

**MODELING INFILTRATION CAPACITY OF MAJOR SOILS: THE
CASE OF UPPER AWASH SUB-BASIN**

BY

MEGERSA REGASA NIKUSE



**A THESIS SUBMITTED TO THE DEPARTMENT OF WATER RESOURCES
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ARCHITECTURE**

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MEGERSA REGASA NIKUSE

ADVISOR: ZELALEM BIRU (PhD)

CO-ADVISOR: ABDULKERIM BEDAWI (PhD)

A THESIS REPORT SUBMITTED TO THE DEPARTMENT OF WATER
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OFFICE OF GRADUATE STUDIES
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Advisor's Approval Sheet

To: Water Resource Engineering Department

Subject: Thesis Submission

This is to certify that the thesis entitled **Modeling Infiltration Capacity of Major Soils: The Case of Upper Awash Basin** submitted in partial fulfillment of the requirements for the degree of Master's in **Water Resource Engineering (Specialization in Irrigation Engineering)**, the Graduate program of the department of **Water Resource Engineering**, and has been carried out by **Megersa Regasa Nikuse**, Id. No **A/PE 16399/10**, under my advice. Therefore, I recommend that the student has fulfilled the requirements and hence hereby he can submit the thesis/dissertation to the department.

Name of Advisor

Signature

Date

Approval of Board of Examiners

We, the undersigned, members of the Board of Examiners of the final open defense by **Megersa Regasa Nikuse** have read and evaluated his thesis entitled **Modeling Infiltration Capacity of Major Soils: The Case of Upper Awash Basin** and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of master's.

_____	_____	_____
Advisor	Signature	Date
_____	_____	_____
Chairperson	Signature	Date
_____	_____	_____
Internal Examiner	Signature	Date
_____	_____	_____
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DECLARATION

I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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This MSc Thesis has been submitted for examination with my approval as thesis advisor

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Date of submission _____

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LISTS OF ABBREVIATIONS

ANOVA	Analysis of Variance
ASTU	Adama Science and Technology University
AwBA	Awash Basin Authority
CI	Cumulative Infiltration
cm	Centimeters
DRI	Double Ring Infiltrometer
FAO	Food and Agriculture Organization
hr	Hour
IMC	Initial Moisture Content
IR	Infiltration Rate
m.a.s.l	Meter above Sea Level
MAE	Maximum Absolute Error
min	Minutes
ml	Milliliters
NS	Nut-Sutcliffe
NRCS	Natural Resource Conservation Service
R^2	Coefficient of Determination
RMSE	Root Mean Squared Error
SCS	Soil Conservation Service
UAB	Upper Awash Basin
UN	United Nation
UNESCO	United Nation Educational, Scientific, and Cultural Organization

ABSTRACT

Infiltration is complex process, challenging and time-consuming process to quantify it, because the parameters are very difficult to measure directly. It is also vary with respect to time, soil type and land uses. But identifying infiltration rate of certain soil and specific site is very important for different water resource managements. This study was needed to to determine infiltration characteristic of Cambisols and Vertisol, which are most dominant soils of Upper Awash Basin. Double Ring Infiltrrometer of 60cm and 30cm diameter for outer and inner diameter was used to measure infiltration capacity of these soils. Field data collection was carried out at ASTU and Bishoftu Research Center, where proposed soil types exist during dry season. Horton, Philip, Kostiakov and Green Ampt infiltration models were used for this study. The values of various parameters of these infiltration models were calculated by graphical approach. Using these determined infiltration parameters, infiltration models for the site was developed. The observed infiltration rates of those soils from DRI was compared with the infiltration rates calculated by Kostiakov, Philip's, and Horton's and Green-Ampt infiltration models and the best fitting model was tested using RMSE, NS and R^2 . The R^2 and NS values of Horton, Kostiakov, Philip and Green Ampt infiltration models for Cambisols were 0.991 & 0.967, 0.869 & 0.798, 0.990 & 0.990 and 0.995 & 0.996 respectively. In similar way, the values of RMSE were 6.660, 16.520, 3.632 and 2.332 for Horton, Kostiakov, Philip and Green Ampt infiltration models respectively. For vertisols, the result of the R^2 and NS values were 0.992 & 0.963, 0.885 & 0.805, 0.980 & 0.980 and 0.987 & 0.987 for Horton, Kostiakov, Philip and Green Ampt infiltration models respectively. RMSE values of Horton, Kostiakov and Green Ampt infiltration models for Vertisols also showed 2.059, 5.142, 1.628 and 1.32 respectively. From this comparison, Green Ampt infiltration model is best fit model for both sites. The values of field infiltration capacity and the result of the model were compared to set the valid model for the site. Model Equation were tested for accuracy by comparing their cumulative infiltration capacity with field cumulative infiltration capacity of the soil. R^2 , NS and Percentage of Error were used to test the accuracy of these models. Accordingly, Green Ampt infiltration model predicted the most accurate cumulative infiltration capacity of Cambisols showing the values R^2 , NS and RMSE of 0.999, 0.999 and 0.298 respectively. For Vertisols, Green Ampt and Kostiakov infiltration models showed the nearest value of cumulative infiltration capacity. The Values of R^2 and NS of Kostiakov and Green Ampt were 0.998 & 0.996, 0.984 & 0.984 respectively. Therefore, Green Ampt infiltration models was selected as accurate model to estimate both Cambisols and Vertisols for dry season.

Key Words: *Infiltration, Infiltration Parameters, Infiltration Models, Double Ring Infiltrrometer, Model Comparison.*

1. INTRODUCTION

Background of the study, statement of the problem, significance of the study, general and specific objectives, research questions and scope of the study are described under this part.

1.1. Background of the Study

Infiltration is one part of hydrologic cycle and it is the process by which water on the ground surface enters the soil profile vertically. In general soil science, infiltration rate is the velocity or speed at which (rainfall or irrigation) water enters into the soil. It is usually measured by the depth (in mm or cm) of the water that can enter into the soil per hour (Ayu *et al.*, 2013). Haghaibi *et al.*, (2011) also said that, infiltration is the process of water movement from the ground surface into the soil and is an important component in the hydrological cycle. Infiltration has received a great deal of attention from soil and water scientists because of its fundamental role in land-surface and subsurface hydrology, irrigation and agriculture (Mishra *et al.*, 2003). Accurate determination of infiltration rates is an important factor in reliable prediction of surface runoff (Jagdale *et al.*, 2012).

Infiltration capacity varies in space and time due to soil heterogeneities, meteorological characteristics, clogging processes and temperature fluctuations, as well as other processes (Rashidi, *et al.*, 2014). According to Antigha and Essien (2007), variations in the rate of infiltration are caused by precipitation, land use type, and vegetation type. The characteristics of the soil also affect the rate of infiltration (Dagadu and Nimbalkar, 2012). Additionally, David *et al.*, (2018) also stated that infiltration depends upon a large number of factors such as characteristics of the soil, vegetative cover, condition of the soil surface, soil temperature, water content of the soil, rainfall intensity, etc.

Infiltration characteristics of the soil are quantified when field infiltration data are fitted mathematically to infiltration models (Oku and Aiyelari, 2011). According to Rahimi and Byzedi (2012), infiltration differential equations are of nonlinear kind and they could be solving as by computer. They concluded that, basic and physical equations of infiltration are rarely used in designing irrigation systems and the focus is on empirical ones. Ogebe *et al.*, (2011) stated that, several studies have been conducted to establish models parameters,

validate models or compare models efficiencies and applicability for different soil conditions. And they investigated the capacity of Kostiakov, Modified Kostiakov, Philip and Horton infiltration models for sandy soil in central Nigeria and recommend that, Horton's models gave best fit to the measured cumulative infiltration. David *et al.*, (2018) also investigated infiltration rate capacity of sandy soil using Horton, Green Ampt and Kostiakov infiltration models and proved that, Kostiakov models is best fit with field observed infiltration rate. According to Rahimi and Byzedi (2012), Philip model is best fit than Kostiakov, Kostiakov_Lewis and SCS for clay loam soil. Ramesh *et al.*, (2008) proved that the Horton Model gives the best representation on the level of infiltration and the time of infiltration on a variety land use of vertisol soil.

In our country, Ethiopia, there are different soil types which will have different infiltration capacity and infiltration model efficiencies. According to Upper Awash Sub Basin Integrated Land Use Planning Study Report (2014), the identified eight FAO major soil groups of Upper Awash Basin are Vertisols, Luvisols, Cambisols, Nitisols, Andosols, Fluvisols, Regosols, and Leptosols, including its special distribution. Vertisols are the most extensive soils of the sub basin; it covers about 40 % of the total area. The distribution of Vertisols is mainly in the central highland plateaus, or surrounding Finfine zone. The area is known by intensive cultivation of Teff, Wheat, etc. Nitisols, Luvisols, and Cambisols cover about 27%, their distribution is mainly in the Northern part. The Fluvisols cover an area of about 2.6% of the sub basin. Regosols and Leptosols in the sub basin occur mainly, in the eastern part of the sub basin on steep hill side slopes. They are shallow soils with limited profile development and they cover an area about 14% of the sub basin. Andosols are mainly occurring in volcanic areas around Sodere and Metehara, they cover about 9.3%.

