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# Adaptability of Infiltration Equations to the Soils of the Permanent Site Farm of the Federal University of Technology, Minna, in the Guinea Savannah Zone of Nigeria

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## *Abstract*

*Infiltration refers to water moving into soil from rainfall or irrigation and is the first stage of water movement in the soil. Infiltration rate usually shows a sharp decline with time from the start of the application of water. The initial soil moisture content at any given time was considered to influence the initial rate and total amount of infiltration, both decreasing as the soil moisture content rises. The infiltrometer rings were placed at random distance from each other and the measurement was taken to the nearest centimeter. Water from jerry-cans was poured into the infiltrometer compartments simultaneously and as quickly as possible. As soon as the jerry-cans were emptied, the water level from the inner cylinder was read from the float (rule) and the local time was also noted. Repeated readings were taken at intervals of 0, 1, 2, 5, 10, 15, 20, 30, 45, 60, 75, 90, 100 and 120 minutes. The percent count of R square values from the curve fittings from which it could be observed that the Kostiakov's equation has the best fit with 99.35% for fallowed land and 98.79% for cultivated land. Although Philip's equation had a R square value of 53.10% for cultivated land and 55.22% for fallowed land, when compared with the R square value of Kostiakov's, it was far lower, since Philip's model is limited to swelling homogenous soils and for vertical flow while Kostiakov's equation has no limitation. It is also known to apply to the three-dimensional flow.*

**Keywords:** *Kostiakov's equation, Philip's equation, Horton's equation, R square.*

## Introduction

Soil water represents a minimal part of the water on our planet but it is certainly one of the most important. The soil plays a central role in the rate at which water is taken in into the various root zones of plants. Horton (1933) explained the importance of infiltration in the hydrological cycle. Infiltration refers to water moving into soil from rainfall or irrigation and is the first stage of water movement in the soil. It is of great importance in any irrigation plan. For any runoff problem to be solved, it is important to know the infiltration rate, the soil water content after infiltration and the adaptability of some of the infiltration equations to these soils. In hydrological cycle, a falling drop of water may be intercepted by vegetation or may fall directly on the ground. Water on reaching the earth surface is either evaporated to the atmosphere or enters into the soil (infiltration) or as runoff on the soil surface. Infiltration starts as soon as the first drop of rainfall touches the ground surface and continues even after precipitation ceases until the soil is filled to field capacity.

Infiltration rate may be limited by two factors; rainfall intensity and hydraulic conductivity of the soil. There are three processes of water movement within the soil which are the passage of water through the soil surface, movement of water through the soil mass (percolation) and depletion of soil moisture storage.

Infiltration rate usually shows a sharp decline with time from the start of the application of water. The constant rate approached after a sufficiently large time is referred to as the steady infiltration rate. This process is described by several equations showing a decreasing infiltration rate as a function of time.

The mathematical theory of vertical infiltration based upon the solution of the Richards equation (Pillsbury and Richards 1954) as cited by Philip (1969) is given as

$$\frac{d\theta}{dt} = \frac{d}{dz}\left[K(h)\left(\frac{dh}{dz}+1\right)\right], \qquad (1)$$

where $\theta$ is the volumetric moisture content ($m^3/m^3$), $t$ is the time (sec), $z$ is the gravitational potential, $K$ is the hydraulic conductivity (m/sec), $h$ is the hydraulic potential (m) and $K(h)$ is the hydraulic conductivity which is a function of $h$. The infiltration model was derived from Darcy`s equation:

$$q = -k\Delta h, \qquad (2)$$

where $q$ is the flow rate ($m^3/s/m$), and $h$ is the hydraulic potential (m).

