INFILTRATION CHARACTERISTICS OF A TYPIC HAPLUSTULT UNDER DIVERSE TILLAGE PRACTICES AND COVER CROPS IN NORTHERN GUINEA SAVANNA OF NIGERIA†

[CARACTERÍSTICAS DE INFILTRACIÓN DE UN HIPLUSTOL TÍPICO BAJO DIVERSAS PRÁCTICAS DE CULTIVO Y CULTIVOS DE COBERTURA EN LA SAVANA DE GUINEA DEL NORTE DE NIGERIA]

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SUMMARY

Soil tillage and vegetation cover impact a great deal on hydrological processes in soil. However, there exist a dearth of literature on the extent of these effects in semi-arid Nigeria. This study investigated the effect of tillage practices (no-till, (NT) reduced till (RT) and conventional tillage (CT)) and cover crops (*Centrosema pascuorum* (CP), *Macrotyloma uniflorum* (MU), *Glycine max* (GM), *Cucurbita maxima* (CM) and no cover crop (bare) as control) on soil water infiltration rate and characteristics. A double ring infiltrometer was used to carryout infiltration study of soils under the aforementioned tillage practices and cover crops. Data obtained were used to calculate infiltration rate and these were also fitted into the Philip and Kostiakov's models. The quality of adjustment of the models was verified by a chi square and T test, coefficient of determination (r^2) and standard deviation. Result revealed higher infiltration rate in soil under conservation tillage (NT and RT) due to soil pores continuity, than in the CT where the pores had been disrupted by tillage implement. Similarly, the use of any of the evaluated cover crops improved water infiltration better than the bare soil with no cover crop. Conservation tillage system (RT and NT) favoured better soil infiltration rate by 41.25% and 29.53% respectively more than conventional tillage system. Plots with cover crops had 65.27%, 59.46%, 54.88% and 18.9% higher soil water infiltration rate in CP, MU, GM and CM treatments respectively than the bare (no cover crop) treatment. Both Kostiakov and Philip's model were suitable for predicting the first one-minute infiltration rate. However, Kostiakov's equation showed superior performance over Philip's equation, in determining cumulative infiltration, this was evident from the lower standard deviation and CV values of Kostiakov's parameters. In addition to the general non-significance differences obtained between measured and Kostiakov's predicted infiltration values as revealed by Chi square test.

Keywords: Soil water Infiltration; Infiltration models; earthworm count.

RESUMEN

La labranza del suelo y la cobertura vegetal tienen un gran impacto en los procesos hidrológicos en el suelo. Sin embargo, existen pocos trabajos sobre el alcance de estos efectos en las regiones semi áridas de Nigeria. Este estudio investigó el efecto de las prácticas de labranza (labranza cero, (NT) reducción de la labranza (RT) y la labranza convencional (CT)) y cultivos de cobertura (*Centrosema pascuorum* (CP), *Macrotyloma uniflorum* (MU), *Glycine max* (GM), *Cucurbita maxima* (CM) y ningún cultivo de cobertura (suelo desnudo) como control) sobre la tasa de infiltración del agua del suelo y sus características. Se utilizó un infiltrómetro de doble anillo para llevar a cabo el estudio de infiltración de suelos bajo las prácticas de labranza y cultivos de cobertura mencionados anteriormente. Los datos obtenidos se utilizaron para calcular la tasa de infiltración y también se ajustaron a los modelos de Philip y Kostiakov. La calidad de ajuste de los modelos se verificó mediante una prueba de chi cuadrado y T, coeficiente de determinación (r^2) y desviación estándar. El resultado reveló una mayor tasa de infiltración en el suelo bajo labranza de conservación (NT y RT) debido a la continuidad de los poros del suelo, que en la TC donde los poros habían sido interrumpidos por el implemento de labranza. De manera similar, el uso de cualquiera de los cultivos de cobertura evaluados mejoró la infiltración de agua mejor que el suelo desnudo sin cultivo de cobertura. El sistema de labranza de conservación (RT y NT) favoreció una mejor tasa de infiltración del suelo en un 41.25% y un 29.53% respectivamente más que el sistema de labranza convencional. Las parcelas con cultivos de cobertura tuvieron 65.27%, 59.46%, 54.88% y 18.9% mayor tasa de infiltración de agua en el suelo en los tratamientos de CP, MU, GM y CM respectivamente que en el tratamiento suelo desnudo (sin cultivo de cobertura). Tanto el modelo de Kostiakov como el de Philip fueron adecuados para predecir la primera tasa de infiltración de un minuto. Sin embargo, la ecuación de Kostiakov mostró un rendimiento superior al de la ecuación de Philip, al determinar la infiltración acumulada, esto fue

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evidente a partir de la desviación estándar más baja y los valores CV de los parámetros de Kostiakov. Además de las diferencias generales no significativas obtenidas entre los valores de infiltración pronosticados y medidos de Kostiakov según lo revelado por la prueba de Chi cuadrado.

Palabras clave: Infiltración de agua en el suelo; Modelos de infiltración; recuento de lombrices.

INTRODUCTION

Water is an indispensable element for crop growth and development and its infiltration into soil is crucial for soil and water management (Shukla *et al.*, 2003). Infiltration or the downward entry of water into the soil is vital to redistribution of water in the soil system and for plant use. The entry of water into soil is affected by soil surface conditions and inherent soil properties. The climate of Nigerian savanna is characterized by poor amount and distribution of rainfall, the soils are poorly structured and low in organic matter content therefore possessing low water and nutrient holding capacities (Jones and Wild, 1975). In addition, the region had suffered from soil erosion menace and soil fertility depletion due to land use intensification (Jones and Wild, 1975). The erratic and aggressive nature of rainfall in this region has warranted repeated periods of severe drought and dry spells, and consequently inadequate water supply which is a major constraint to crop production in this region. It is therefore necessary to manage scarce water resources for sustainable agricultural productivity.