Even though there are many findings that are related to soil infiltration rate of different area, yet, there is no scientific study that shows infiltration capacity of upper Awash Basin of Ethiopia. Since competition of the available water resources from different use is very high in upper awash basin, major soil infiltration rate of the basin is very important to plan and manage the water resource of the basin.

1.2. Statement of the Problem

Applying infiltration equations in modeling of both surface and subsurface flows results in easier surface irrigation systems designing and evaluating. Due to the correlation between the coefficients of the equations and type of soil and surface conditions exacting field tests seems to be really necessary. The infiltration rate into the soil is one of the important parameters in designing and performing irrigation and drainage projects, hydrological studies, soil conservation and water supply management, designing and performing green areas, soil pools of fish farming etc (Rahimi and Byzedi, 2012). Arshad *et al.*, (2015) and Ieke *et al.*, (2013) stated that, infiltration plays an important role in generation of runoff volume and modeling of this surface runoff.

So, infiltration is the most important process in hydrologic processes. All flooding, erosion, irrigation scheduling, identification of recharge area and pollutant transportation predictions are depends on infiltration. But this important process, infiltration, is vary temporary and spatially. Therefore, for accurate quantification of this process in-situ, the development of models for specific time and space is paramount. Even though, infiltration process determines these different hydrologic processes, yet, there is no study that shows infiltration rate of most dominant soil of upper awash basin.

Regardless of this, there is the fact that, because of the rapid population growth and increased water demand of different sectors in the last few years, the water resource in the basin has become issues of concern and source of conflicts. Irrigation sector is one of the sectors competing for water. To allocate water for irrigation, identifying soil infiltration capacity and climate condition is mandatory. Over- and inefficient utilization triggered by no or limited knowledge of the water resources availability regardless of the spatial and temporal distribution is significantly facilitating competition and conflicts for water in the basin (Awash Basin Water Allocation Plan, 2016). Despite of these facts, till today, no clear finding exist that shows infiltration capacity Cambisols and Vertisols of the area.

And therefore this study was conducted to identify infiltration capacity of the soils and to select best fit infiltration model for the site was done. Specially, this study has great role for irrigation water management.

1.3. Significance of the Study

Soil and water are the vital natural resources used in the crop production system. Efficient management of water requires a greater control of infiltration in the soil. Increased infiltration control would help to solve such wide range of problems as upland flooding, pollution of surface and groundwater, declining water tables, inefficient irrigation of agricultural lands, and wastage of useful water (Rashidi *et al.*, 2014). Soil infiltration rate is the most essential process that affects the surface irrigation uniformity and efficiency because of its mechanism of transfer and distributes water from surface to soil profile (Rashidi *et al.*, 2014).

Adequate knowledge of infiltration rate of different soils is very essential for water resource management. Moreover, prediction of cumulative infiltration is important for estimation of the amount of water entering and its distribution in the soil. Design, operation, management, and hydraulic evaluation of on-farm water applications have also rely on the infiltration properties of the soil because infiltration behavior of the soil directly determines the essential variables such as inflow rate, length of run, application time, depth of percolation, and tail water run-off in irrigation systems (Sarmadian and Mehrjardi, 2014). Therefore, the result of the study has vital role for irrigation water management, selection and design of irrigation type and irrigation structures. It will be used for water harvest and runoff prediction too.

1.4.Objective of the Study

1.4.1. General objective

The main objective of this study was to determine infiltration capacity of Cambisols and Vertisols.

1.4.2. Specific objectives

- i. To quantify the values of different infiltration models parameters
- ii. To compare the performance of different infiltration models
- iii. To set infiltration equations for Cambisols and Vertisols
- iv. To test accuracy of infiltration models

1.5. Research Questions

The study contains the following research questions

- What are the values of different infiltration parameters for the site?
- Which infiltration model has close relationship with field infiltration data?
- Which infiltration model is accurate to predict infiltration capacity of the soil?

1.6. Delimitation/Scope

According to Upper Awash Basin Integrated Land Use Planning Study (2014), Vertisols, Luvisols, Cambisols, Nitisols, Andosols, Fluvisols, Regosols, and Leptosols, are found to be major soil groups of Upper Awash Basin. Even though different soil types result different infiltration rates, this study is limited only to Vertisol and Cambisols, which are most dominant, because of time and cost constraint. For this study, representative data were collected from two selected sites of Upper Awash Basin, Adama Science and Technology University and Bishoftu Research Center.

According to Upper Awash Basin Integrated Land Use Planning Study, the land cover/vegetation cover types identified in the Upper Awash sub-basin includes Afro-Alpine and Sub Afro-Alpine vegetation, Cultivated Land, Forest Land, Grass Land, Shrub Land, Water body, Wood land, bare land. A large proportion of the sub basin is accounted as cultivated land, Forest Land, Grass Land and Water body. From these land uses of Upper Awash basin, only agricultural land was tested for soil infiltration rate using DRI since Upper Awash basin, which has about 68% flat landscape to gently undulating, was selected for this research. And also, from wet and dry seasons, only dry season was selected for this research due to time and budget.

2. LITERATURE REVIEW

In this part, the review of different theoretical approaches and related studies by scholars that have relation with infiltration and infiltration rates are described.

2.1. Theoretical Approaches of Infiltration and Infiltration Rates

2.1.1. Water and Soil

Lal and Shukla (2005), stated that, from the sum of all water bodies (oceans, rivers, lakes), groundwater (renewable and fossil), and soil water, about 97.2% (volume basis) of the world water is in oceans and seas. Fresh water accounts for merely 2.8% of the total volume, of which groundwater is 0.6% and soil water accounts for less than 0.1% of the total.

According to Miyazaki (2006), property of water in soils differs a little from that of ordinary water. Even when pure water is added to a dry soil, absorbed materials on particle surfaces may be dissolved in the penetrating water, and hence the water is no longer pure but will behave as a solution. A solution that dissolves cations and anions is affected by the negative charge on the surface of clay minerals, resulting in diffuse electrical double layers around the clay minerals due to the attraction of cations and the repulsion of anions.

Freud and Rahardjo (1993), describe water movement in soil clearly. The slow movement of water through soil is commonly referred to as seepage or percolation. Seepage analyses may form an important part of studies related to slope stability, groundwater contamination control, and earth dam design. Seepage analyses involve the computation of the rate and direction of water flow and the pore-water pressure distributions within the flow regime.

The flow of water in the saturated zone has been the primary concern in conventional seepage analyses. However, water flow in the unsaturated zone is of increasing interest to engineers. A constant water flux across the surface boundary may develop a steady-state water flux through the unsaturated zone of the slope. Water flow through unsaturated soils is governed by the same law as flow through saturated soils (Le. Darcy's law). The main difference is that the water coefficient of permeability is assumed to be a constant for saturated soils, while it must be assumed to be a function of suction, water content, or some other variable for unsaturated

soils. Also, the pore-water pressure generally has a positive gauge value in a saturated soil and a negative gauge value in an unsaturated soil. In spite of these differences, the formulation of the partial differential flow equation is similar in both cases.

2.1.2. Infiltration and Infiltration Models

According to Lal and Shukla (2005), entry of water into the soil matrix through air-soil interface is called infiltration. The water entry is generally referred to as vertical downward infiltration. The rate of infiltration of water into soil matrix governs the amount of water storage in soil, which is available for plants. It also influences the amount of runoff and erosion. And the book recommended that the knowledge of water infiltration into soil is essential for soil and water conservation, and minimizing the risk of nonpoint source pollution.

Regarding the infiltration rate, they explained that when water is supplied to an initially dry soil, the suction gradients across the soil surface become very high, which results in a high infiltration rate. As the wetting front moves downward, the suction gradient across the soil profile decreases, which limits the rate of water infiltration into the soil surface. Eventually, after a long time, the infiltration rate approaches zero.

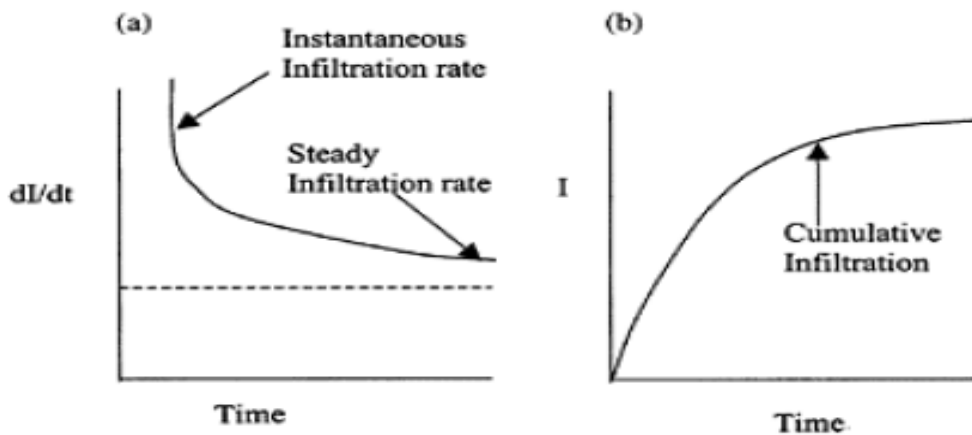


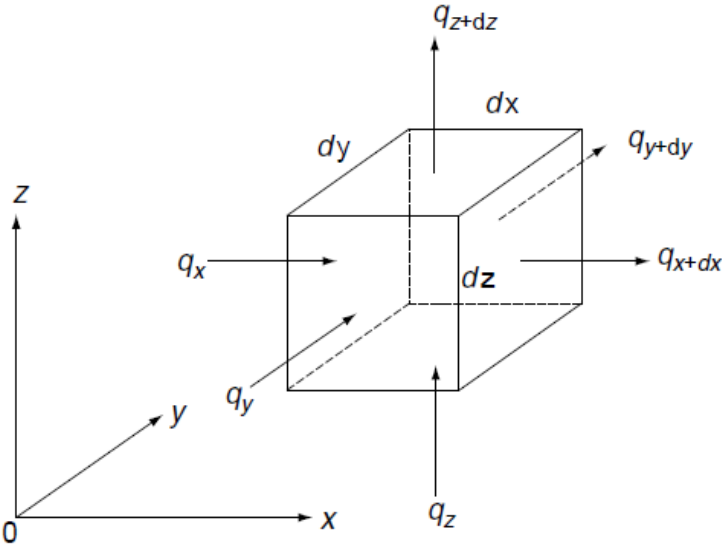
Fig 1: Typical (a) infiltration rate and (b) cumulative infiltration

Subramanya (2008) explained different methods of determining infiltration. Among these, infiltrometers, observation in pits and ponds, placing a catch basin below a laboratory sample,

artificial rain simulators and hydrograph analysis are common. Double ring infiltrometer is most common method used for soil infiltration rate test in field.