## Kostiakov's Equation

The functional relationship between infiltration, $I$, and time, $t$, is given by the equation

$$I = Mt^n + b \qquad (3)$$

where $I$ is the Infiltration rate (cm/hr). The values of $b$, $M$ and $n$ may be determined by the method of averages using the procedure suggested by Davis (1943). The first step is to plot the graph of infiltration rate, $I$, against time, $t$ and using normal graph, choose two points ($t_1$, $I_1$) and ($t_2$, $I_2$) on and near the extremes of the smooth curve representing the data. After which, a point $t_3\surd\, t_1, I_1$ is chosen, $I_3$ is read against $t_3$. The value of $b$ is then determined by using the following equation:

$$b = \frac{I_1 I_3 - I^2{}_3}{I_1 + I_2 - 2I_3}. \qquad (4)$$

The value of $b$ would be subtracted from each value of $I$, and the logarithms of ($I - b$) and $t$ taken. Rearranging Eq. 3:

$$I - b = Mt^n. \qquad (5)$$

Taking the logarithm of Eq. 5:

$$\mathrm{Log}(I - b) = \mathrm{Log}\, M + n\, \mathrm{Log}\, t. \qquad (6)$$

The logarithm of the above equation helps to express it to the form of a straight line equation of the form $Y = Mx + C$ where $M$ is the slope, $X$ is the variable and $C$ is the intercept along the Y axis.

Assuming the relationship between $t$ and $I$ is expressed by Eq. 3, it is not important to determine the value of the rectifying factor, $b$, and the logarithm form of the expression will therefore take the form

$$\mathrm{Log}\, I = \mathrm{Log}\, M + n\, \mathrm{Log}\, t. \qquad (7)$$

To determine the values that fit the equation, the values of $I$ would be calculated by substituting the values of $b$, $M$ and $n$ in Eq. 3 for each value observed at $t$. However, the values may be substituted in the equation in the logarithm form. From Eq. 6:

$$I - b = \mathrm{Log}^{-1}\,(\mathrm{Log}\, M + n\, \mathrm{Log}\, t), \qquad (8)$$

$$I = \mathrm{Log}^{-1}\,(\mathrm{Log}\, M + n\, \mathrm{Log}\, t) + b. \qquad (9)$$

The instantaneous infiltration rate at any time, $t$, after the beginning of the test may be obtained from

$$\frac{di}{dt} = Mnt^{n^{2-1}}. \qquad (10)$$

## Horton's Equation

This equation is given by

$$I = I_c + (I_o - I_c)e^{-kt}. \qquad (11)$$

Changing Eq. 12 to the form of $Y = Mx + C$, we have to take the logarithm of both sides of the equation

$$\mathrm{Log}(I - I_c) = \mathrm{Log}(I_0 - I_c) - k\mathrm{Log}et, \qquad (12)$$

where $C$ is $\mathrm{Log}(I - I_0)$ which is the intercept on the $Y$-axis, $M$ is $k\mathrm{Log}e$ which is the slope and $X$ is the $t$ which is the variable.

If $M = k\mathrm{Log}e$, then:

$$K = \frac{-M}{Loge}. \qquad (13)$$

The results obtained will be used to plot the graph of the infiltration, $I$, against time, $t$, to obtain the value for $I_0$ and $I_c$. The coefficient of ($I_0 - I_c$) in Horton`s model according to Ahmed and Duru (1985) is constant for any given soil condition.

## Philip's Equation

The mathematical and physical analysis of the infiltration process developed by Philip (1957) separated the process into two components which are that caused by a sorptivity factors and that influenced by gravity. Sorptivity is the rate at which water will be drawn into a soil in the absence of gravity; it comprises the combined effects of absorption at surfaces of soil particles and capillarity in soil pores. The gravity factor is due to the impact of pore on the flow of water through soil under the influence of gravity. The Philip`s model takes the form of a power series but in practice an adequate description is given by the two-parameter equation

$$i = st^{\frac{1}{2}} + At\,. \qquad (14)$$

The value of the constants *A* and *S* can be determined by employing the method of multiple regression analysis. From the above equation, there is one dependent variable, *i* (cumulative infiltration, cm) and two independent variable $t^{-1/2}$ and *t* where *A* is the intercept and *S* is the slope. To know the goodness of fit, the values of *I* are calculated by substituting the values of *A* and *S* in the analytic expression in Eq. 13 for each observed value of it.