The planting of cover crops along with staples in northern Nigeria is yet to gain popularity. However, these cover crops when grown on soil, covers the soil surface and serve as barrier to impact of rain drops on the poorly structured savanna soils thereby preventing soil detachment and transportation, away from its original spot in the form of runoff water and ultimately increase water infiltration into soil (Lawal, 2017). Conventional soil tillage method which involves intensive soil pulverization before crop cultivation, removes overlying crop residues and soil organic matter. Hence, leaving the soil surface bare at earlier part of the cropping season before crop attain full canopy and consequently, pre-disposes the soil to risk of being eroded. This is because, slaking and subsequent crusting of bare soil surface exposed to the impact or beating action of rain drops results in low water infiltration and loss of excess to runoff during rainfall events. In addition to evaporative losses from bare soil surfaces after the rains, therefore warranting insufficient moisture storage for plant use.

The amount of water that infiltrates a soil over a period has an inverse relationship with the amount of runoff that will occur over the soil (Weil and Brady, 2017; Shukla *et al.*, 2003). Proper knowledge of infiltration rate under different tillage practices and cover crops regime is thus important for planning water management activities.

Field infiltration measurement is a tedious task, but infiltration characteristics of a soil can be estimated from proposed infiltration models. Philip (1957) and Kostiakov (1932) models have been used to characterize field water infiltration due to spatial variability in an Alfisols at Samaru northern Nigeria and was proposed as effective (Wuddivira and Abdulkadir, 2000). However, there exists little knowledge on the use of these models under different soil management practices (such as the use of tillage and cover crops) in Ultisols of this region.

The objectives of this study are therefore (i) to evaluate the effect of tillage practices and cover crops on soil water infiltration rate of a Typic haplustults in northern Nigeria. (ii) to test the applicability of Philip and Kostiakov's infiltration models in estimating soil water infiltration characteristics of an Ultisols under different management practices.

MATERIALS AND METHODS

Description of Experimental Site

The study was carried out at the horticultural garden of the Institute for Agricultural Research Samaru, (11^{o}10.416'N, 07^{o}37.812'E, 700m above sea level) in the Northern Guinea Savanna ecological zone of Nigeria. The soil type is Typic haplustult derived from pre-Cambrian crystalline basement complex rocks with some quaternary aeolian deposits (Shobayo *et al.*, 2015). Samaru is characterized by a mono modal rainfall pattern with a long term mean annual rainfall of about 1011 ± 16 1mm, which spreads from March/April to October with the highest concentration in the three months of July to September. Samaru has a long – term mean minimum and maximum temperatures of 21.1^{0}C and 33.5^{0}C respectively and relative humidity of 55.23% (Oluwasemire and Alabi, 2004).

Treatments and Experimental Design

The treatments consisted of three tillage practices as follows: No - tillage (NT), this involved no soil disturbance except boring holes for seed sowing; Reduced tillage (RT), here fields were harrowed once then seed sowed and the Conventional tillage (CT), which involved ploughing, harrowing and ridging before seed sowing. Four cover crops namely: *Centrosema pascuorum, Macrotyloma uniflorum, Glycine max, Cucurbita maxima* and no cover crop (bare) as control/ check. The experiment was laid out in a randomized complete block design with split plot arrangement and replicated three times. Tillage practices were allocated to the main plots and cover crops to sub plots. Tillage operations were carried out using a tractor-drawn disc plough, disc harrow and disc ridge as per treatment. The experimental plots were appropriately marked out; each gross plot measured 2.0m in length and consisted of eight rows spaced 0.75m apart (2.0 m x 8 x 0.75m = 12m^2), while the net plot consisted of the six inner rows and measured 2.0m x 6 x 0.75m = 9m^2. The main plots consisted of five sub plots each planted to one of the four cover crops, then a bare/control all replicated three times. The test crop was maize, and the trials was carried out for three cropping seasons (2011 – 2013).

Soil Sampling and laboratory analysis

After marking out the field, prior to establishment of the trial; composite auger soil samples were collected at depths of 0-15 cm at ten different points, sampled diagonally across each of the 45 subplots. Also, undisturbed core cylinder soil samples were collected. The soil samples were analyzed for the following physical and chemical properties using standard procedures; Organic carbon (Nelson and Sommers, 1982), total N by macro Kjeldhal method (Bremner and Mulvaney, 1982), available P was by Bray 1 method, exchangeable bases (Anderson and Ingram, 1998), soil pH (Mclean, 1982), particle size distribution (Gee and Or, 2002) and dry bulk density (Grossman and Reinsch, 2002).

Field Study

Water infiltration characteristics

Infiltration study was carried out before commencement of trial in 2011 and in subsequent years, after the crop harvest in the dry season. The infiltration study was done with the aid of a double ring infiltrometer. The double ring infiltrometer was placed on the soil surface of each plot, its cover was placed on it and the infiltrometer was carefully driven into the soil (10cm deep) with the aid of a plastic insulated mallet. The infiltration study lasted for 2 hours during which depth of infiltrated water was measured with the aid of a meter rule after 1, 5, 10, 15, 30, 60 and 120 minutes. Antecedent moisture content of each plot was also determined prior to the infiltration study.

Infiltration rates in mm hr^{-1} was compared among treatments means; first one-minute infiltration rate and cumulative infiltration measured from the field was then fitted to Philip's (1957) and Kostiakov's (1932) infiltration models to obtain sorptivity and transmissivity values at harvest for the three years trials.

