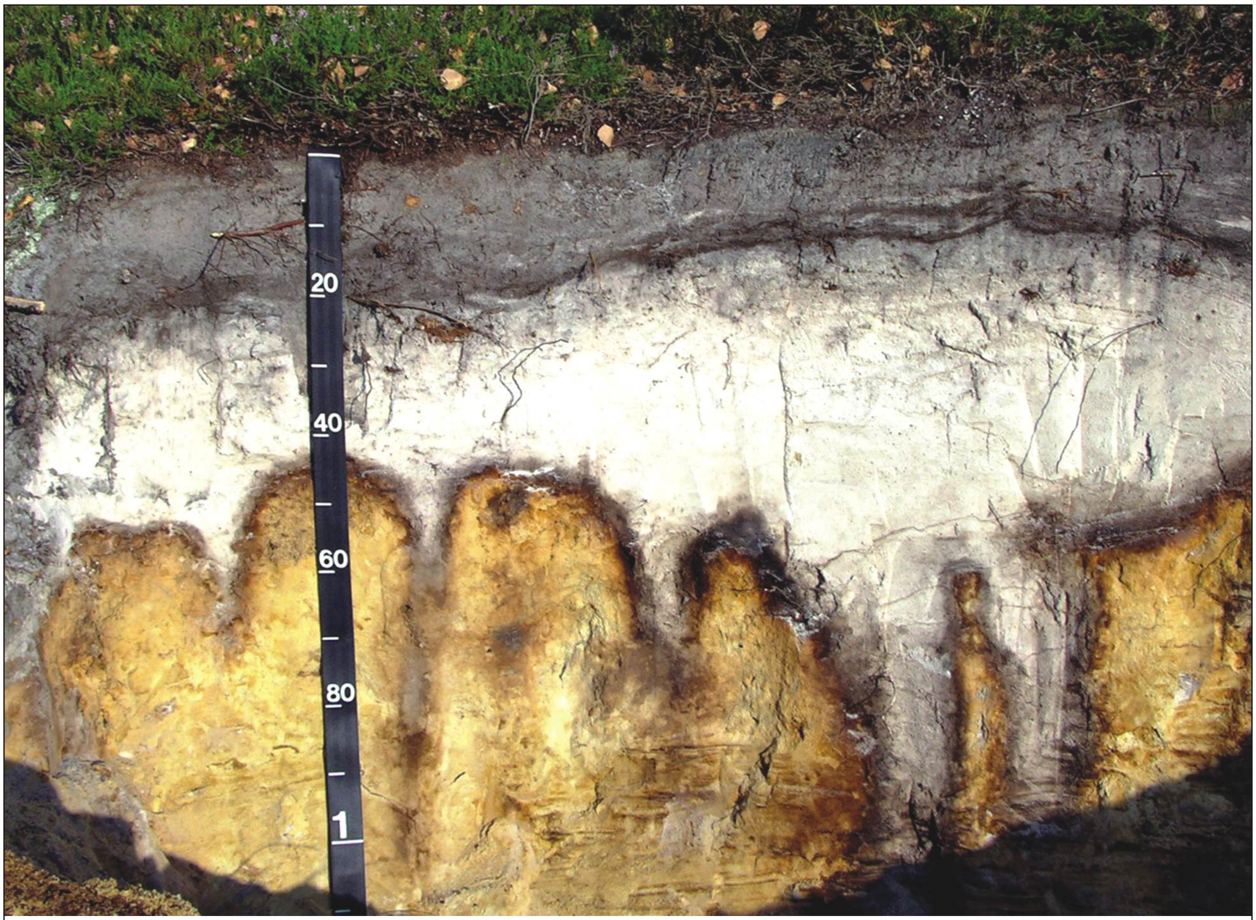

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Research Article
Impacts of Varying Tillage Operations on Infiltration Capacity of Agricultural Soils

[1,3]Christopher O. Akinbile, [1]Olanipo A. Famuyiwa, [2]Fidelis O. Ajibade and [1]Toju E. Babalola

[1]Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure, Nigeria
[2]Department of Civil and Environmental Engineering, Federal University of Technology, Akure, Nigeria
[3]Department of Biological and Agricultural Engineering, Universiti Putra Malaysia, Selangor, Malaysia