The rate of infiltration is determined by differentiating Eq. 14:

$$\frac{di}{dt} = \frac{1}{2} st^{-\frac{1}{2}} + A\,. \qquad (15)$$

The constants of *A* and *S* may be determined by plotting the graph of *di*/*dt* against $t^{-1/2}$.

The objectives of this study are to predict relative infiltration rates using some time dependent infiltration equations and to determine which of these equations best fits the soil of the permanent site farm of the Federal University of Technology Minna, Nigeria.

## Material and Methods

The Federal University of Technology permanent site is known to have a total land mass of eighteen thousand nine hundred hectares (18,900 ha) which is located along Km 10 Minna-Bida road, Southeast of Minna under the Bosso local Government area of Niger State. It has a horse-shoe shaped stretch of land, lying approximately on longitude of 06°28’ E and latitude of 09°35’ N (Sani 1999). The site is bounded at Northwards by the Western rail line from Lagos to the northern part of the country and the Eastern side by the Minna-Bida road. The entire site is drained by rivers Gwakodna, Weminate, Grambuku, Legbedna. Tofa and their tributaries. They are all ephemeral stream and the most prominent among them is the river Dagga.

The infiltration equations and models chosen for this research work are Kostiakov`s, Horton`s and Philip`s equations.

The initial soil moisture content at any given time was considered to influence the initial rate and total amount of infiltration, both decreasing as the soil moisture content rises (Michael 1992). The drier the soil, the greater the rate of entry of water because the gradient of the matric potential is then of greater magnitude. The initial moisture content of the soil per site was obtained by pushing a core sampler (50mm diameter and 50mm high) into the ground and was gradually brought out. The ends were scraped with a knife and the content emptied into moisture cans of known weights and covered immediately. In the laboratory, the cans were weighed and dried in an oven at 115°C for 24 hours, after which they were weighed again. The moisture content of the soil was obtained from

M.C. = [(Weight of wet soil + can) – (Weight of dry soil + can)]/(Weight of dry soil + can), (16)

where M.C. = moisture content.

According to Marshall and Holmes (1988), bulk density increases with the degree of compaction which may be due to the effect of cultivation practices and/or rainfall events on the top soil. A high bulk density would affect infiltration rates (Brady 1984). It has been noted that bulk density decrease is closely associated with an increase in infiltration capacity. Ahmed and Duru (1985) found a strong correlation between bulk density and infiltration rate of soil tested in Samaru, Kaduna State of Nigeria.

After all infiltration replicates had been completed in the given site, two of the spots where measurement had taken place were covered with a plastic sheet to prevent evaporation for about twenty-four hours. Eight soil samples were taken from this site, as described above for determination of field capacity and the bulk density. On each of each the two spots, two samples were taken on the surface and two at 50cm down the soil profile. The field capacity was determined in the same way as the initial moisture content. The bulk density (BD) was calculated from the equation given below:

BD = [(Weight of dry soil + can) – (Weight of + can)] / (Volume of core sampler). (17)

## Infiltration Measurement

The infiltrometer rings were placed at random distance from each other and the measurement were taken to the nearest centimeter. The rings were then driven into the ground by hammering a wooden bar placed diametrically on the rings to prevent any blowout effects around the bottoms of the rings. In areas where ridges and furrows existed, the inner rings were always placed in the furrow. A jute sack was then spread at the bottom of the inner and outer compartments of each infiltrometer so as to minimize soil surface disturbance when water was poured into the compartments. In areas covered by grass, they were cut as low as possible with a cutlass so that the float could have free movement and care was taken not to uproot the grasses. Four infiltration measurements were conducted at each location and average was taken later. Randomization technique was used to choose point measurements.

Water from jerry-cans was poured into the infiltrometer compartments simultaneously and as quickly as possible. As soon as the jerry –cans were emptied, the water level from the inner cylinder was read from the float (rule) and the local time was also noted. Repeated readings were taken at intervals of 0, 1, 2, 5, 10, 15, 20, 30, 45, 60, 75, 90, 100 and finally at 120 minutes. The cylinder compartment was refilled from time to time when the water level dropped half way. The water levels at both compartments (inner and outer) were constantly kept equal by adding water, as needed, into the outer compartment, which is faster. Some time was allowed before starting another replicate. So that no two infiltrometers should require reading at the same time, each replicate was allowed a time duration.