Philip's model (1)

$$I = St^{1/2} + At$$

Kostiakov's model (2)

$$I = Ct^{\alpha}$$

Where:

I = Cumulative infiltration (cm)

C = Initial infiltration (cm min^{-1})

α = Index of sorptivity of the soil reflecting the decline of the infiltration rate

S = Sorptivity, influence of the soil water relation (matric suction and conductivity) in the wetting process

A = Transmissivity (hydraulic conductivity) and represents the effect of gravity

t = time elapsed (min)

The nonlinear, least–square fitting procedure was employed to determine the parameter of the infiltration models. The nonlinear least square method was used for curve fitting to obtain transmissivity and sorptivity of Philip's model, and the index of soil sorptivity and the initial infiltration (sorptivity) of Kostiakov's model. The coefficient of variability (CV) of infiltration was determined using Fishers classical statistics i.e. CV = (standard deviation/mean) x 100. The CV values were grouped into three classes: least (low) variable, where $CV < 15\%$; moderately (medium) variable, where $15 \leq CV \leq 35\%$; and highly (high) variable, where $CV > 35\%$ (Wilding *et al.*, 1994). A Chi square test, paired t test and coefficient of determination (r^2) values obtained when the measured and the predicted infiltration were plotted in a regression graph was used to test for goodness of fit and disparity between the measured and the predicted infiltration (Kothari and Garg, 2014).

Earthworm Count

Earthworm count was taken from 0-15 cm soil depth on per m^2 basis from all the treatment plot at 50 % maize tasseling stage.Data collected on infiltration rate in this study due to variation in tillage and cover crops were subjected to statistical analysis of variance as described by Snedecor and Cochran (1967), using the SAS computer package (SAS, 2008) and differences among the treatment means were separated using Duncan Multiple Range Test (DMRT) (Duncan, 1955).

RESULTS

Characterization of Soil of the Study Area

The physical and chemical properties of soil of the study area is presented in Table 1. The soil is generally loam (L) in texture with 43% sand, 43% silt and 14% clay and moderately acidic in soil reaction, with moderate organic carbon (10.17 g kg^{-1}) and bulk density (1.4 Mg m^{-3}); but poor in total nitrogen (0.72 g kg^{-1}). The soil has very low available phosphorus (2.56 mg kg^{-1}), exchangeable calcium and cation exchange capacity. While exchangeable magnesium, potassium and Sodium are generally low, in line with published findings of savanna soils in Nigeria (Jones and Wild, 1975).

Table 1: Initial physical and chemical properties at soil depth of 0-15cm of the experimental site.

Parameters	Mean values across 45 plots	% CV
Sand (g kg^{-1})	431.11	5.93
Silt (g kg^{-1})	425.77	6.89
Clay (g kg^{-1})	143.11	14.09
Texture	Loam	-
pH (water)	6.3	1.56
pH ($CaCl_2$)	5.4	2.55
Organic carbon (g kg^{-1})	10.17	20.32
Total nitrogen (g kg^{-1})	0.72	19.41
Available P (mg kg^{-1})	2.56	24.33
Exchangeable Calcium (cmol kg^{-1})	1.96	32.05
Exchangeable Magnesium (cmol kg^{-1})	1.03	33.25
Exchangeable Potassium (cmol kg^{-1})	0.24	37.30
Exchangeable Sodium (cmol kg^{-1})	0.1	51.47
Cation exchange capacity (cmol kg^{-1})	4.3	22.34
Bulk density (Mg m^{-3})	1.47	7.68

Effect of Tillage and Cover Crop on Water Infiltration Characteristics

Effect of tillage and cover crop on infiltration rate

Table 2 shows the influence of tillage practice and cover crops on infiltration rate (mm hr^{-1}) for three years (i.e. 2011, 2012, and 2013); and the mean across the years of study. Infiltration rate on reduced tillage (RT) plots were consistently higher than on conventionally tilled (CT) and no-tilled (NT) plots except in year 2013 and the mean across the years of experimentation when NT had statistically similar infiltration rate as the RT, while CT plots recorded the least infiltration rate. Conservation tillage system (RT and NT) favoured better soil infiltration by 41.25% and 29.53% respectively more than conventional tillage system.

The bare plots *i.e.* plot with no cover crop consistently had the least infiltration rate. The use of any of the evaluated cover crops in this study significantly enhanced soil water infiltration rate better than the bare soil with no cover crop. Meanwhile, the effect of the different cover crops on infiltration rate were statistically similar throughout the years of study and the mean across the years. All plots with cover crops had on the average 64.37% higher soil water infiltration than the bare (no cover crop) treatment. However, individually there was 65.27%, 59.46%, 54.88% and 18.9% higher soil water infiltration rate in CP, MU, GM and CM treatments respectively than the bare (no cover crop) treatment. The interaction between Tillage and Cover crop was not significant for all the years of study.

Infiltration characteristics of the experimental field

Table 3 shows infiltration characteristic of the experimental field at Samaru, the behavior of the soil water and the infiltration rate among the treatment plots for the Initial one-minute infiltration and cumulative infiltration (cm) after 2 hours elapsed time, showed moderate variation among treatment plots with CV values of 27 and 39% respectively. The coefficient of determination (r^2) was within 0.002 and 0.68 for the Philip's model with a mean of 0.284 and a mean r^2 value of 0.971 for Kostiakov's model.

The sorptive forces of the soil largely govern the initial water infiltration rate. The sorptivity values obtained in this study were moderate (1.942 to 4.324). Transmissivity (constant A) of Philip's model ranged from -0.017 to 0.256. These values accord the soil conductivity status as "moderate". Water transmissivity showed high variation among the treatments (CV 46.98 %) with some conservation tillage (RTGm, RTCm and NTCp) treatments having higher transmissivity than the conventional tilled soil. However, three points out of the 15 averages of 45 points of infiltration showed negative values of transmissivity.

Table 2: Tillage and cover crop effects on infiltration rate (mm hr^{-1}) during the 2011, 2012, 2013 cropping seasons and the mean across the three years in a Typic haplustults at Samaru, Nigeria.