Abstract
Three tillage practices, Zero Tillage (ZT), Minimum Tillage (MT) and Conventional Tillage (CT) on infiltration capacity and other physicochemical soil properties were investigated using, double ring infiltrometer at two locations which were Agricultural and Environmental Engineering (AGE) research farm and Federal University of Technology, Akure (FUTA)'s Teaching and Research (T and R) farm. Soil physicochemical properties determined include; bulk density, porosity, moisture content, organic matter, organic carbon, pH, sodium, potassium, calcium and magnesium. Two models, Kostiakov and Philips were also used to model infiltration rates and results were compared with measured values and were subjected to statistical analysis. Linear relationship exists between infiltration rate and duration of water application and all infiltration rates decreased as time increased. High correlation (R^2) values were obtained for the two farms and in the three treatments which were 0.979 and 0.984 for ZT, 0.962 and 0.996 for MT and 0.999 and 0.997 for CT for both AGE and T and R farms, respectively. Although, T and R farm has higher infiltration rates when compared with the AGE farm, Kostiakov and Philips models showed that Minimum Tillage (MT) on AGE farm was the best of all the tillage treatments considered.

Key words: Infiltration rate, Kostiakov, Philips, soil, tillage, FUTA

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Corresponding Author: Christopher O. Akinbile, Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure, Nigeria Tel: +2348035798635

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Tillage is one of the key soil management practices in agricultural land use and is one of the fundamental agro technical operations because of its influence on soil properties, environment and crop production (Abdollahi *et al*., 2015). The fundamental purpose of tillage includes; among other things, to prepare suitable seed bed for plant growth, destroy competitive weed and improve physical soil conditions. Tillage practices greatly influence the soil physical properties which in turn affect soil structure. Physicochemical and biological processes in soils are largely influenced by its properties. Several studies have addressed how these properties change with tillage intensity (McVay *et al*., 2006) and ideally, it is recommended to keep soil properties at optimum (Husnjak *et al*., 2002), but tillage systems result in soil modification and often degradation. The magnitude of change in bulk density depends upon its antecedent properties, time of measurement and depth and intensity of tillage operations. Most of the studies have reported a decrease in bulk density with increase in tillage intensity (Bhattacharyya *et al*., 2008; Li *et al*., 2007). Tillage affects the soil water status as well as the capacity of plants to utilize it, while it also increases detention of surface water and its entry into the soil. It has been shown that tillage can increase hydraulic conductivity (Bhattacharyya *et al*., 2008) and improve water use efficiency (Li *et al*., 2007). Tillage also influences soil wetness through reduction in evaporation and weed control. The changes in surface roughness and plant residue cover are effected by tillage and can influence the thermal regimes of the soil. One crucial function of soil is transmission of water, which directly affects plant productivity and the environment (Akinbile and Ogedengbe, 2006).

Tillage operations have effect on soil structure and the rate of infiltration which is simply referred to as water movement into the soil surface. The rate at which infiltration occurs is controlled by the inherent properties of the soil, the level of soil saturation when rainfall starts and by the ways in which humans have modified the landscape. Infiltration rates, in turn, control runoff rates and soil erosion, which are important because these processes influence the quality and quantity of our water resources (Akinbile, 2010). The nature of pores and water content are the most important factors determining the amount of precipitation that infiltrates and the amount that run off. High infiltration rate increases the amount of water stored in the soil for plant use and also reduce flood threats and erosion resulting from runoff. Raindrops increases infiltration due to its impact on bare soil while overgrazing, deforestation and soil compaction resulting from traffic decreases infiltration rate (Akinbile, 2010). The infiltration rate actually experienced in a given soil depends on the amount and distribution of soil moisture and on the availability of water at the surface and there is a maximum rate at which the soil in a given condition can absorb water. This upper limit is called the infiltration capacity which varies from one type of soil to the other depending on the aggregates, bulk density, porosity and also the type of tillage practiced on the soil (Kurothe *et al*., 2014). Conversion from conventional tillage to zero tillage usually increases available water capacity and infiltration rate (Bhattacharyya *et al*., 2008; McGarry *et al*., 2000) and decreases runoff (Wright *et al*., 1999). It has been reported that untilled compared to tilled soil had greater (Arshad *et al*., 1999; McGarry *et al*., 2000) and lower infiltration rates (Gomez *et al*., 1999). Therefore, this study was conducted to investigate the effects of tillage practices on soil properties and most especially the infiltration capacity of the soil.