At each site, ten soil samples were taken using the 50mm x 50mm core sampler from the surface layer (0-50cm) in the area outside the outer rings. These were bulked for the determination of the initial moisture content and bulk densities.

## Results and Discussion

Table 1 shows the percent count of *R* square values from the curve fittings from which it could be observed that the Kostiakov's equation has the best fit with 99.35% for fallowed land and 98.79% for cultivated land. Although Philip's equation had a *R* square value of 53.10% for cultivated land and 55.22%for fallowed land, when compared with the *R* square value of Kostiakov's, it was far lower, since Philip's model is limited to swelling homogenous soils and for vertical flow while Kostiakov's equation has no limitation, it is also known to apply to the three-dimensional flow (Serrano 1990). Table 2 shows the average infiltration rate (cm/hr) for various land use practices during the dry and wet season while Table 3 shows the average infiltration rate for 12 weeks in fallowed and cultivated soils.

Table 1. The *R* square values for the three models used.

| % of *R* square greater than | Horton's | Philip's | Kostiakov's |
|---|---|---|---|
| 0.50 | Nil | 53.10 (Cultivated land) | Nil |
| | | 55.22 (Fallowed land) | Nil |
| 0.60 | 75.88 (Cultivated land) | Nil | Nil |
| 0.70 | 75.69(Fallowed Land) | Nil | Nil |
| 0.80 | Nil | Nil | 98.79 (Cultivated land) |
| 0.90 | Nil | Nil | 99.35 (Fallowed Land) |

Table 2A. Average infiltration rate (cm/hr) for the dry season for various land use practice.

| Time (min.) | Dry season | | | |
|---|---|---|---|---|
| | Fallowed land Cultivated land | | | |
| | Cum. water intake (cm) | Infiltration rate (cm/hr) | Cum. water Intake (cm) | Infiltration rate (cm/hr) |
| 0 | - | - | - | - |
| 1 | 0.82 | 49.00 | 1.33 | 79.50 |
| 2 | 1.42 | 42.50 | 2.38 | 71.50 |
| 5 | 2.65 | 31.58 | 4.94 | 58.58 |
| 10 | 4.30 | 25.80 | 8.56 | 51.35 |
| 15 | 5.72 | 22.87 | 11.73 | 46.90 |
| 20 | 6.93 | 20.80 | 15.22 | 45.90 |
| 30 | 9.15 | 18.28 | 21.45 | 42.86 |
| 45 | 12.56 | 16.75 | 28.98 | 39.98 |
| 60 | 15.61 | 15.61 | 38.42 | 38.42 |
| 75 | 36.38 | 14.34 | 46.00 | 36.80 |
| 90 | 21.33 | 14.22 | 53.98 | 35.99 |
| 100 | 23.09 | 13.86 | 58.35 | 34.99 |
| 120 | 26.54 | 13.27 | 67.45 | 33.91 |

Table 2B. Average infiltration rate (cm/hr) for the wet season for various land use practice.

| Time (min) | Wet season | | | |
|---|---|---|---|---|
| | Fallowed land Cultivated land | | | |
| | Cum. water Intake (cm) | Infiltration rate (cm/hr) | Cum. water Intake (cm) | Infiltration rate (cm/hr) |
| 0 | - | - | - | - |
| 1 | 0.72 | 42.98 | 0.91 | 54.68 |
| 2 | 1.22 | 37.09 | 1.60 | 47.85 |
| 5 | 4.93 | 29.58 | 3.32 | 39.42 |
| 10 | 4.96 | 25.55 | 5.74 | 34.44 |
| 15 | 5.89 | 23.55 | 5.74 | 31.12 |
| 20 | 7.85 | 22.16 | 9.56 | 28.83 |
| 30 | 10.10 | 20.17 | 13.18 | 26.35 |
| 45 | 13.56 | 17.86 | 18.61 | 24.81 |
| 60 | 16.96 | 16.81 | 23.69 | 23.73 |
| 75 | 20.47 | 16.36 | 28.43 | 22.74 |
| 90 | 23.95 | 15.99 | 33.15 | 22.10 |
| 100 | 25.97 | 15.63 | 36.26 | 21.74 |
| 120 | 30.04 | 15.02 | 41.49 | 20.75 |