2.1.3. Darc’s Law of Water Flow in Soil

Miyazaki (2006) explained Darc’s law for liquid flow in soil as follows. Liquid water flows through continuous and tortuous pores in soils. Darcy’s law is a macroscopic law deduced by the integration of the individual water flow in each pore, which has various shapes microscopically. The basic equation of water flow in soils is constructed by applying Darcy’s law to a small cube of dx dy dz as shown in Figure 2.3, which contains a sufficiently large number of soil particles and therefore demonstrates representative properties of the entire soil sample. Denoting the change in volumetric water content in this small cube by du, the total quantitative change of water in this cube is given by du dx dy dz. When there are no source of water and no sink of water in the cube, the total quantitative change of water is produced by the difference between inflows (qx, qy, and qz) and outflows (qx+dx; qy+dy; and qz+dz), given by:



$$\begin{aligned}
 q_x + d_x &= q_x + \frac{\partial q_x}{\partial x} d_x \\
 q_y + d_y &= q_y + \frac{\partial q_y}{\partial y} d_y \dots\dots\dots \text{eq. (2.1)}
 \end{aligned}$$

$$q_z + d_z = q_z + \frac{\partial q_z}{\partial z} d_z$$

The continuity equation of water during a given time dt is then given by

$$d_\theta d_x d_y d_z = \left(-\frac{\partial q_x}{\partial x} d_x d_y d_z - \frac{\partial q_y}{\partial y} d_x d_y d_z - \frac{\partial q_z}{\partial z} d_x d_y d_z \right) dt. \dots\dots\dots \text{eq. (2.2)}$$

Which results in

$$\frac{\partial \theta}{\partial t} = - \left(\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial q_z}{\partial z} \right) \dots\dots\dots \text{eq. (2.3)}$$

Applying Darcy's law

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x} \left(K_x \frac{\partial H}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_y \frac{\partial H}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_z \frac{\partial H}{\partial z} \right) \dots\dots\dots \text{eq. (2.4)}$$

2.2. Some Scientific Studies Related to Infiltration Rates

2.2.1. Horton Infiltration Model

Ayu *et al.*, (2013) studied infiltration capacity using Horton infiltration model. The scholars used Double Ring Infiltrometer and collected data using field observations, interviews, and documentation. The simple random sampling was used to determine locations for infiltration measurement. Soil sampling and measurement of infiltration were performed on three different land uses with six replications in each location.

The researchers estimated the value of f_c from plotting of the relationship between the infiltration rate and time and the result showed that there are different infiltration rates for different land uses. According to the researchers, soil properties affecting infiltration rate in the research locations were sand and clay percentages, soil moisture content, bulk density, particle density, soil organic matter, and soil porosity. Finally, the scholars concluded that estimated value of soil infiltration using Horton Model was similar with the value of infiltration measurement in the field.

Abdulkadir *et al.*, (2011) also used Horton infiltration model to test 15 points of infiltration by ponding water into a double ring infiltrometer and readings was recorded at 1 minute intervals for the first 5 minutes, 5 minutes intervals for the next 50 minutes, 10 minutes intervals to 60 minutes then 20 minutes intervals for the next 60 minutes until a total elapsed

time of 120 minutes was reached. To determine infiltration parameters, Horton infiltration model was used.

They concluded that calculated infiltration rates by Horton Model was similar to those from field measurements and the Horton equation was best explained in the exponential curve fitting technique. There was a good relationship between the measured and predicted infiltration rates with mean R^2 value of 0.811 for all 15 sample points.

2.2.2. Kostiakov Infiltration Model

Hasan *et al.*, (2015) had done the research at dry season using Double Ring Infiltrometer. The modified Kostiakov method was tested if it suits the local soil condition and if it can be represented for the accumulated infiltration and infiltration rate. The finding showed that very good agreement between the actual and calculated values of accumulated infiltration. The scholars agreed that, this will also be a good representative of the infiltration characteristic of the site. Finally, they recommended that this information can be valued asset for irrigation scheduling for any crop cultivated in that field to ensure the best water management practices.

Uloma *et al.*, (2014) also made field infiltration measurements using double ring infiltrometer during wet season. Repeated readings were taken at 5, 10, 15 and 30 minutes intervals in all the locations and Kostiakov's equation was used. The scholars agreed that, infiltration rates (IR) values were low and this is attributed to the high moisture content of the soil since the experiments were conducted in rainy (wet) season.

2.2.3. Philip Infiltration Model

Singh *et al.*, (2014) evaluated infiltration capacity of soil of nine different locations using double ring infiltrometer. The Infiltration rate mm/hr and measured data $F(t)$ were plotted in graph and the method of nonlinear regression is applied to find out unknown parameter K and S of Philip infiltration model.

Scholars observed that there is a lot of variation in the infiltration rate from time to time. They recommended that, it is mainly due to the meteorological properties also. And the result showed that initial infiltration rate is very high and after 60 minutes the infiltration rate is low.

There was also large variation in infiltration parameter particularly saturated hydraulic conductivity. The researchers concluded that it is noted that different infiltration rates are observed for same soil due to the variation in water content.

2.3.Comparison of Different Infiltration Models

Ogbe *et al.*, (2011) carried out field experiment at the College of Agriculture experimental farm, Lafia. Three points at 30m interval the length was marked out and infiltration test carried out at those points for each strip. Soil samples were also collected from the adjacent area of the marked points at different depths for soil analysis. Infiltration measurement was carried out using a double ring infiltrometer. Readings were then taken at intervals to determine the amount of water infiltrated during the time interval with an average infiltration head of 5cm maintained. The infiltration rate and the cumulative infiltration were then calculated. Moisture content was determined by gravimetric method. The soil texture of the site was determined by mechanical analysis method.

Several models including Kostiakov, Modified Kostiakov, Philip and Horton models have been developed for monitoring infiltration process. The cumulative infiltration values predicted using the infiltration models and those measured were plotted against each other and fitted with a linear equation with zero intercept to verify the validity of each prediction. The slope of the line of best fit and its coefficient of determination (R^2) for each model and strip were given. Statistical results indicates that all the models used satisfactorily predicted the cumulative infiltration given that the t-calculated values for all the models in each strip are less than the t-table value. Therefore, it can be concluded that the field measured cumulative infiltration do not differ from those predicted by the models since the observed difference can be accounted for by experimental error.

They concluded that, from the four infiltration models evaluated, the Horton's models gave best fit to the measured cumulative infiltration, although the other models provided good overall agreement with the field measured cumulative infiltration depths and are therefore capable of simulating infiltration under the field conditions encountered in the present study. Consequently, the application of these equations under verified field conditions leads to the

determination of the appropriate infiltration characteristics for the equations that would optimize infiltration simulation, irrigation performance and minimize water wastage.

Sreejani *et al.*, (2017) also used Double ring infiltrometer for measurement of infiltration rates at all the sites and readings were taken at regular time interval of 2, 5, 10, 15, 30, 60 min. till getting a constant infiltration rate. Then the values of various constants of the models were calculated by graphical approach. To get best fitting model for a particular soil condition the results obtained from various infiltration models were compared with observed field data and graphs are drawn with correlation coefficient and standard error as tools.

The researchers got that the values of parameters of Infiltration models vary from soil to soil and from place to place. From the analysis they concluded that, for all regions selected in the study area, Kostiakov's Model was best fitting with high degree of Correlation Coefficient and Minimum standard Error.

Arshad *et al.*, (2016) conducted research to analyze the water transmission behavior for sandy loam soil under different tillage operations of Raja MB Plough and its comparison with different infiltration models. The results were found that the values of parameters regarding infiltration rate and cumulative infiltration vary from unploughed soil to the ploughed soil with different number of tillage operations of Raja MB plough. The statistical data and various infiltration models results showed different results for each tillage operation.

From their analysis, they found that initially infiltration rates were high in all experiments and decreased with time up to steady infiltration rate base flow acquired. And finally they concluded that, there was a strong correlation of field data with Horton's model and hence, it is concluded that Horton's model is appropriate model with high significant results of correlation coefficient and minimum standard error.