MATERIALS AND METHODS

Site description: Two research sites were chosen for the study which were the Agricultural and Environmental Engineering (AGE) farm and the University Teaching and Research (T and R) farm and are both within the premises of the Federal University of Technology, Akure, Nigeria. Akure is a city in South western Nigeria and is the capital of Ondo State which lies within latitude 7.14°North of the equator and longitude 5.08°East of the Greenwich Mean Time (GMT). Akure has a tropical humid climate with two distinct seasons, a relatively dry season from November-March and a rainy season from April-October. Akure is about 351 m above the sea level. Akure is an area of about 2,303 km^2, situated within the western upland area. The soil is made up of ferruginous tropical soils (Ibitoye, 2001). Crystalline acid rocks constitute the main parent material of these soils. The main features include a sandy surface horizon underlain by a weakly developed clayey, mottled and occasionally concretionary sub-soil. The soil is however sensitive to erosion and occasional water logging as a result of the clay sub-soil. The soils have an exceptional clayey texture, but combine good drainage and aeration with good properties of moisture and nutrient retention (Akinbile, 2010).

Soil samples analysis: The 50±0.2 g of soils at depths 0-10, 0-20 and 20-30 cm were sampled randomly from the two farms to determine the following physicochemical parameters;

soil pH, Electrical Conductivity (EC) using Time Domain Reflectometry (TDR), bulk density, total porosity, phosphorus, soil moisture content, organic matter content and sodium and nitrogen.

Bulk density of the soils was determined by using Eq. 1:

$$\text{Bulk density} = \frac{\text{Weight of oven dried soil}}{\text{Volume of the soil}} \quad (1)$$

Total porosity was determined using Eq. 2 described by Suzuki *et al*. (2005) assuming a particle density of 2.65 mg m^{-3}:

$$PT = 1 - \frac{DS}{DP} \times 100 \quad (2)$$

Where:
PT = Total porosity
DS = Bulk density
DP = Particle density

Other parameters were determined in the University Central laboratory using the standards analytical methods as adopted by Dalal *et al*. (2011).

Validation of measured results with models: Two models, Kostiakov and Philips models were used validation the results obtained from the field by subjecting the modeled results with the measured results to comparative analysis and therefore generating equations for all the three tillage treatments on the two soils, AGE and T and R farms. Also, goodness of fits, correlation coefficients and Root Mean Square Error (RMSE) were also obtained. This is to validate findings from the measured results.

Kostiakov is given by Zhang *et al*. (2012) as Eq. 3:

$$f(t) = Akt^{a-1} \quad (3)$$

Where:
f = Infiltration mm h^{-1}
T = Time (min)
a and k are empirical parameters.

Philips model is given by Leite *et al*. (2010) as Eq. 4:

$$f(t) = St^{1/2} + K \quad (4)$$

Statistical analysis: Results were subjected to statistical analysis such as SPSS 18.0 with method used as between-subject factor. Differences were separated using *post hoc* test with a Bonferroni correction and significance level of $p<0.05$ used to determine significance.

RESULTS AND DISCUSSION

Physical and chemical properties of the sampled soils: Table 1 shows physicochemical properties of the two sets of soils, Table 2 shows the standards for assessing the constituents presence in the soils and Table 3 shows textural classification and other physical properties of soils analyzed respectively at two different locations in FUTA (AGE farm and the University (T and R) farm). When comparing the values

Table 1: Physicochemical properties of the soil

Parameters	AGE farm	SCH farm
Organic matter	5.040±0.02	5.43±0.05
Organic carbon	2.920±0.02	3.22±0.04
pH	6.920±0.02	6.79±0.02
N	0.910±0.02	1.10±0.01
EC	87.000±0.00	88.00±0.00
P (mg kg^{-1})	8.310±0.01	10.65±0.01
Na (mg kg^{-1})	10.580±0.04	11.01±0.01
K (mg kg^{-1})	16.800±0.00	14.20±0.00
Ca (mg kg^{-1})	22.000±0.00	19.45±0.07
Mg (mg kg^{-1})	2.440±0.01	2.41±0.01
Cu (mg kg^{-1})	1.245±0.01	1.87±0.01
CEC	14.270±0.10	13.04±0.74