Treatments	2011	2012	2013	Combined
Tillage (T)	infiltration rate (mm hr^{-1})			
No till	153.37 b	168.30b	235.83a	210.84a
Reduced	259.20 a	220.60a	219.92a	229.91a
Conventional	185.37 b	145.3b	160.21b	162.77b
SEM ±	23.399	12.522	12.726	12.833
Significance	**	*	*	*
Cover Crops (C)				
No Cover	103.22b	131.83b	119.53b	118.63b
Macrotyloma uniflorum	233.0a	152.00ab	192.5a	189.17a
Centrosema pascorum	231.94a	160.17ab	196.06a	196.07a
Glycine max	168.67ab	198.75a	183.81a	183.74a
Cucurbita maxima	259.72a	164.25ab	211.99a	212.23a
SEM ±	30.2083	16.166	16.429	16.733
Significance	**	**	*	*
Interactions				
T x C	NS	NS	NS	NS

Means followed by the same letter (s) within a treatment group are not significantly different at 5% level of significance using Duncan Multiple Range Test. SEM = standard error of mean, * Significant at $p \leq 0.05$, ** Significant at $p \leq 0.01$ and NS = not significant.

The index of sorptivity (α) showed moderate variability (CV 17.61%) with treatments imposed. The initial infiltration sorptivity of Kostiakov's model ranged from 0.51 to 1.336 with the values showing moderate variation with imposed treatments (CV 25.21%).

Comparison of measured first one-minute infiltration with the predicted first one-minute infiltration by Philip's and Kostiakov's models is illustrated in Figure 1. The measured (field) values of the first one-minute initial infiltration showed no significant difference with the first one-minute initial infiltration values predicted by both Philip's (Pr > |t|0.1472; SEM = 0.1580) and Kostiakov's (Pr > |t| 0.4937; SE = 0.10401) models as indicated by paired t test when the field values were fitted to these two models. Furthermore, it was observed that the calculated t value (-1.53) for the mean difference (-0.2424) of the 15 treatments for paired comparison t test for the Philip's model was lower than the table t values (2.145 and 2.977) at both 0.05 and 0.01 levels of significance respectively. Similarly, when the field values were fitted to Kostiakov's models, it was observed that the calculated t value (-0.70) for the mean difference (0.07311) of the 15 treatments for paired comparison t test was lower than the table t values at the 0.05 and 0.01 levels of significance.

Furthermore, the Chi square goodness of fit test which expresses the amount of disparity between the measured and predicted values of the two models, showed no significant difference between the measured and predicted. As the calculated chi square values (1.972 and 0.864) for both the Philip and kostiakov's models respectively were lower than the table chi square value (23.685 and 29.141) at 5% and 1% levels of significance respectively.

Comparison of measured cumulative infiltration with the predicted cumulative infiltration by Philip's and Kostiakov's models is presented in Figure 2. The differences between the means of measured values of cumulative infiltration and those predicted by Kostiakov's model (-1.96) were not significant (t value = -1.80; SEM = 1.094; Pr > |t|= 0.0937). Similarly, the differences between the means of measured values compared with those predicted by Philip's model (-19.09) did not show any significant disparity (t-value = -1.38; SE = 13.883 Pr > |t|= 0.1906). The Chi square goodness of fit showed there was no significant difference between measured and predicted cumulative infiltration under Kostiakov's model, as the calculated Chi square values (7.026) was lower than the table Chi square value (23.685 and 29.141) at 5% and 1% levels of significance respectively. However highly significant difference was observed when the measured cumulative infiltration was compared with those predicted by Philip model as the calculated Chi square value (32.086) was higher than the table Chi square. Although, when individual comparison of measured and Philip predicted cumulative infiltration for each treatment was made, only three (NTNC, CTNC and CTGm) out of all the 15 treatments imposed showed significant difference at 5% level of significance while the other 12 treatments showed no significant difference.

Table 3: Infiltration characteristics of the experimental field (mean across three cropping seasons)

Treatments	Initial infiltration (cm min^{-1})	Cumulative infiltration (cm)	Philip's model			Kostiakov's model		
			A	S	r^2	α	C	r^2
RT Gm	1.25	50.00	0.256	2.156	0.686	0.742	0.510	0.974
RT NC	2.80	31.00	0.013	2.408	0.031	0.493	0.920	0.982
RT Mu	3.00	40.50	0.014	4.324	0.004	0.536	1.336	0.926
RT Cm	3.00	43.00	0.149	2.874	0.254	0.624	0.897	0.905
RT Cp	4.00	51.00	0.104	3.662	0.554	0.548	1.294	0.990
NT NC	1.50	16.3	0.036	2.060	0.173	0.490	0.644	0.956
NT Gm	3.00	32.10	-0.013	2.875	0.063	0.483	1.075	0.993
NT Cp	3.00	54.00	0.147	3.973	0.308	0.600	1.258	0.977
NT Cm	2.10	30.00	0.005	2.775	0.002	0.532	0.933	0.977
NT Mu	2.00	26.50	-0.017	2.618	0.030	0.511	0.890	0.972
CT NC	3.10	17.2	0.122	2.609	0.616	0.354	1.063	0.989
CT Cm	2.30	20.10	0.020	2.024	0.093	0.470	0.728	0.979
CT Cp	2.70	30.20	0.022	2.415	0.207	0.507	0.904	0.993
CT Mu	3.40	25.00	-0.105	3.503	0.677	0.430	1.272	0.977
CT Gm	2.25	14.50	0.065	1.942	0.559	0.401	0.735	0.989
SEM±	0.1875	3.3545	0.0219	0.1839		0.0234	0.0627	
SD	0.7016	12.55	0.0851	0.7125		0.0905	0.2427	
CV%	26.68	39.11	46.98	26.50		17.61	25.21	

A = transmissivity; S = sorptivity; α = index of sorptivity of soil related to decline of infiltration rate; C = initial infiltration (sorptivity); r^2 = coefficient of determination; SEM = standard error of mean; SD = standard deviation; CV = coefficient of variability.