David *et al.*, (2018) used double ring Infiltrometer which consists of two cylinders which has diameter of the inner ring is 30 cm and that of outer ring is 60 cm to collect field infiltration rate. The researchers used three statistical parameters such as one way ANOVA test, correlation coefficient and standard error for comparing the observed values of infiltration rate with the Horton model, Green ampt model and Kostiakov model infiltration models. And they

concluded that Kostiakov's model is the best fit model with observed infiltration rate for the site.

Rahimi and Byzedi (2012) calculated Kostiakov, Kostiakov - Lwies, SCS and Philip's infiltration equations coefficients and integrated infiltration equations infiltration rate and average infiltration rate by practicing the best empirical data graph. The researchers found that, K coefficient in Kostiakov equation is its proximity to S or absorption coefficient in Philip's equation which shows the dependency of K coefficient on physical characteristics of soil. They concluded that, Philips model estimates integrated infiltration and infiltration rate with high precise and the SCS model underestimated integrated infiltration and infiltration rate in all condition so it is not recommended for the area.

So, they recommended that, the best model for estimating the integrated infiltration and infiltration rate for agricultural fields of the area and similar fields is the Philips model and therefore, obtained results of this model can be used for estimating the integrated infiltration and infiltration rate in designing surface irrigation systems (except furrow irrigation method) and other given objectives.

Sihag *et al.*, (2017) used Double ring Infiltrometer for measurement of infiltration rates at all selected locations. They proposed models such as Kostiakov, Kostiakov modified, SCS and the novel for evaluation in the study. The researchers evaluated these infiltration models on the basis of experimental data of the study area and to obtain numerical values for the parameters of the models using XLSTAT software. To compare infiltration models, Maximum Absolute Error (MAE), Bias and Root Mean Square Error (RMSE) statistical criteria was used by researchers. According to these statistical criteria, they concluded that, the novel model is performing better than other models and it may be used to assess the infiltration rate with similar field characteristics of the site.

Dagadu and Nimbalkar (2012) compared infiltration models For black cotton soil, three regions were selected in which first region was of compact soil type, second region was ploughed, and third was of harrowed condition. Two regions were selected for clay soil, of which first was unploughed condition and second was ploughed condition. For sandy soil one region was selected. From the results, they found that, the values of parameters of infiltration

models vary from soil to soil and soil type. Also the correlation coefficients and standard errors were different for different soils and different soil conditions.

Finally the researchers concluded that, from the correlation coefficient and standard error calculations it was found that for all type of soils and their conditions Horton's model is best fitting with high degree of correlation coefficient and minimum standard error except for ploughed clay soil to which Green_Ampt model is best fitting. So from the study it is concluded that Horton's model is best fitting with measured values of infiltration rates for all types of soils and soil conditions except for ploughed clay soil in the region.

Nitin P Sonaje (2017) reviewed methods for estimation of water infiltration rate such as, In situ measurement techniques, Empirical models, Green-Ampt models, Richard's equation models.

The researcher stated that in situ measurement technique includes be measured or estimated either by measurement on undisturbed samples in laboratory or in situ measurements. The DRI is used for measuring cumulative infiltration, infiltration rate and field-saturated hydraulic conductivity. And he concluded that in situ measurement techniques have some limitations such as rate of infiltration decreases with increase in the depth and rate of infiltration increases with increase in head of water, boundary condition of infiltrometer effect on rate of infiltration, the driving of tube or rings disturbs the soil structure; and raindrop-impact is not simulated and Complex and less accurate

The Author agreed that, empirical models are usually in simple form of equations when compared with in situ method and they provide estimates of cumulative infiltration and infiltration rates quite accurately. However, they are unable to provide information regarding water content distribution. The empirical models that reviewed by the Author includes Kostiakov, Modified Kostiakov, Horton, Philip, Mezencev and Holtan models.

The researcher identified that, Kostiakov model describes the infiltration quite well at small time but less accurate at large times. It was further modified as Modified Kostiakov's Equation which is most commonly used in surface irrigation applications. Horton's Equation is the theory proposed by Horton (1940) describes the basic behavior of infiltration but the

physical interpretation of exponential constant is poorly defined. The researcher identified that, the striking drawback of this equation is inadequacy to represent the rapid decrease of 'i' from very high values at 't' as shown by Philip. And he stated that Philip equation is valid in the limiting condition of 't' not being too large. The limitations of Kostiakov's equation for large times, was modified by Mezencev. NRCS (SCS) Equation assumes that for a single storm, ratio of actual soil retention to potential maximum retention is equal to the ratio of direct runoff to available rainfall. In case of lack of soil moisture data or insufficient definition of boundary conditions, the NRCS model is suitable semi-empirical model. Holtan model specifically takes into account the effects of vegetation and soil water condition in the form of available pore space for moisture storage.

Being widely-accepted concepts of soil physics and easy to use, easily obtained hydraulic parameters from literature and electronic databases, no need of site-specific measurements of all parameters, easily incorporation of spatial variability of soil parameters can be more into the mathematical models are some advantages of empirical models stated by the author.

The researcher stated that, Green Ampt model is the model which addresses surface ponding and movement of wetting front. According to the researcher, the core importance in this method is evaluation of soil moisture-pressure profile. Simplicity to use, Adaptability to varying scenarios, Easily-measurable variables are advantages of Green Ampt Model. Depending on the simplicity (or complexity) of input parameters, Richard's equation has been solved exactly or partially. Limitations of Richard Equation includes colloidal swelling and shrinking of soils may demand that the water movement be considered relative to the movement of soil particles; this phenomenon may also cause significant changes in soil permeability, two-phase flow involving air movement may be important when air pressures differ significantly from atmospheric pressure, thermal effects may be important, especially for evaporation during redistribution of infiltrated water, in which case the simultaneous transfer of both heat and moisture needs to be considered and depending on the simplicity (or complexity) of these input parameters, the Richards equation can be solved exactly or numerically.

2.1. Spatial and Temporal Variation of Infiltration Rate

Balstad *et al.*, (2018) investigated the design implications of seasonal variations in infiltration capacity, simulations of a typical rain garden located in Trondheim. The results presented in this paper indicated that, large seasonal variations in infiltration capacity. The infiltration capacity changed from 1 cm/h in October too close to 0.05 cm/h in November- April and up to 3 cm/h in May.

Eze *et al.*, (2011) computed mean infiltration rate for bare and crusted, sparsely vegetated with 50cm depth of litter cover. “Crust Factor” was calculated using the ratio of the steady state infiltration rate of bare surface divided by the steady state infiltration rate of vegetated soils. The result posited that infiltration rates for vegetated surface were higher than those of the bare crusted and sparsely vegetated surfaces. It implies that the vegetated land use contributes better to soil protection against surface runoff and erosion than bare crusted and sparsely vegetated surface in the study area. The research also revealed that porosity is a measure of the water bearing capacity of a soil and it plays a role in the determining the capability of the soil to transmit water Calculating the “crust factor” which is the ratio of the infiltration rate of the bare and crusted surface to that of vegetated surface it gave a value of 0.0530.

The research showed that vegetation cover is one of the most important factors that accelerates infiltration rate and thus reduces overland flow which and ultimately in turns conserves the soil. From the analysis, they concluded that, the area is unsuitable for surface irrigation due to its high infiltration capacity. They also recommended that human activities in the form of deforestation, bush burning and grazing by livestock should be discouraged, while in this area; planting of trees on bare lands should be encouraged to reduce erosion.

Vianová *et al.*, (2011) carried out evaluation of soil infiltration capacity at both sites of interest on the basis of data acquired during the on-site infiltration tests and processed in compliance with Kostiakov’s method. 24 tests were carried out in total, each time three tests took place at each site. Infiltration characteristics were assessed with regard to soil physical properties, changing properties during the reference period. The finding showed that infiltration capacity of the soil, at both sites, is low at rainy time and compaction places and high at dry season. Depending on the time of measurement the result shows that soil

infiltration capacity was lower in spring and autumn and higher in summer (until harvest of the grown crop-plant) due to higher initial moisture content of the soil. Finally, the scholars concluded that Soil compaction is a problem that manifests itself not only by reduced infiltration capacity of soils, but also causes many other phenomena having a negative influence on the overall soil quality and fertility.

Patle *et al.*, (2018) identified twenty five points at 10 m grid interval and field measurements were performed using DRI. A soil sample was collected for estimating: Soil Moisture, Bulk Density, Particle Density and Texture and organic carbon content. The coefficient of determination was also determined to check reliability of the model.

The relationship between infiltration rate and each soil properties were analyzed and it is seen that sand, particle density, and organic content had positive correlation with observed infiltration rate which means increase in sand, particle density, and organic content will increase the infiltration rate. Silt, clay, bulk density, and moisture content had a negative correlation with infiltration rate which means that increasing silt, clay, bulk density, and moisture content will decrease infiltration rate.

2.2. Accuracy Test for Infiltration Models

Arshad *et al.*, (2015) investigated the effect of tillage intensity to the water transmission behavior for sandy loam soil in terms of infiltration rates and cumulative infiltration and its validation with different infiltration models. The scholar used to compare observed cumulative infiltration and model cumulative infiltration for model validation. Standard Deviation, Standard Error and Coefficient of determination was used for comparison. Finally, the scholar concluded that Horton infiltration model is accurate model for the site.