Table 3. Average infiltration rate (cm/hr) for 12 weeks for the various land use practice.

| Time (min) | Fallowed land Cultivated land | | | |
|---|---|---|---|---|
| | cum. water intake (cm) | infiltration rate (cm/hr) | cum. water intake (cm) | infiltration rate (cm/hr) |
| 0 | - | - | - | - |
| 1 | 0.77 | 45.99 | 1.12 | 67.09 |
| 2 | 1.32 | 39.80 | 1.99 | 59.68 |
| 5 | 2.56 | 30.58 | 4.13 | 49.51 |
| 10 | 4.28 | 25.67 | 1.15 | 42.89 |
| 15 | 5.80 | 23.21 | 9.83 | 39.01 |
| 20 | 7.39 | 21.48 | 12.39 | 37.36 |
| 30 | 9.16 | 19.22 | 17.31 | 34.61 |
| 45 | 13.06 | 17.30 | 23.79 | 32.39 |
| 60 | 16.29 | 16.21 | 31.05 | 31.08 |
| 75 | 19.42 | 15.53 | 37.21 | 29.77 |
| 90 | 22.64 | 15.10 | 43.56 | 29.04 |
| 100 | 24.53 | 14.74 | 47.30 | 28.36 |
| 120 | 28.29 | 14.14 | 54.47 | 27.33 |

It was discovered that the infiltration rate of cultivated land when compared with the fallowed land was higher which may be due to the undisturbed nature of the soils. Where this is present, it will not allow easy penetration of water. Another reason may also be that the area under fallow may have a high water table. In the month of May, the cultivated land had an infiltration rate of 32.28cm/hr, and cumulative water intake rate of 64.57cm while the infiltration rate for the fallowed land was 11.30cm/hr and the cumulative water intake rate was 22.60cm; a reduction in the water intake rate was observed between the month of April and May which may be due to the two day rain during that month. In the month of June, a further reduction was observed in the cultivated land, an infiltration rate of 24.37cm/hr and a cumulative water intake rate of 48.74cm was observed respectively. There was further reduction in soil-water intake rate in the month of July, for the cultivated land the infiltration rate was 17.12cm/hr and cumulative water intake rate was 34.24cm while for the fallowed land the infiltration rate was 14.12 cm/hr and the cumulative water intake was 28.31cm. These reductions signifies the intense rate of rainfall during those months (April and May), which the test was carried out.

Table 2A shows the average infiltration rate (cm/hr) for the dry season for the various land use practices which show that the cultivated land had an infiltration rate of 33.91cm/hr while the cumulative intake was 67.45cm. The fallowed land infiltration rate was 13.27cm/hr and the cumulative water intake rate had a staggering figure because at the 75th minute, the intake rate increased to 36.38cm and at the 90th minute, it dropped to 21.33cm from were it increased gradually to 26.54cm at the 120th min. Table 2B shows the average infiltration rate (cm/hr) for the wet season for various land practice which shows that infiltration rate for the cultivated land was 20.75cm/hr while the cumulative water intake was 41.49cm and the fallowed land, the infiltration rate was 15.02cm/hr and the cumulative water intake was 30.04cm. When the data obtained from the dry and wet seasons were compared, the values of wet seasons were known to have a higher water intake rate. On the average, as seen on Table 3, the infiltration rate for cultivated land was 27.33cm/hr and the cumulative water intake was 54.47cm while for the fallowed the infiltration rate was 14.14cm/hr and the cumulative water intake was 28.29cm. It was observed, therefore, that on the average there was a higher water intake rate in the cultivated land when compared with the fallowed land which could possible be due to undisturbed nature of soil in the area.