RTGm = reduced till + *Glycine max,* RTNC = reduced till + no cover crop, RTMu = reduced till + *Macrotyloma uniflorum,* RTCm = reduced till + *Cucurbita maxima,* RTCp = reduced till + *Centrosema pascuorum*, NTGm = no-till + *Glycine max,* NTNC = no-till + no cover crop, NTMu = no-till + *Macrotyloma uniflorum,* NTCm = no-till + *Cucurbita maxima,* NTCp = no-till + *Centrosema pascuorum*, CTGm = conventional till + *Glycine max*.CTNC = conventional till + no cover crop, CTMu = conventional till + *Macrotyloma uniflorum*, CTCm = conventional till + *Cucurbita maxima* and CTCp = conventional till + *Centrosema pascuorum.*

Effect of tillage and cover crop on number of earthworms per square meters

The effect of tillage practice and cover crops on number of earthworms per m^2 is presented in Table 4. It was revealed that effect due to tillage and cover crops on number of earthworms per m^2 for three years (i.e. 2011, 2012, and 2013); and the mean across the years of study followed a similar trend. Plots under NT treatments consistently had significantly higher number of earthworms per m^2, relative to the RT and CT treatment plots. However, the CT treatment plot recorded the least number of earthworms per m^2. No-till and Reduced till systems had 127.76% and 66.73% respectively more earthworm per m^2 than the conventionally tilled soil.

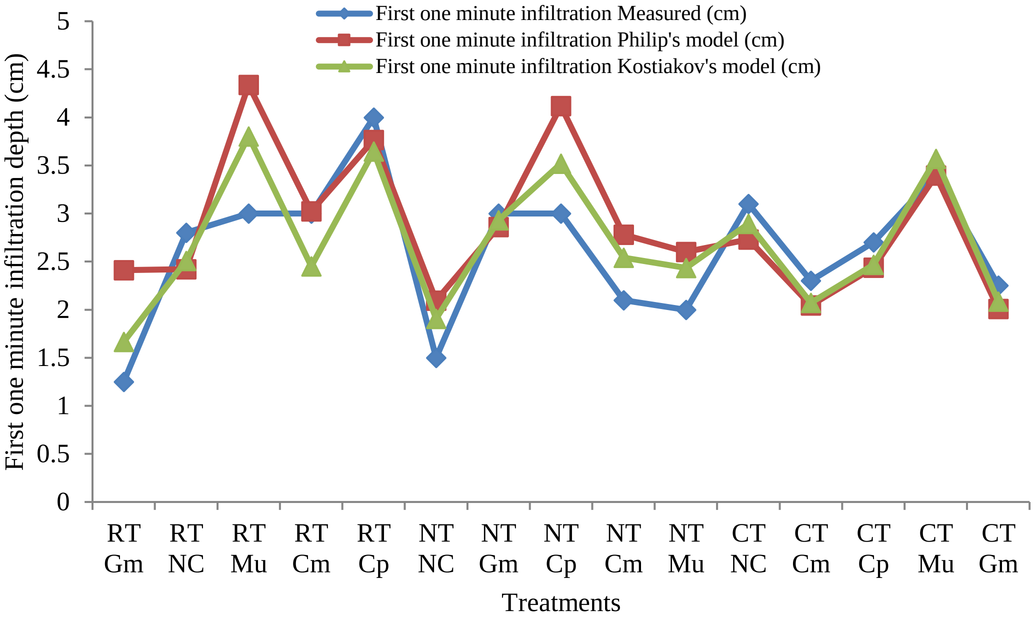

Figure. 1: Comparison of measured first one minute infiltration with the predicted first one minute infiltration by Philip's and Kostiakov's models.

RTGm = reduced till + *Glycine max,* RTNC = reduced till + no cover crop, RTMu = reduced till + *Macrotyloma uniflorum*, RTCm = reduced till + *Cucurbita maxima*, RTCp = reduced till + *Centrosema pascuorum*, NTGm = no-till + *Glycine max*, NTNC = no-till + no cover crop, NTMu = no-till + *Macrotyloma uniflorum*, NTCm = no-till + *Cucurbita maxima*, NTCp = no-till + *Centrosema pascuorum*, CTGm = conventional till + *Glycine max* CTNC = conventional till + no cover crop, CTMu = conventional till + *Macrotyloma uniflorum*, CTCm = conventional till + *Cucurbita maxima* and CTCp = conventional till + *Centrosema pascuorum.*

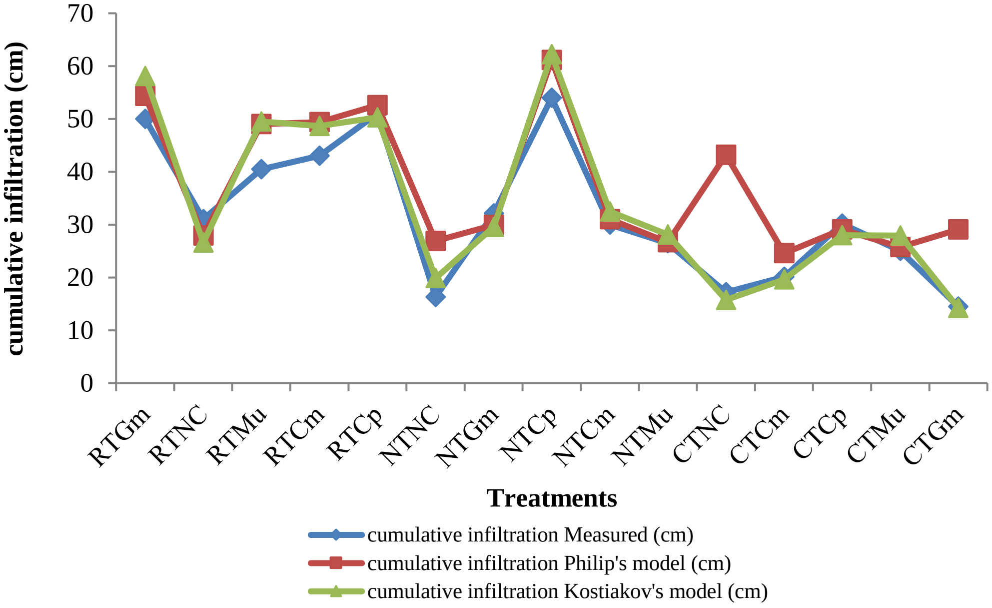

Figure 2. Comparison of measured cumulative infiltration with the predicted cumulative by Philip's and Kostiakov's models.