The accuracy of the different equations for predicting the cumulative infiltration were evaluated by comparing the observed values of measurement on the field and the predicted values based on the fitted equation. The cumulative infiltration values predicted using the infiltration models and those measured were plotted against each other and fitted with a linear equation with zero intercept to verify the validity of each prediction. The slope of the line of best fit and its coefficient of determination (R^2) for each model. To check the discrepancies

between the predicted and the measured values, paired t-test and Root Mean Square Error (RMSE) were used. Considering the four infiltration models evaluated, the Horton's models gave best fit to the measured cumulative infiltration, although the other models provided good overall agreement with the field measured cumulative infiltration depths (Ogbe *et al.*, 2011)

2.3. Soil Classification

According to FAO (2001), Soil Map of the World was published 1974. Compilation of the Soil Map of the World was a formidable task involving collection and correlation of soil information from all over the world. Initially, the Legend to the Soil Map of the World consisted of 26 ('first level') "Major Soil Groupings" comprising a total of 106 ('second level') 'Soil Units'.

In 1990, a 'Revised Legend' was published and a third hierarchical level of 'Soil Subunits' was introduced to support soil inventory at larger scales. Soil Subunits were not defined as such but guidelines for their identification and naming were given. In 1998, the International Union of Soil Sciences officially adopted the World Reference Base for soil resources as the union's system for soil correlation. The structure, concepts and definitions of the world reference base are strongly influenced by the Food and Agriculture Organization -UNESCO soil classification system. At the time of its inception, the world reference base proposed 30 'Soil Reference Groups' accommodating more than 200 ('second level') Soil Units.

Table 1: All Reference Soil Groups of the World Reference Base assembled in 10 sets

Set 1	Organic soil	Histosols
Set 2	Mineral soils whose formation was conditioned by human influences (not confined to any particular region)	Anthrosols
Set 3	Mineral soils whose formation was conditioned by their Parent material - Soils developed in volcanic material - Soils developed in residual and shifting sands - Soils developed in expanding clays	Andosols, Arenosols, Vertisols
Set 4	Mineral soils whose formation was conditioned by the topography/physiography of the terrain - Soils in lowlands (wetlands) with level topography	Fluvisols, Gleysols, Leptosols, Regosols
Set 5	Mineral soils whose formation is conditioned by their Limited age (not confined to any particular region)	Cambisols
Set 6	Mineral soils whose formation was conditioned by Climate: (sub-)humid tropics	Plinthosols, Ferralsols, Nitisols, Acrisols, Alisols, Lixisols
Set 7	Mineral soils whose formation was conditioned by Climate: arid and semi-arid regions	Solonchaks, Solonetz Gypsisols, Durisols, Calcisols
Set 8	Mineral soils whose formation was conditioned by Climate: steppes and steppe regions	Kastanozems, Chernozems, Phaeozems
Set 9	Mineral soils whose formation was conditioned by Climate: (sub-)humid temperate regions	Podzols, Planosols, Albeluvisols, Luvisols, Umbrisols
Set 10	Mineral soils whose formation was conditioned by Climate: permafrost regions	Cryosols

In the 2001, the 30 Reference Soil Groups are aggregated in 10 ‘sets’ composed as follows: First, a separation is made between organic soils and mineral soils; all organic soils are grouped in Set #1. Second the remaining (mineral) Major Soil Groups are each allocated to

one of nine sets on the basis of ‘dominant identifiers’, i.e. those soil forming factor(s) which most clearly conditioned soil formation.

From these sets, Food and Agriculture Organization describes vertisol and Cambisols, which are major soils Upper Awash Basin, were selected for the evaluation of infiltration rate. And infiltration models were developed for these two major soil types. The detail description of these soil types are described below.

2.3.1. Vertisols

Vertisols are churning heavy clay soils with a high proportion of swelling 2:1 lattice clays. These soils form deep wide cracks from the surface downward when they dry out, which happens in most years. The name Vertisols (from L. *vertere*, to turn) refers to the constant internal turnover of soil material. Some of the many local names became internationally known, e.g. ‘black cotton soils’ (USA), ‘regur’ (India), ‘vlei soils’ (South Africa), ‘margalites (Indonesia), and ‘gilgai’ (Australia).

According to Food and Agriculture Organization report, Vertisols cover 335 million hectares world-wide. An estimated 150 million hectares is potential cropland. Vertisols in the tropics cover some 200 million hectares; a quarter of this is considered to be ‘useful’. Most Vertisols occur in the semi-arid tropics, with an average annual rainfall sum between 500 and 1000 mm but Vertisols are also found in the wet tropics, e.g. in Trinidad where the annual rainfall sum amounts to 3000 mm. The largest Vertisol areas are on sediments that have a high content of smectitic clays or produce such clays upon post-depositional weathering (e.g. in the Sudan) and on extensive basalt plateaux (e.g. in India and Ethiopia). Vertisols are also prominent in Australia, southwestern USA (Texas), Uruguay, Paraguay and Argentina.

Food and Agriculture Organization report indicate that, infiltration of water in dry (cracked) Vertisols with surface mulch or a fine tilth is initially rapid. However, once the surface soil is thoroughly wetted and cracks have closed, the rate of water infiltration becomes almost zero. (The very process of swell/shrink implies that pores are discontinuous and non-permanent.) If, at this stage, the rains continue (or irrigation is prolonged), Vertisols flood readily. The highest infiltration rates are measured on Vertisols that have a considerable shrink/swell capacity, but

maintain a relatively fine class of structure. Not only the cracks transmit water from the (first) rains but also the open spaces between slickensided ped surfaces that developed as the peds shrunk.

According to Upper Awash Basin Integrated Land Use Planning Study Report (2014), Vertisols are the most dominant and important soils of the Upper Awash sub basin and they cover an area about 774,156 ha or 40%. The report stated that, the soils of this category are, very deep and uniformly thick consisting of dark grey or very dark grayish brown color and during the dry season these soils develop cracks.

2.3.2. Cambisols

The Reference Soil Group of the Cambisols holds soils with incipient soil formation. Beginning transformation of soil material is evident from weak, mostly brownish discolouration and/or structure formation below the surface horizon. Cambisols cover an estimated 1.5 billion hectares worldwide. This Reference Soil Group is particularly well represented in temperate and boreal regions that were under the influence of glaciation during the Pleistocene, partly because the soil's parent material is still young but also because soil formation is comparatively slow in the cool, northern regions. Erosion and deposition cycles account for the widespread occurrence of Cambisols in mountain regions (FAO, 2001).

According to FAO (2001), Cambisols are also common in areas with active geologic erosion where they may occur in association with mature tropical soils. FAO (2001) stated that Cambisols make good agricultural land and are intensively used. The Eutric Cambisols of the Temperate Zone are among the most productive soils on earth. The Dystric Cambisols, though less fertile, are used for (mixed) arable farming and as grazing land. Cambisols on steep slopes are best kept under forest; this is particularly true for Cambisols in highlands. Vertic and Calcaric Cambisols in (irrigated) alluvial plains in the dry zone are intensively used for production of food and oil crops. Eutric, Calcaric and Chromic Cambisols in undulating or hilly (mainly colluvial) terrain are planted to a variety of annual and perennial crops or are used as grazing land. Dystric and Ferralic Cambisols in the humid tropics are poor in nutrients but still richer than associated Acrisols or Ferralsols and they have a greater cation exchange capacity.

Upper Awash Basin Integrated Land Use Planning Study Report (2014) showed that, these major soil units are well, to somewhat excessively drained, deep, and light to medium textured, with variable colors. The soils are formed on a wide range of parent materials. The soils have a moderately developed subsoil horizon, which is only at initial stage of development. Structure is weak to strongly developed angular blocky, occasionally prismatic in the topsoil over moderate angular blocky to massive in the subsoil. Consistence is hard when dry, friable to firm when moist and slightly sticky and slightly plastic when wet. The study identified that, Cambisols are the widely distributed soils in the sub basin; they cover about 313,033 ha or 16% . These soils are sub classified as Chromic, Vertic, Calcaric, and Eutric Cambisols.

3. MATERIALS AND METHODS

This part contains detail description of study area, material used for the study, methods followed to collect and analysis soil infiltration data.

3.1. Description of the Study Area

3.1.1. Location and Description

The Awash basin is part of the Great Rift Valley in Ethiopia which is located from latitude 8.5⁰ N to 12⁰N and longitude: 38° to 41.8° E, altitude: 250-3927 m.a.s.l. It covers a total area of 110,000 km² of which 64,000 km² comprises the Western Catchment, drains to the main river or its tributaries. The remaining 46,000 km², most of which comprises the so called Eastern Catchment, drains into a desert area and does not contribute to the main river course. The river rises on the High plateau near Ginchi town west of Addis Ababa in Ethiopia and flows along the rift valley into the Afar triangle, and terminates in salty Lake Abbe on the border with Djibouti.

Based on physical and socio-economic factors, the Awash Basin is divided into Upper Awash, Middle Awash, Lower Awash and Eastern Catchment. The Upper, Middle and Lower Valley are part of the Great Rift Valleys systems (Awash Basin Water Allocation Plan, 2016).