Fig. 1 shows the best fit line for the graph of observed and calculated for 12 weeks during which the infiltration rate test was carried out in the study site. The percentage error for 12 weeks is 0.0325 for Kostiakov equation, 27.534 for Philip equation and 23.3043 for Horton equation for the whole farm site during cultivation period. Figure 2 shows the best fit line for the graph of observed and calculated for 12 weeks during which the infiltration rate test was carried out in the study site. The percentage error for 12 weeks is 0.03395 for Kostiakov equation, 37.726 for Philip equation and 21.030 for Horton equation for the whole farm site for fallowed soil. Figure 3 shows the best fit line for the graph of observed and calculated for dry season during which the infiltration rate test was carried out in the study site. The percentage error is 0.0563 for Kostiakov equation, 1458.2361 for Philip equation and 149.0171 for Horton equation for the cultivated soils during the seasons. Figure 4 shows the best fit line for the graph of observed and calculated for fallowed soils during dry season, which the infiltration rate test was carried out in the study site. The percentage error for the period is 13.2629 for Kostiakov equation, 1150.409 for Philip equation and 159.814 for Horton equation for the whole farm site for fallowed soils in the dry season. Fig. 5 shows the best fit line for the graph of observed and calculated for cultivated soils in the wet season during which the infiltration rate test was carried out in the study site. The percentage error for the period is -960.0281 for Kostiakov equation, 1132.154 for Philip equation and 129.3879 for Horton equation for the whole farm site during wet season cultivation period. Figure 6 shows the best fit line for the graph of observed and calculated for fallowed soils in the wet season during which the infiltration rate test was carried out in the study site. The percentage error for the period is -4076.2344 for Kostiakov equation, 1175.350 for Philip equation and 111.9058 for Horton equation for the whole farm site during fallowed soils in the wet season.

### Predicting Infiltration Rate

The chi-square/regression and least square methods were used to calculate the expected infiltration rate data for the three equations. The curve fitting methods gave an almost same figure for a given parameter in the equations considered. The cumulative infiltration is compared to the calculated data for the cumulative infiltration under Kostiakov's model, it shows a negligible difference between the calculated and the observed data as shown in the figures which makes the model closer in predicting infiltration rate when compared to those of Philip and Horton's. It is discovered that Philip model had a higher deviation in all cases tested which means that Kostiakov's model/equation adequately describes the field experimental data. It was observed that the figures obtained for the calculated cumulative infiltration was negative under the Kostiakov's equation as shown in Figs. 5 and 6. This could be due to the fact that water was being given off during the rainy season and also a clear indication that water is not required during the season on the farm, instead water is given off which in turn accounts for the *fadama* nature of some parts of the farm.

The result is similar to those of Eze (2000), Wuddirira (1998) and Ahmed and Duru (1985) who used similar models for the soil of Minna, Niger State and Samaru in Zaria (Kaduna State), respectively.

Table 4. Estimated soil parameters for infiltration for 12 weeks.

| Land Use Practice | Estimated Soil Parameter (Kostiakov's) | Estimated Soil Parameter (Philip's) | Estimated Soil Parameter (Horton's) |
|---|---|---|---|
| Cultivated Soil | $M$ = 1.069<br>$n$ = 0.821<br>$b$ = 0.054 | $A$ = 25.811<br>$S$ = 45.131 | $I_o$ = 67.09<br>$I_c$ = 27.33<br>$M$ = 0.006<br>Ø = 2.98 |
| Fallowed Soil | $M$ = 0.741<br>$n$ = 0.760<br>$b$ = 0.034 | $A$ = 12.259<br>$S$ = 26.506 | $I_o$ = 45.99<br>$I_c$ = 14.14<br>$M$ = 0.0081<br>Ø = $2.98^{-3}$ |

Table 5. Estimated soil parameters for infiltration for dry and wet seasons.

