sandy loam with the dominance of sand. The results showed that the soil hydrological properties especially

Ksat_in-situ were influenced by land use. Higher values of the soil hydrological properties were obtained under the FSG and upslope. The study also revealed widespread disparity between in-situ and laboratory determined soil hydrological properties especially hydraulic conductivity, and its inter-dependency on soil management practices. Soil moisture content was influenced by land use and soil management practices. The soil moisture dynamics were also driven by the rainfall characteristics. Although soil moisture dynamics were captured better at 30-minutes timescale, soil moisture monitoring at daily timescale provided realistic information necessary for effective daily irrigation scheduling. We conclude that soil hydrological properties were influenced by land use, and also dependent on the determination method or approach.

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Data Availability. Data are available with Chukwuebuka Vincent Azuka, chukwuebuka.azuka@unn.edu.ng upon reasonable request.

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