Variations due to different cover crops revealed that plots under CP and MU had significantly higher number of earth worms per m^2 than the GM and CM treatment plots while the bare (NC) plot recorded the least number of earthworms per m^2. Generally, with respect to the combine analysis there was 2.7 times more earthworms in plots with either CP or MU as cover crop relative to the bare plot. However, plots with either GM or CM have 2.33 times more earthworms relative to the plots with no cover crop.

Interaction between tillage and cover crops for all for all the 3 years and the combine across the years was highly significant. Since, the result across the years of experimentation followed a similar trend, thus; only the interaction result for the combine analysis across the years of study is presented.

Figure 3 shows the interaction between tillage and cover crops on number of earthworms per m^2. Treatment plots NTCP and NTMU had significantly higher number of earthworms per m^2 relative to all other tillage and cover crop combinations, they were followed by treatment plots NTGM then NTCM which were statistically higher than all combinations of reduced till and conventional till with cover crops. However, the number of earthworms per m^2 in RTMU, RTCP and RTCM treatments were statistically at par but recorded significantly higher number of earthworms per m^2 than the following listed treatments, which were in the order viz: RTGM > CTMU > CTCP >CTGM > NTNC > CTCM > RTNC > CTNC. The least number of earthworms per m^2 was in the CTNC treatment plot.

Table 4: Tillage and cover crop effects on number of earthworms per m^2 during the 2011, 2012, 2013 cropping seasons and the mean across the three years in a Typic haplustults at Samaru, Nigeria.

Treatments	2011	2012	2013	Combined
Tillage (T)	Number of earthworms per m^2			
No till	73.93 a	71.33 a	80.22 a	77.54 a
Reduced	52.20 b	53.12 b	51.78 b	52.37 b
Conventional	32.73 c	31.46 c	30.12 c	31.41 c
SEM ±	0.3782	0.3779	0.3791	0.3780
Significance	**	**	**	**
Cover Crops (C.)				
No Cover	27.22 c	25.33 c	20.66 c	24.46 c
Macrotyloma uniflorum	62.78 a	64.67 a	69.66 a	65.73 a
Centrosema pascorum	61.89 a	60.99 a	68.46 a	65.26 a
Glycine max	56.67 b	57.28 b	58.37 b	57.39 b
Cucurbita maxima	56.22 b	55.78 b	56.88 b	55.67 b
SEM ±	0.4883	0.4879	0.4888	0.4889
Significance	**	**	**	**
Interactions				
T x C	**	**	**	**

Means followed by the same letter (s) within a treatment group are not significantly different at 1% level of significance using Duncan Multiple Range Test. SEM = standard error of mean and ** Significant at $p \leq 0.01$.

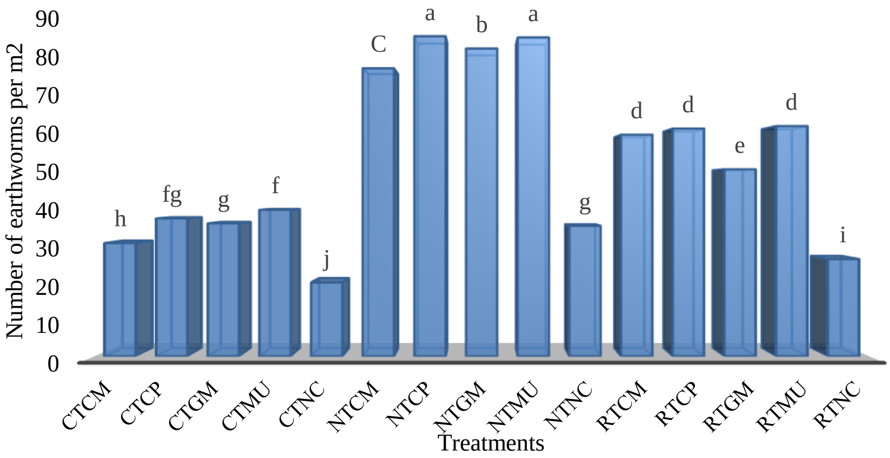

Figure 3: Interaction of tillage and cover crops on number of earthworms per m^2.

Bars followed by the same letter(s) are not significantly different at 1% level of significance using Duncan Multiple Range Test, SEM±0.8389.

RTGm = reduced till + *Glycine max,* RTNC = reduced till + no cover crop, RTMu = reduced till + *Macrotyloma uniflorum,* RTCm = reduced till + *Cucurbita maxima,* RTCp = reduced till + *Centrosema pascuorum,* NTGm = no-till + *Glycine max,* NTNC = no-till + no cover crop, NTMu = no-till + *Macrotyloma uniflorum,* NTCm = no-till + *Cucurbita maxima,* NTCp = no-till + *Centrosema pascuorum,* CTGm = conventional till + *Glycine max* CTNC = conventional till + no cover crop, CTMu = conventional till + *Macrotyloma uniflorum,* CTCm = conventional till + *Cucurbita maxima* and CTCp = conventional till + *Centrosema pascuorum.*

DISCUSSION

High infiltration rate in the no-till and reduced tillage soils could be attributed to the non/minimal disruption of soil pores especially the biopores which allows for better water infiltration in the NT and RT plots relative to the CT plot where tillage operations had disrupted continuity of natural soil pores and soil aggregates. Thereby, resulting into slaking of soil aggregates and absence of macro and biopores; hence, reduced water infiltration. Hangen *et al.* (2002) also reported higher vertical connectivity and continuity of macro pores in conservation tillage than in CT treatment. Furthermore, in the conservation tillage (NT and RT) systems plant residues were left on the soil surface, thereby improving soil organic matter content and consequently soil structure. More so, these plant residues provide improved habitation and sustenance for earthworms and other microorganisms. The population of earthworms in NT and RT plots in this study was 2.5 times (77.54 earthworms per m^2) and 1.7 times (52.37 earthworms per m^2) respectively higher than that in CT plots (31.41 earthworms per m^2). Earthworms play a key role in modifying the physical structure of soils by producing new aggregates and pores which improves soil tilth, aeration, infiltration and drainage. In addition, earthworms participate in plant residue decomposition, nutrient cycling and redistribution of nutrients in the soil profile as they feed; hence producing binding agents responsible for the formation of water-stable macro-aggregate. All these will enhance soil porosity as earth worms burrow and mix soils thus ensuring higher total soil porosity and infiltration rates in the NT and RT systems. Willoughby *et al.* (1997) reported higher infiltration rate in no-till treatments as a result of higher earthworms' activities. Similarly, Hubbard *et al.* (1999) reported that there are 2 – 3 times more population of earthworms in NT than in the conventionally tilled soil, because soil tillage causes destruction of burrows and depletion of surface residues.