| Land Use Practice | Estimated Soil Parameter (Kostiakov's) | | Estimated Soil Parameter (Philip's) | | Estimated Soil Parameter (Horton's) | |
|---|---|---|---|---|---|---|
| | Dry | Wet | Dry | Wet | Dry | Wet |
| Cultivated Soil | $M$ = 1.2454<br>$n$ = 0.834<br>$b$ = 0.102 | $M$ = -1.3970<br>$n$ = 0.8363<br>$b$ = 1.9074 | $A$ = 6.6865<br>$S$ = 11.074 | $A$ = 4.0961<br>$S$ = 6.4691 | $I_o$ = 79.50<br>$M$ = 0.0057<br>$K$ = 0.0021 | $I_o$ = 54.68<br>$I_c$ = 20.75<br>$M$ = -0.0065 |
| Fallowed Soil | $M$ = 0.7269<br>$n$ = 0.7759<br>$b$ = 0.023 | $M$ = -3.9057<br>$n$ = 1.1265<br>$b$ = 0.0303 | $A$ = 2.9456<br>$S$ = 4.2292 | $A$ = 2.8682<br>$S$ = 3.8257 | $I_o$ = 67.09<br>$I_c$ = 27.33<br>$M$ = 0.006<br>Ø = 2.98 | $I_o$ = 42.98<br>$I_c$ = 15.02<br>$M$ = -0.0072<br>$K$ = -0.0026 |

## Conclusion

It was discovered that the infiltration rates of the tested soil range between 5.80 - 46.20 cm/hr. This infiltration capacity can become stable over a long period of time. Based on the end data obtained from the infiltration rates, Kostiakov's equation showed a better performance over those of Philip's and Horton's equations which is known to have the following parameters for cultivated soils of the irrigation farm site, $M$=1.069, $n$=0.821 and $b$=0.054 while for the fallowed soils of the same location as $M$=0.741, $n$=0.760 and $b$=0.034, based on the values, a higher degree of calculated infiltration data is observed in the case of Kostiakov than those of Horton and Philip's equation. The equation that best describe the irrigation farm of the Federal University of Technology, Minna, Niger State, Nigeria; is given as $Y = 0.4881x + 1.2192$; while that which describe the graph of cumulative infiltration against elapsed time $\{t(\text{mins.})\}$ as $Y = 0.5094x - 9.0431$ for the same area; where $x$ is the time. The infiltration tests performed during the dry season are preferable, as tests performed in the wet season are unlikely to reflect the stable soil characteristics which show the influence of antecedent soil water content on the measured infiltration capacity.

## Recommendation

It is recommended that Kostiakov's equation is appropriate for the tested soils and other similar soils of the Federal University Of Technology, Minna. The usefulness of this infiltration model can be used to design and carefully plan irrigation projects on this part of the campus. A theoretically derived equation may have physical significance but the assumption made could cause serious deviation from field conditions. Secondly, the application of Kostiakov's equation is best applied to irrigation works where there is ponding and is therefore best for border and basin irrigation.

Also, the infiltration grouping carried out is tentative because the data is insufficient for comprehensive soil grouping in the guinea savannah zone. The best would have been to collect data from other parts of this zone for the adequate grouping. Any other soil not tested have been put into any of the groups to which its description best fits.

Finally, it is recommended that similar work should be carried out in other part of the guinea savannah zone where such work has not been done.

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# Appendix

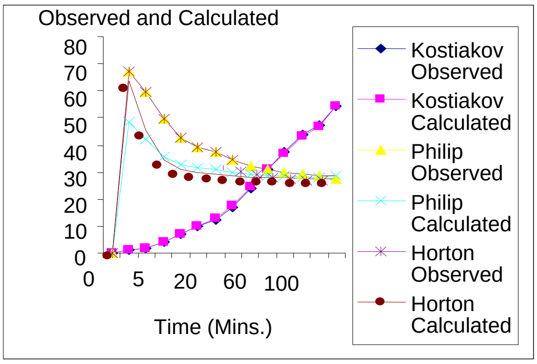

Fig. 1. Goodness of fit of Kostiakov's, Philip's and Horton's infiltration models using Chi-square test for cultivated soils on the permanent site farm.