According to Upper Awash Sub Basin Integrated Land Use Planning Study, Upper Awash sub-basin is limited on the upper part of the Awash River basin, which extended from the head up to Arba River within Fentale district and clipped by the boundary of Oromia Regional State. The study showed that, the geographical extent of the Upper Awash Basin ranges from 7⁰53'44.55" N to 9⁰24'05.36" N and 37⁰56'43'24"E to 40⁰10'50.74"E. And the study showed that Vertisols are the most extensive soils of the sub basin; they cover about 40 % of the total area while Nitisols, Luvisols, and Cambisols cover about 27%. Regosols and Leptosols in the sub basin cover an area about 14% of the sub basin.

The land cover/vegetation cover types identified in the Upper Awash sub-basin includes Afro-Alpine and Sub Afro-Alpine vegetation, Cultivated Land, Forest Land, Grass Land, Shrub Land, Water body, Wood land, bare land. A large proportion of the sub basin is accounted as

cultivated land, Forest Land, Grass Land, Water body also consumable significant in the sub-basin.

The experiments were carried out at Adama Science and Technology University and Bishoftu Research Center. Adama Science and Technology University is located in Adama town where Leptosols, Andosols and Cambisols exist. The land cover of Adama Science and Technonlogy are grass land, forest, residential, agricultural land and paved land. From these land use land covers, agricultural land was used for the research.

Bishoftu Research Center was established under Haramaya University in 1953 and transferred to Ethiopian Agricultural Research Organization in 1984. It has total area of 147 hectares. Vertisols, Leptosols and Cambisols are major soil types that exist in the research center. Vertisols are most dominant soils that cover 127 hectares which is 86% from the total area.

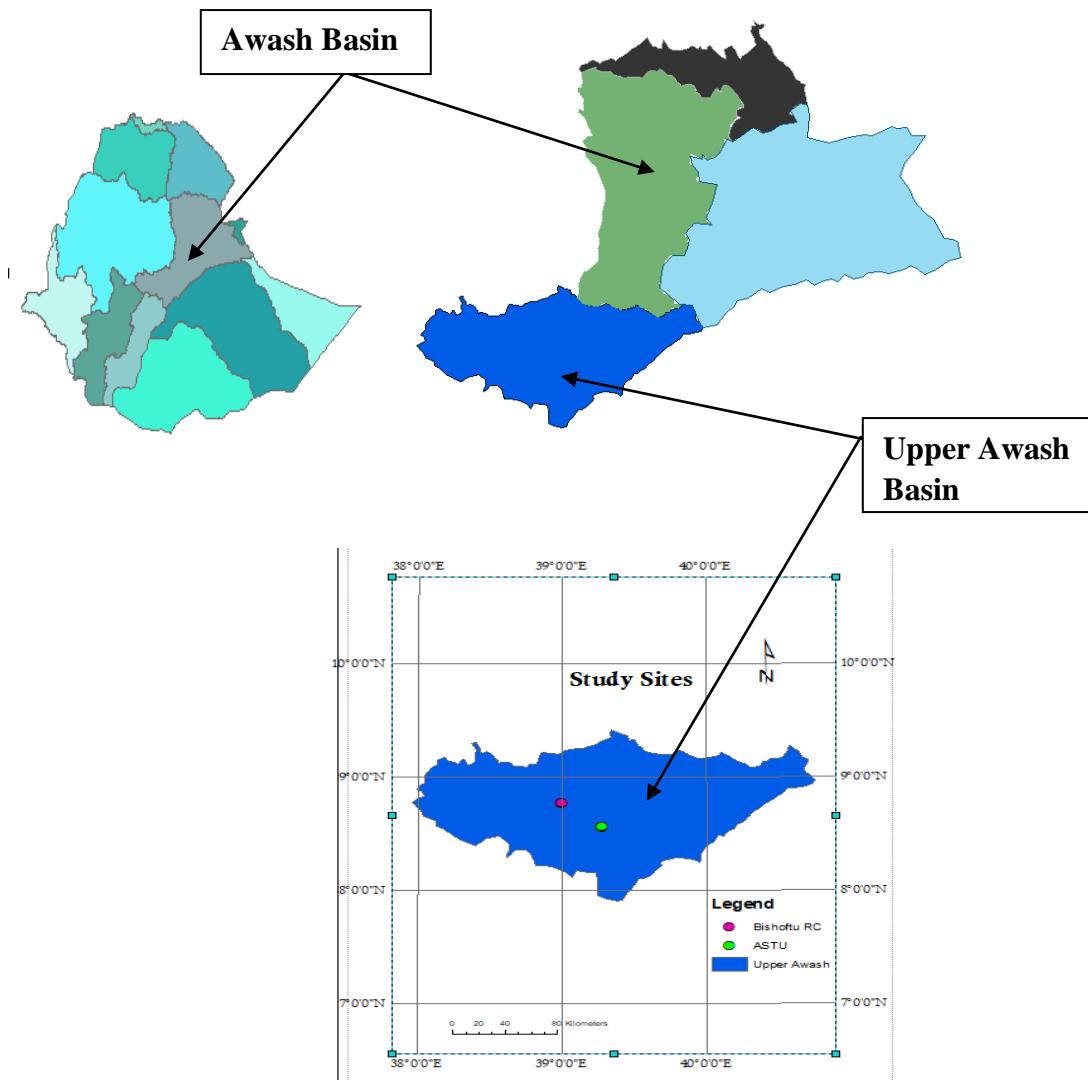


Fig 2: Location Map of Study Site

3.2. Materials

Double ring infiltrometer (DRI), which has two concentric rings of 25 cm deep, and diameter of 30 cm for inner ring and 60 cm for outer ring, was used for measurement of infiltration. The rings were driven at about 10cm deep in soil by using falling weight type hammer striking on a wooden plank placed on top of ring uniformly without undue disturbance to soil surface. Water was poured into the rings and the observations were carried out in the inner ring with measuring scale and stop watch. Oven dry and Soil canes were used to analysis soil initial moisture in soil laboratory. The summary of these materials are described in table 2 below.

Table 2: Material used for Field Experiment

R.No	Materials	Used for	Remark
1	Two rings	To hold water that is needed to infiltrate to soil	Having diameter of 30 & 60 cm
2	Hammer	To driven rings into soil	
3	Spade	To collect sample from site	
4	Bags	To transport soil sample	
5	Transparent Ruler	To measurement amount of water depleted with respect to time	
6	Stop Watch	To take reading at proposed time	
9	Sufficient amount of water	To add it to rings for depletion measurement up to constant rate is gained	

3.3. Methods

3.3.1. Data Collection and Analysis

Data collection methods included field infiltration tests, laboratory analysis, and documentation. Soil infiltration rate measurements were performed on two soil types, namely Vertisol and Cambisols. Primary data of infiltration test and soil physical properties analysis were collected from field. Secondary data, such as soil shape file, soil texture data, which is recent one, and some information about the basin was collected from relevant stakeholders. These stakeholders include AwBA, ASTU and Bishoftu Research Center.

Soil infiltration rate of selected places was collected during dry season using Double Ring Infiltrometer. Readings was taken at regular time interval of 2, 5, 10, 20, 30, 50, 60, 80, 100, 120, 140, 160, 180 minutes for Cambisols, which is found at ASTU. Similarly infiltration data was taken at 2, 5, 10, 20, 30, 60, 80, 110, 140, 170, 200, 210, 230 minutes for Vertisol, which is found at Bishoftu Research Center, till getting a constant infiltration rate. Soil sample was collected adjacent to every point, where infiltration rate was collected, for laboratory analysis. Soil sample was taken at 20cm and 40cm depth to identify soil initial moisture.

To test infiltration rates of the selected dominant soils, ten sample points were selected for measurement of soil infiltration using Double Ring Infiltrometer. The test was repeated three times. The Double Ring Infiltrometer was installed using wooden plate to drive it into soil about 10cm after cleaning the place. The two rings were placed at similar depth and outer ring was filled with water first and then inner ring carefully. Sponge was used to protect soil disturbance while pouring the water in the rings. Then measuring was started immediately using transparent ruler by noting the time and the drop in the water level of the inner ring and stopped after the infiltration rate has reached a constant.



Picture 1: Material Used to Collect Field Infiltration Data

3.3.2. Identifying Initial Moisture of the Soil

Initial moisture content of the sites were determined using oven dry. Even though the infiltration data collection was done at dry season, it is necessary to identify IMC of the soil at each sample points. A soil sample for estimating initial moisture content (IMC) was collected nearby prior to infiltration from that station at the depth of 20 cm and 40 cm. IMC was determined using oven drying method, keeping soil samples at 150°C for 24 h. The IMC was calculated by:

$$IMC = \frac{\text{Mass of wet soil} - \text{mass of dry soil}}{\text{mass of dry soil}} * 100 \dots \dots \dots \text{eq. (3.1)}$$

3.3.3. Estimating Infiltration Parameters of Cambisols and Vertisols

To identify infiltration capacities of both Vertisol and Cambisols, field infiltration data was collected from ASTU and Bishoftu Research Center. Four infiltration models, Horton, Philip, Kostiakov and Green-Ampt were used. Using field infiltration data, the values of various parameters of these models was determined. To determine these infiltration parameters, the graphing method was used. This approach is stated by Subramanya (2008). Additionally, Sreejani *et al.* (2017), Ibrahim *et al.* (2019), Abubakr and Byzedi (2012), Ayu *et al.* (2013), Abdulkadir *et al.* (2011) were used graph approach to find infiltration parameters. Accordingly, graph method used to determine infiltration parameters of the four infiltration models is described below.