Table 2: Soil science society of nigeria, standard for soil fertility nutrient

Parameters	Very low	Low	Moderate low	Moderate	High	Very high
P (mg kg^{-1})	<3	3.00-7.0	-	7.00-20	>20	-
K (cmol kg^{-1})	0.12-0.2	0.21-0.3		0.31-0.6	0.61-0.73	-
N (%)	0.03-0.05	0.06-0.1	0.11-0.15	0.16-0.2	0.21-0.34	
OC (%)	<0.3	0.40-1.0	-	1.01-1.50	1.51-0.02	>2.0
OM (%)	<0.67	0.68-1.72	-	1.73-2.59	2.60-3.45	>3.45
CEC (meq/100 g)	<6	6.01-12	-	12.01-25	25.01- 40	>40
BS (%)	<20	20.01-40	-	40.01-60	60.01- 80	>80
Ca^{2+}	<2	2.00-5.0		5.00-10	10.00-20	>20
Mg^{+}	<0.5	0.50-1.5		1.50-3	3.00-8	>8

Soil science society of Nigeria (2012)

Table 3: Textural classifications and some properties of the soil at various depths

	AGE farm			T and R farm		
	Depths (cm)			Depths (cm)		
Parameters	0-10	10-20	20-30	0-10	10-20	20-30
MC	12.07±1.56	9.50±2.02	8.78±1.44	10.70±0.2	9.93±1.07	6.18±1.77
BD (g)	01.44±0.14	1.66±0.12	1.62±0.07	1.57±0.07	1.67±0.08	1.59±0.12
P (cm^3)	00.46±0.05	0.37±0.04	0.39±0.02	0.38±0.04	0.37±0.02	0.40±0.05
Clay (%)	35.20±0.01				32.00±0.28	
Silt (%)	36.00±0				27.00±0	
Sand (%)	32.80±0				42.45±0.07	
USDA class	clay loam				clay loam	

obtained in most of the parameters with the standards (Table 2), the nutrients were present in sufficient quantities and even most were very high in terms of composition in the soil. The average OM, pH, OC and others were almost identical in the two soils which clearly underscored the intensity of agricultural practices going on simultaneously on both farms. Page *et al*. (2013) remarked that OC is often associated with the OM which showed that increase in OM would result in increase in OC. The actual amount of soil carbon that could be stored is dependent on the farming system, soil types and climatic condition, as well as the initial soil carbon level of the site (Mishra *et al*., 2010).

Other nutrients such as nitrogen, phosphorus, sodium, copper were in higher proportion at the T and R farm when compared with the AGE farm while the AGE farm on the other hand had higher composition in constituents such as potassium, calcium and magnesium when compared with T and R farm. The high potassium is as a result of introducing cover crops to farm and leading to high amount of calcium and magnesium because too much potassium ties up calcium. Excess magnesium tightens the clay soil restricting air, water availability and organic matter decay (Roper *et al*., 2010) which could be the result of having more clay content and less organic matter in the AGE farm.

The soil classification was carried out using the USDA textural class triangle for the two locations and it was found to be clay loam with percentage clay, slit and loam to be 35.20±0.01, 36.00±0 and 32.80±0% for AGE farm while 32±0.28, 27.00±0 and 42.45±0.07% for T and R farm, respectively (Table 3). Little variations were observed in the compositions of the soil classes and from the analysis, T and R farm had highest sand content (42.45±0.07%) also with the lowest silt content (27.00±0%) while AGE farm had the highest clay composition (36.00±0%).

From Table 3, MC decreased with depth in both in both locations decreased with AGE having 12.07±1.56, 9.05±2.02, 8.78±1.44% for depths 0-10, 10-20 and 20-30 cm, respectively while, for T and R farm, 10.70±0.2, 9.93±1.07, 6.18±1.77%, respectively were recorded for the same depths as in AGE farm. The MC decreased as depth increased in both instances and this agreed with the work of Alvarez *et al*. (2014) who also noted that soil moisture increases with depth and that might be as a result of the terrain of the soil and may be the effect of subsequent rainfall during the time when the sample was taken. Glab (2014) and Tromp-van Meerveld and McDonnell (2006) also made similar observations in their studies. Bulk density varied with depth on both locations with depth 10-20 cm having the highest and depth 0-10 cm having the lowest. Increased activity of microorganisms resulting in increased OM, increased san and slit in the soil profile as well as increased activities of soil manipulation may have been responsible for this observation. Porosity also varied significantly with depth as depth 10-20 cm had highest porosity values ranging from 0.464-0.37 cm on the AGE farm while 0-10 cm depth lowest porosity on the T and R farm which ranged from 0.4-0.37 cm.