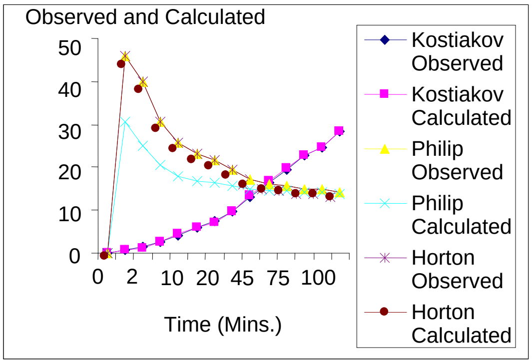

Fig. 2. Goodness of fit of Kostiakov's, Philip's and Horton's infiltration models using Chi-square test for fallowed soils on the permanent site farm.

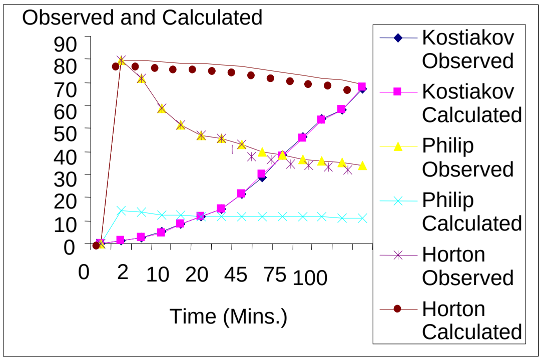

Fig. 3. Goodness of fit of Kostiakov's, Philip's and Horton's infiltration models using Chi-square test for cultivated soils in the dry seasons on the permanent site farm.

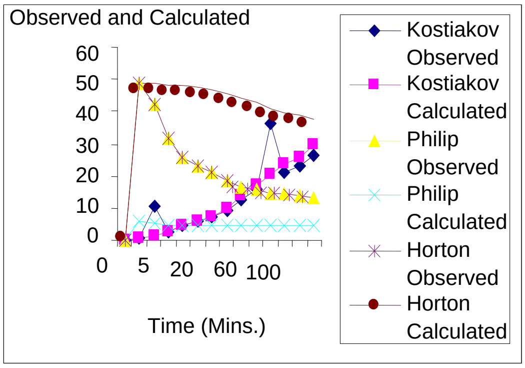

Fig. 4. Goodness of fit of Kostiakov's, Philip's and Horton's infiltration models using Chi-square test for fallowed soils in the dry seasons on the permanent site farm.

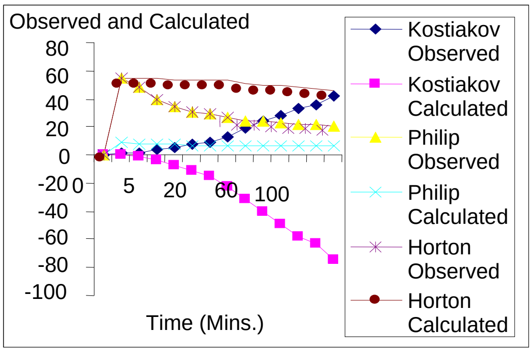

Fig. 5. Goodness of fit of Kostiakov's, Philip's and Horton's infiltration models using Chi-square test for cultivated soils in the wet seasons on the permanent site farm.

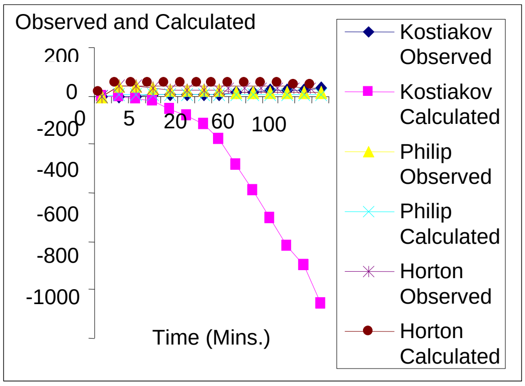

Fig.6. Goodness of fit of Kostiakov's, Philip's and Horton's infiltration models using Chi-square test for fallowed soils in the wet seasons on the permanent site farm.