The introduction of any of the selected cover crops in this study enhanced water infiltration into the soil relative to the bare plots with no cover crop. This could be an indication that bare soil is subjected to direct impact and erosive forces of raindrops that dislodge soil particles and overlying crop residues. Dislodged soil particles fill in and block surface pores, contributing to the development of surface crust (during alternating wet-dry condition) which restrict water movement into the soil, and encourages runoff and erosion. Furthermore, all plots with cover crop on the average had 2.5 times (61 earthworms per m^2) more earthworms than the bare plots (24.5 earthworms per m^2). Crop rotation or intercropping with legumes and cover crops encourages earth worm's activities (burrowing and cast formation) because of the quantity and quality of residues produced from this cropping system, as stated earlier, sustains the earthworms and enhances soil microbial activities thereby improving soil porosity and aggregation (Hubbard *et al.*, 1999) and consequently facilitating infiltration.

The coefficient of determination (r^2) was within 0.003 and 0.68 for the Philip's model with a mean of 0.284 and a mean r^2 value of 0.971 for Kostiakov's model. Implying that Kostiakov's model accounted for almost all of the variability in the data and indicating that Kostiakov's model will give a better fit to the data. This further verify a close agreement of the measured infiltration and the Kostiakov's calculated infiltration rates, thereby confirming that the Kostiakov's model can be applied to estimate parameters and predict infiltration rates for soils of northern guinea savanna of Nigeria. Similar inferences had been reported by Kureve *et al.* (1995) and Wuddivira and Abdulkadir (2000) for the Typic Haplustalf soil type of the Northern Guinea savannah of Nigeria. Additionally, the use of Kostiakov's equation is practical and gives better result than the theoretically founded equation of Philip (1957) and Green and Ampt (1911) (Shukla *et* al., 2003). The higher transmissivity values obtained in some conservation tillage treatments indicates that conservation tillage improve soil structure hence water transmission properties. The negative values of transmissivity obtained in some treatments is due to reduction in infiltration rate i.e., infiltration rates for these three points started from high values (about 2 to 3.4 cm min^{-1}) and reduced rapidly to about 0.11 to 0.22 cm min^{-1} within two hours infiltration runs. This rapid decrease resulted in a steep on the regression line, to the extent that its extension intercepts the y axis below zero resulting in a negative intercept. This could be an indication that Philip's model must have restriction on structurally poor soils. Since negative values were obtained at longer periods when the first term is insignificant, prediction of infiltration rate using Philip's model is therefore possible within a limited time range. This may explain the non-significant differences obtained between the measured and the Philip predicted first one-minute infiltration rate as confirmed by Chi square test; as against the significant difference (poor prediction) obtained in the Philip predicted cumulative infiltration. The non-significant difference between calculated and measured values of the first one-minute infiltration rate showed that the difference between the measured and the predicted values was not significant. Therefore, both Philip's and Kostiakov's models could be used to predict the first one-minute initial infiltration into the soil of experimental fields. The non-significant difference observed between calculated and measured cumulative infiltration using paired t-test, shows that both Kostiakov's and Philip's model were suitable for predicting the cumulative infiltration. However, Kostiakov's equation showed superior performance over Philip's equation, this was evident from the lower standard deviation and CV values of Kostiakov's parameters, in addition to non-significant difference between measured and Kostiakov's predicted cumulative infiltration as revealed by the Chi square goodness of fit test. This finding is supported by that of Mustafa *et al.* (2003) who reported that observed cumulative infiltration from the field compared well with the predictions by Kostiakov's model.

CONCLUSION

Conservation tillage improved soil water infiltration rate due to soil pore continuity and earthworm's activities. Similarly, the use of cover crop protected the soil surface against erosive impact of rain drops hence improved soil water infiltration. The Kostiakov's infiltration model was more applicable in this study due to its superior performance over Philip's model, this was obvious from the lower standard deviation and CV values of Kostiakov's parameters, in addition to non-significant difference between measured and Kostiakov's predicted first one-minute and cumulative infiltration as revealed by the Chi square goodness of fit test. The Chi square test proofed to be a better test than the paired t test for making comparison between field measured and model predicted infiltration values in this study.

REFERENCES

Anderson, J.M. and Ingram, J.S.I. (eds) 1993. Tropical soil biology and fertility: A hand book of Methods 2nd edition. C.A.B International Wallingford, UK. pp. 221. In: Soil Science 157(4):265. April 1994. DOI: 10.2307/2261129.

Bremner, J.M. and Mulvaney, C.S. 1982. Nitrogen-total. In Page et al (eds) Methods of soil analysis. Part 2.

Chemical and microbiological properties, 2nd edition. pp. 595-624. Agronomy monograph 9.2, American Society of Agronomy, Madison, WI. DOI: 10.2134/agronmonogr9.2.2ed.c.31.

Duncan, D.B. 1955. Multiple Range and Multiple "F"-test Biometrics II: 1- 41. http://dx.doi.org/10.2307/3001478

Gee, G.W. and Or, D. 2002. Particle size analysis. In: Dane, J.H., Topp, G.C. (eds.), Methods of Soil Analysis, Part 4. Physical Methods. Soil Science Society America. Book Series No. 5, American Society of Agronomy and Soil Science Society of America, Madison, WI, pp. 255–293. DOI: 10.2136/sssabookser5.4.c12

Grossman, R.B. and Reinsch, T.G. 2002. Bulk density and linear extensibility. In: Dane, J.H., Topp, G. C. (eds), Methods of Soil Analysis, Part 4. Physical Methods. Soil Science Society America. Book Series No. 5, American Society of Agronomy and Soil Science Society of America, Madison, WI, pp. 201–228. DOI:10.2136/sssabookser5.4.c9.