Infiltration rates in the two farm soils and under the three tillage operations: Figure 1, 2 and 3 show the infiltration rates observed using three different treatments which were zero (ZT), minimum (MT) and Conventional Tillage (CT) on both the AGE and T and R farms, respectively. One common phenomenon in all the figures was that infiltration rate decreased as time increased which could be as a result of high degree of saturation in the soils. This could also be responsible for the very high correlations obtained for the two farms and in the three treatments. Kishor *et al*. (2013) reported that there is a positive, direct and linear relationship between infiltration rate and saturation in soils as it was evident in this study. High correlation (R^2) values were obtained for ZT (0.979 and 0.984), MT (0.962 and 0.996) and for CT (0.999 and 0.997)

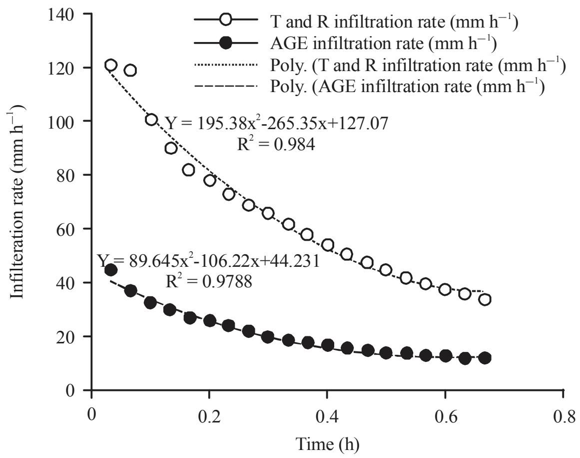

Fig. 1: Combined Infiltration rate curve of soils in both AGE and T and R farms at ZT

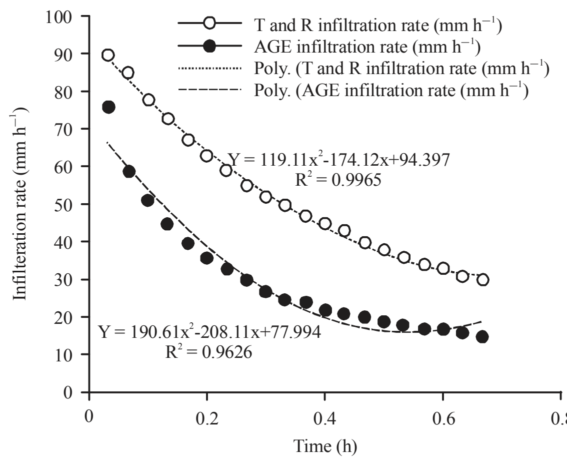

Fig. 2: Combined Infiltration rate curve of soils in both AGE and T and R farms at MT

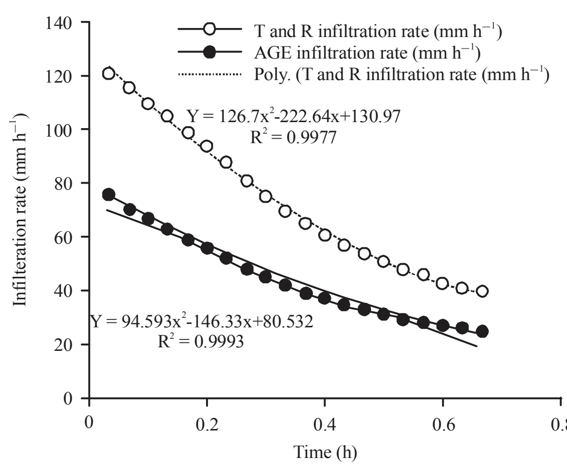

Fig. 3: Combined Infiltration rate curve of soils in both AGE and T and R farms at CT

Table 4: Models of the three tillage methods on the two farms using Kostiakov and Philips equations

	Kostiakov equation	
Treatments	AGE farm	T and R farm
ZT	$F=11.91t^{-0.41}$	$F=38.55t^{-0.38}$
MT	$F=14.85t^{-0.50}$	$F=33.08t^{-0.33}$
CT	$F=27.89t^{-0.34}$	$F=46.47t^{-0.34}$
Philips equation		
ZT	$F=8.36t^{-1/2}+3.95$	$F=23.25t^{-1/2}+17.18$
MT	$F=15.17t^{-1/2}-1.02$	$F=15.86t^{-1/2}+19.45$
CT	$F=13.63t^{-1/2}+16.03$	$F=22.05t^{-1/2}+27.35$