A. Horton’s Equation (1933): Horton expressed the decay of infiltration capacity with time as an exponential decay given by

$$f_p = f_c + (f_0 - f_c)e^{-\beta t}, \text{ for } 0 \geq t \leq t_c \dots\dots\dots \text{Eq. (3.2)}$$

Where,

f_p = infiltration capacity at any time t from the start of the rainfall.

f_0 = initial infiltration capacity at $t = 0$

f_c = final steady state infiltration capacity occurring at $t = t_c$. Also, f_c is sometimes known as constant rate or ultimate infiltration capacity

β = Horton’s decay coefficient which depends upon soil characteristics and Vegetation cover.

By rearranging equation 1:

$$f_p - f_c = (f_0 - f_c)e^{-\beta t} \dots\dots\dots \text{Eq. (3.3)}$$

Taking natural logarithm to both sides

$$\ln(f_p - f_c) = \ln(f_0 - f_c) - \beta t \dots\dots\dots \text{Eq. (3.4)}$$

Computing the values of the infiltration rates at different times and final steady-state infiltration (f_c), $\ln(f_p - f_c) = \ln(f_0 - f_c) - \beta t$ was plotted on graph, using excel sheet. So, the values of f_p and f_c were identified from field infiltration rate data. Then arranging time and the values of $\ln(f_p - f_c)$ on the excel sheet and graphing it was used to find the value of $\ln(f_0 - f_c)$ as intercept and k is taken as slope.

B. Philip's Equation (1957) Philip's two term model relates $F_p(t)$ as

$$F_p = st^{\frac{1}{2}} + Kt \dots \dots \dots \text{Eq. (3.5)}$$

Where

s = a function of soil suction potential and called as *sorptivity*.

K = Darcy's hydraulic Conductivity.

F_p = Cumulative infiltration capacity

To determine these infiltration parameters, graph approach was also used as described for Horton Model.

$$f = \frac{1}{2} st^{-1/2} + k \dots \dots \dots \text{Eq. (3.6)}$$

Where: f = infiltration rate

From field observation data, infiltration rate data with its respect to time was arranged in excel sheet and the time was arranged as $t^{-1/2}$. Then by plotting the graph of this infiltration rate with this value of time t , the value of, $S/2$ and K were identified as slope and intercept respectively from the graph as described earlier.

C. Kostiakov Equation (1932): it expresses cumulative infiltration capacity as

$$F_p = at^b \dots \dots \dots \text{Eq. (3.7)}$$

Where,

F_p is Cumulative infiltration capacity

a and b are local parameters with $a > 0$ and $0 < b < 1$.

To determine a and b parameters, taking natural logarithm to both sides

$\ln F_p = \ln(at^b)$, and this can be written as:

$$\ln F_p = \ln a + b \ln t \dots \dots \dots \text{Eq. (3.8)}$$

Different cumulative infiltration capacity at different time and $\ln t$ was arranged on excel and then graph was used to find $\ln a$ as intercept and b as slope.

D. Green – Ampt Equation (1911): Green and Ampt proposed a model for infiltration capacity based on Darcy's law as

$$f_p = K \left(1 + \left(\frac{\eta s_c}{F_p} \right) \right) \dots \dots \dots \text{Eq. (3.9)}$$

Where

η = Porosity of the soil.

s_c = Capillary suction at the wetting front and

K = Darcy's Hydraulic Conductivity.

f_p = infiltration capacity

F_p = cumulative infiltration capacity

The above equation can be considered as,

$$f_p = m + \left(\frac{n}{F_p} \right) \dots \dots \dots \text{Eq. (3.10)}$$

Where m and n are Green – Ampt parameters of infiltration model

To determine these m and n parameters, the values of f_p were plotted against $\frac{1}{F_p}$, using excel sheet. Then the intercept and slope of the line are m and n respectively.

After the values of f_0 , f_c and β of Horton, S and K of Philip, a and b of Kostiakov and m and n of Green Ampt infiltration models were collected from the graph, the models were used to calculate infiltration capacity and infiltration rate of both Cambisols and Vertisols. Then the models were compared using R^2 and RMSE to select best fit model. The detail comparison method was described below.

3.3.4. Comparing Performance of Different Infiltration Models

Using determined infiltration parameters, four infiltration models were compared with the values of infiltration rates of field observed one and at any time t . The root mean square error (RMSE), coefficient of determination (R^2) and Nash-Sutcliffe (NS) were used for comparison. Different scholars used different statistical tools to compare Infiltration Models. Ogbe *et al.* (2011) used the RMSE and R^2 to compare Kostiakov, modified Kostiakov, Philip and Horton's Infiltration Models while Sreejani *et al.* (2017) used Correlation Coefficient and Standard Error tools to compare Horton, Kostiakov, Philip and Green Ampt Infiltration Models. On the other hand, David *et al.* (2018) used Correlation Coefficient, Standard Error

and coefficient of determination (R^2) to compare Horton, Kostiakov and Green Ampt Infiltration Models. And Abubakr and Byzedi (2012) also used coefficient of determination and variation to compare Kostiakov, Kostiakov_Lowies, Philip and SCS.

The goodness of fit of each model was tested by both the R^2 and the RMSE to evaluate how closely each model describes the measured infiltration. The R^2 values indicate the degree to which data variations are explained by each model, while RMSE shows the amount of divergence of the model values from the observed values. Therefore, a high R^2 which is close to 1 and a low RMSE value which is close to 0 both indicate a good agreement between the predicted and observed infiltration curves.

The RMSE provides a measure of deviation of predicted values from measured data and has frequently been used as means of evaluating the accuracy of hydrologic models. The RMSE is calculated as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (P_i - O_i)^2}{n}} \dots \dots \dots \text{Eq. (3.11)}$$

Where:

- P_i = Predicted Value
- O_i = Measured/observed value
- n = number of measurements

Predicted value of infiltration rate will be plotted versus observed values and coefficient of determination (R^2) will be calculated for each model according to the equation

$$R^2 = 1 - \frac{SSE}{SST} \dots \dots \dots \text{Eq. (3.12)}$$

Where,

- SSE = Explained Sum of Square
- SST = Total Sum of Square

The R^2 values indicate the degree to which data variations are explained by each model. RMSE shows the amount of divergence of the model values from the observed values.

Nash-Sutcliffe is the most frequently used to compare hydrological parameters. The equation of Nash-Sutcliffe is:

$$NS = 1 - \frac{\sum_{ti=1}^n (y_{ti}^m - y_{ti})^2}{\sum_{ti=1}^n (y_{ti} - \bar{y})^2} \dots\dots\dots \text{Eq. (3.13)}$$

Where,

n = number of observed data point

y_{ti} = observation values

y_{ti}^m = model values

\bar{y} = average value of observation

3.3.5. Setting Equation for Both Cambisols and Vertisols

Infiltration rate and infiltration capacity of both Cambisols and Vertisols was collected from field. These data were analyzed using Excel sheet to quantify infiltration parameters of the four infiltration models, those selected for the analysis. Then using the values of different infiltration parameters of these infiltration models, Horton, Kostiakov, Philip and Green Ampt, the equations of these models were set.

The determined infiltration parameters of all ten sample points were inserted in infiltration model equations to develop equation for the sites. Finally, from estimated infiltration parameters, infiltration model for both Cambisols and Vertisols was developed by substituting it into the model equation to obtain the specific infiltration equations for the soils of the study area. These equations were also tested for accuracy by comparing cumulative infiltration capacity that was measured at field and cumulative infiltration capacity the model estimate.

3.3.6. Check for Accuracy of Model Infiltration Equations

The developed infiltration models for each point was checked for validity by relating cumulative infiltration rate of the soil that was measured at field and the cumulative infiltration value that is calculated from the model. Integration of the developed infiltration model was used to compare with cumulative infiltration rate of the model. The model was integrated by the time from the infiltration start, zero, to the time required to get constant infiltration rate. And the model which estimate the value of cumulative infiltration that is similar or nearly similar with field cumulative infiltration was recommended as valid model for the site.

This method was used by different scholars. Arshad *et al.*, (2015) investigated the effect of tillage intensity to the water transmission behavior for sandy loam soil in terms of infiltration rates and cumulative infiltration and its validation with different infiltration models. The scholar used to compare observed cumulative infiltration and model cumulative infiltration for model validation. Standard Deviation, Standard Error and Coefficient of determination was used for comparison. Finally, the scholar concluded that Horton infiltration model is accurate model for the site.

The accuracy of the different equations for predicting the cumulative infiltration were evaluated by comparing the observed values of measurement on the field and the predicted values based on the fitted equation. The cumulative infiltration values predicted using the infiltration models and those measured were plotted against each other and fitted with a linear equation with zero intercept to verify the validity of each prediction. The slope of the line of best fit and its coefficient of determination (R^2) for each model. To check the discrepancies between the predicted and the measured values, paired t-test and Root Mean Square Error (RMSE) were used. Considering the four infiltration models evaluated, the Horton's models gave best fit to the measured cumulative infiltration, although the other models provided good overall agreement with the field measured cumulative infiltration depths (Ogbe *et al.*, 2011)

Based on this, accuracy of the models were tested by comparing field cumulative infiltration capacity data and the model cumulative infiltration capacity. The infiltration equations of the four infiltration models were integrated to calculate infiltration capacity using these models. Then, the values of cumulative infiltration capacity were compared with values of the field cumulative infiltration capacity with respect to time. Standard Error, Coefficient of determination, percentage of error and Nash-Sutcliffe were used for comparison

4. RESULTS AND DISCUSSIONS

In this section result and discussion part of infiltration parameter determination, comparison of the Horton, Philip, Kostiakov and Green Ampt infiltration models, set of infiltration equations from determined infiltration parameters and the test for accuracy of infiltration models are presented in details.