Hangen, E., Buczko, U., Bens, O., Brunotte, J. and Heuttle, R.F. 2002. Infiltration patterns into two soils under conventional and conservation tillage: Influence of spatial distribution of plant root structures and soil animal activity. Soil and Tillage Research. 63(3):181-186. DOI: 10:1016/S0167-1987(01)00234-3.

Hubbard, V.C., Jordan, D., Stecker, J.A. 1999. Earthworm response to rotation and tillage in a Missouri Claypan soil. Biology and Fertility of Soils. 29(4),343-347. DOI: 10.1007/s003740050563.

Jones, M.J. and Wild, A. 1975. Soils of the West Africa Savanna. Technical Communication. *No. 55.* Harpenden. Commonwealth Bureau of Soils. https://doi.org/10.1177/030913337700100122.

Kothari, C.R. and Garg, G. 2014. Research methodology, methods and techniques, third edition. New age international publishers. India. 449 pp. ISBN 10:8122436234, ISBN 13:9788122436235

Kureve, B. L., Jensen, J. R., Adeoye, K. B. and Chude, V. O., 1995. Water intake characteristics of a Savannah soil. Nigerian Journal of Soil Science. 11:54-61. https://www.ajol.info/index.php/njss.

Lawal, H.M. 2017. Maize seedling emergence and growth as influenced by soil penetration resistance and bulk density under varying tillage practices and cover crops. Nigerian Journal of Soil and Environmental Research. 15:1-16. Ahmadu Bello University, Zaria Nigeria. https://www.abu.edu.ng/njser ISSN 1595 – 61 21.

Mclean, E.O., 1982. Soil pH and lime requirement. In: Page, A.L. (ed.), Methods of Soil Analysis, Part II, 2nd ed., America Society of Agronomy Monograph No. 9. Madison, WI, pp. 199–224. Doi:10.2134/agronmonogr9.2.2ed.c12

Mustafa, O.S., Arshad, M., Sattar, I., Ali, S. 2003. Adoption of Kostiakov model to determine the soil infiltration for surface irrigation methods under local conditions. International Journal of Agriculture and Biology. 5(1):40–42. http://www.ijab.org 1560-8530/2003/05-1-40-42

Nelson D.W and Sommers, L.E 1982. Total Carbon, Organic Carbon and Organic Matter. In Page, A.: Miller, R.H and Keeney, D.R (eds) Methods of Soil Analysis II American Society of Agronomy Madison NY 539-579. Doi:10.2134/agronmonogr9.2.2ed.c29

Oluwasemire, K.O. and Alabi, S. O. 2004. Ecological impact of changing rainfall pattern, soil processes and environmental pollution in the Nigerian Sudan and northern Guinea savannah agro-ecological zones. Nigerian Journal of Soil Research. 5:23-31. https://www.abu.edu.ng/njser ISSN 1595 – 61 21.

Philip, J.R. 1957. The theory of infiltration. A sorptivity and algebraic infiltration. Soil Science. 84:257–264.

SAS Institute Inc. 2008. SAS/STAT 9.2 user's guide Version 8 Vol.2. Cary. NC: SAS institute incorporation.

Shobayo, A.B., Aliyu, J., Malgwi, W.B. and Jimoh A. I. 2015. Characterization and classification of soils of the Institute for Agricultural Research (IAR) Horticultural Garden, Zaria. Paper presented at the 39th Annual Conference of the Soil Science Society of Nigeria at Landmark university Omu-Aran, Kwara state, Nigeria. March 2015.

Shukla, M.K., Lal, R., Unkefer, P., 2003. Experimental evaluation of infiltration models for different land use and soil management system. Soil Science. 168(3):178-191. DOI:10.1097/01.ss.0000058890.60072.7c

Snedecor, G.W. Cochran, W.G. 1967. Statistical Methods. Ames IA, 6th edition. The Iowa State University Press, U.S.A. 38. 135-137. Doi:10.2307/2530332.

Weil, R.R. and Brady, N.C. 2017. The nature and properties of soil. 15th edition Pearson Education limited, Edinburgh Gate, Harlow, Essex CM20 2JE, England. 1071pp. ISBN 978-0-13-325448-8, ISBN 10: 1-292-16223-6, ISBN 13: 978-1-292-16223-2

Wilding, L.P., Bonma J., Boss, D.W. 1994. Impact of spatial variability of interpretive modelling, pp. 61-75. In*;* Bryant, R.B. and Arnold, R.W. (eds.). Quantitative Modelling of Soil Forming Processes. Soil Science Society of America. Special Publication No 39 Madison, USA. DOI:10.2136/sssaspecpub39.c4.

Willoughby, G. L., Kladivo, E. J. and Savabi, M. R. 1997. Seasonal variations in infiltration rate under no-till and conventional (disk) tillage systems as effected by *Lumbricus terrestris* activity. Soil Biology Biochemistry. 29: (3-4) March- April, 481-484. https://doi.org/10.1016/50038-0717(96)00039-9

Wuddivira, H.N. and Abdulkadir, A. 2000. Determination of infiltration characteristics of a Typic haplustalf in Samaru, Northern Guinea Savanna, Nigeria. In: O. Babalola, (ed.) Proceedings of the 26th Annual Conference of the Soil Science Society of Nigeria. 30 October to 3 November, 2000. Ibadan, Nigeria. pp. 99 - 101.

Samaru, Northern Guinea Savanna, Nigeria, In: O. Babalola, (ed.) Proceedings of the 26th Annual Conference of the Soil Science Society of Nigeria. 30 October to 3 November, 2000. Ibadan, Nigeria. pp. 99 - 101.