ZT: Zero tillage, MT: Minimum tillage, CT: Conventional tillage

for both AGE and T and R farms, respectively (Fig. 1, 2 and 3). This is an indication that a linear relationship exist between the infiltration rate and duration of water application, the longer there is water application, the more deeper the water Infiltrates into the soil until such a time when the soil is saturated, at that time, further increase in water application with longer time does not implied higher infiltration. The soil will plateau and therefore, super saturation and surface runoff would be inevitable and it agreed with the findings of Yao *et al.* (2015). Another issue of note was the infiltration rate at time zero on both soils which was higher in T and R farm when compared with AGE farm which speaks volume of the porosity, degree of compaction and bulk density of the soils in both farms. Under ZT, infiltration rate was 45 mm h^{-1} in AGE farm while it was 121 mm h^{-1} in T and R farm. The same trends were observed in the two other treatments, MT, it was 76 mm h^{-1} in AGE farm while it was 90 mm h^{-1} in T and R farm. For the CT, infiltration rate was 76 mm h^{-1} in AGE farm but was 121 mm h^{-1} in T and R farm. From these values, infiltration was higher in T and R farm when compared with AGE farm under all the tillage types. This further gave credence to relative higher values of bulk density and low MC values which were recorded in T and R farm and further supported the findings of Saito *et al.* (2010).

Kostiakov and Philips models' for modeling infiltration rates in the two soils and three tillage treatments: Two models, Kostiakov and Philips were used to model infiltration rates on the two farm soils under three tillage treatments and the modeled results were compared with the measured results obtained from the field measurements. The results were as presented in Table 4. Linear relationships were obtained in all the soils under the three tillage treatments which corroborated the linear relationship obtained between the infiltration rate and time.

Table 5 contains information regarding basic statistics of comparing the two models, their correlation coefficients and

Table 5: Comparison of goodness of fit for two infiltration equations in the treatments

Locations	Models	Constant coefficients	R^2	RMSE (mm h^{-1})
AGE farm (ZT)	Philip	a = 8.360, b = 3.95	0.936	2.4213
	Kostiakov	a = 11.91, n = -0.41	0.951	1.7688
AGE farm (MT)	Philip	a = 15.17, b = -1.02	0.971	3.5183
	Kostiakov	a = 14.85, n = -0.50	0.969	3.6179
AGE farm (CT)	Philip	a = 13.63, b = 16.03	0.771	23.3563
	Kostiakov	a = 27.89, n = -0.34	0.826	16.9090
SCH farm (ZT)	Philip	a = 23.25, b =17.18	0.854	42.7257
	Kostiakov	a = 38.55, n = -0.38	0.884	31.942
SCH farm (MT)	Philip	a = 15.86, b =19.45	0.845	24.8474
	Kostiakov	a = 33.08, n = -0.33	0.872	16.9178
SCH farm (CT)	Philip	a = 22.05, b = 27.35	0.768	78.8681
	Kostiakov	a = 46.47, n = -0.33	0.769	58.8467

ZT: Zero tillage, MT: Minimum tillage and CT: Conventional tillage

Root Mean Square Error (RMSE) and degree of relationships with the measured infiltrations rates on the two soils and three tillage treatments. Highest correlation values were recorded between modeled and measured values on AGE farm with MT. Philips model gave R^2 value of 0.971 while, Kostiakov model gave the value of 0.969. This inferred that although all the tillage treatments are good for effective infiltration, the best in the context of good was minimum tillage in AGE farm as shown by the measured results and also modeled using the two models. This clearly underscored the findings of Zhang *et al.* (2012) on the efficacy of modeling in soil water studies.

CONCLUSION

From the studies, it has been shown that tillage practices have profound effect on soil's physical and chemical properties. Although the results revealed that University (T and R) farm has higher infiltration rates when compared with the AGE farm which perhaps was due to continuous cultivation year-in year-out and higher MC, the models, Kostiakov and Philips showed that Minimum Tillage (MT) on AGE farm was the best of all the tillage treatments considered. There was no significant difference between MT and CT at AGE farm on infiltration rates while significant difference was observed between the two treatments at the T and R farm perhaps due to the use of tillage implements. Further results showed that initial MC determined the initial infiltration rate while porosity was responsible for the total available moisture in pore spaces at point of saturation. It was also shown that infiltration capacity increased in the order of ZT, MT and CT, respectively on the AGE farm which inferred that infiltration capacity increased with porosity.

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