4.1. Determination of Infiltration Parameters

Field infiltration data was collected from five samples of both Vertisol and Cambisols with three replications. Values of field infiltration rate were used to fix parameters of Kostiakov, Philip, Horton and Green Ampt infiltration models. The information such as location, soil texture, soil initial moisture and land use is described below.

Table 3: Research Site General Information

Points	Location			IMC	Land Use	Soil Type
	X	Y	Z			
C1	531289	945934	1652	22.62	Agricultural Land	Cambisols
C2	531339	946034	1654	15.45		
C3	531291	946240	1658	12.71		
C4	531335	946103	1659	17.51		
C5	531355	946221	1664	21.04		
V1	500449	969251	1869	21.78	Agricultural Land	Vertisols
V2	500309	969309	1871	11.17		
V3	500444	969180	1867	16.13		
V4	500351	969146	1871	21.97		
V5	500216	969234	1873	26.43		

The result of IMC of Cambisols and Vertisols were ranged from 12.71 % to 22.62 % and 11.17 % to 26.43 % respectively. This showed that, there is difference in moisture content from one sample to another. This difference in soil moisture also determine infiltration capacity of the soil, since soil with low initial moisture has high soil infiltration capacity.

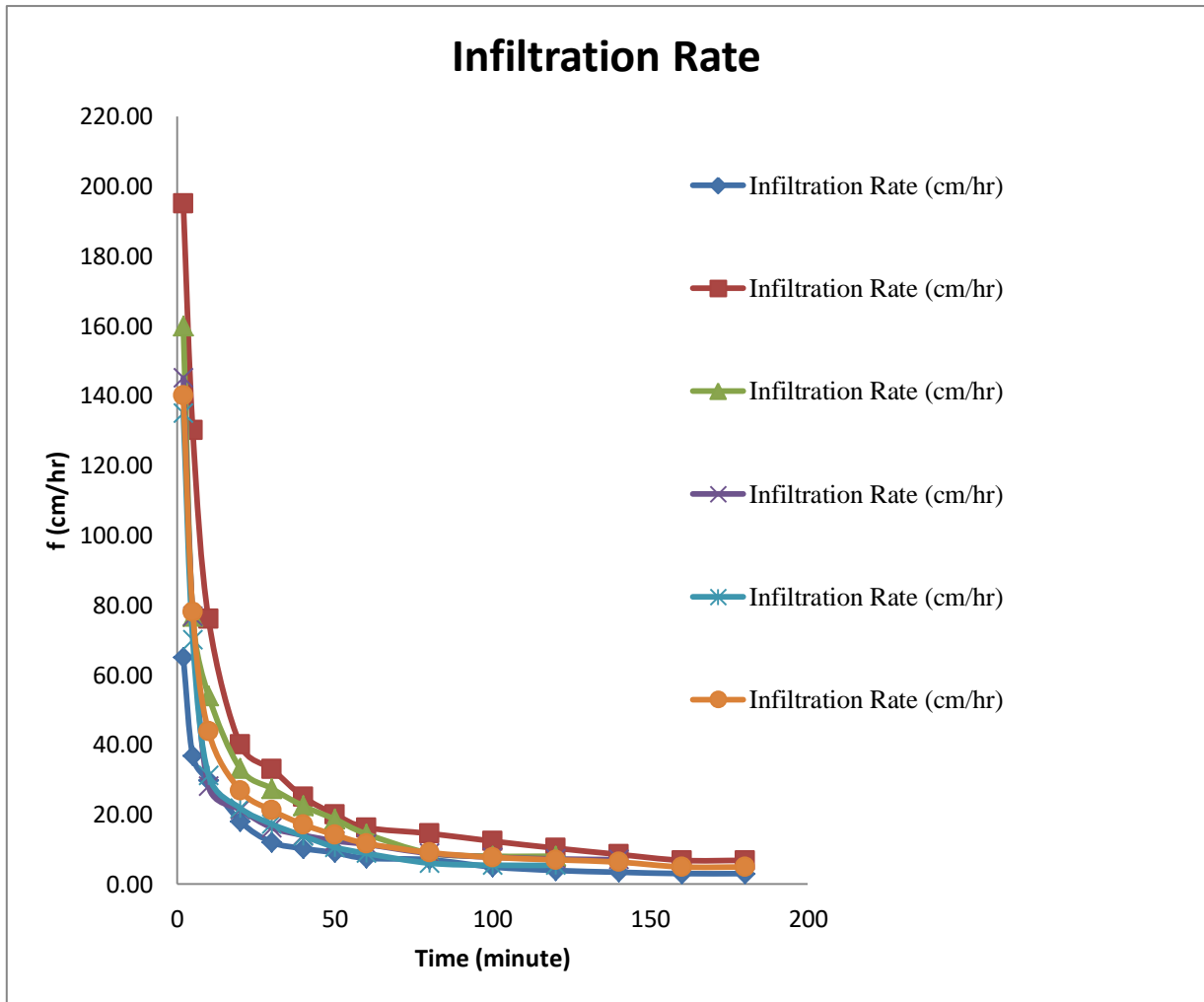


Fig. 3: Infiltration Rate for Cambisols

Infiltration data was collected from five infiltration test samples with three replications. The average values of each replication was used for analysis. For Cambisols, the time required to get constant infiltration rate was ranged from 120 minutes to 180 minutes. The result showed that, there is a difference from one point to another of infiltration rate for Cambisols. At the beginning of first two minutes, infiltration rate of sample C1, C2, C3, C4, and C5 was 65 cm/hr, 195 cm/hr, 160 cm/hr, 145 cm/hr and 135 cm/hr respectively. Final steady state infiltration rate of Horton Infiltration ranges from 3 cm/hr to 8 cm/hr respectively.

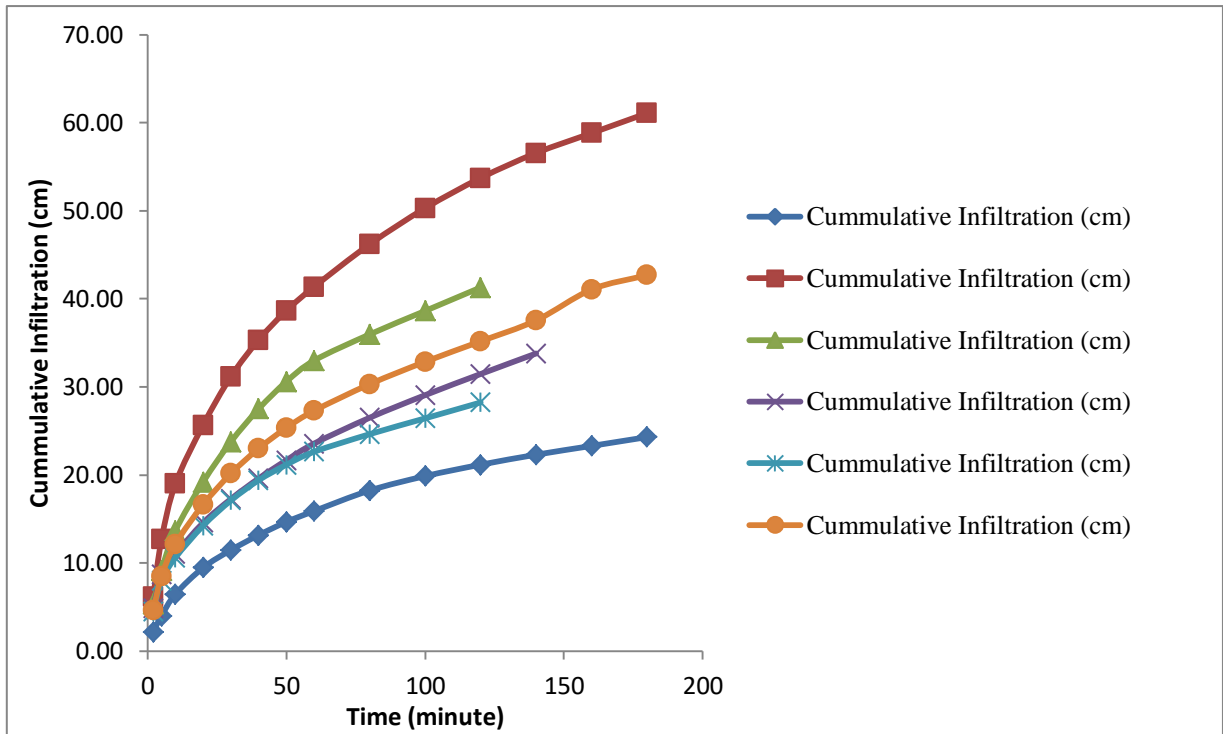


Fig 4: Cumulative Infiltration Capacity for Cambisols

And similarly, cumulative infiltration capacity was also different from one sample to another. The values of cumulative infiltration capacity of Sample C1, C2, C3, C4, and C5 were 24.3 cm, 61.1 cm, 41.3 cm, 33.8 cm and 28.23 cm.

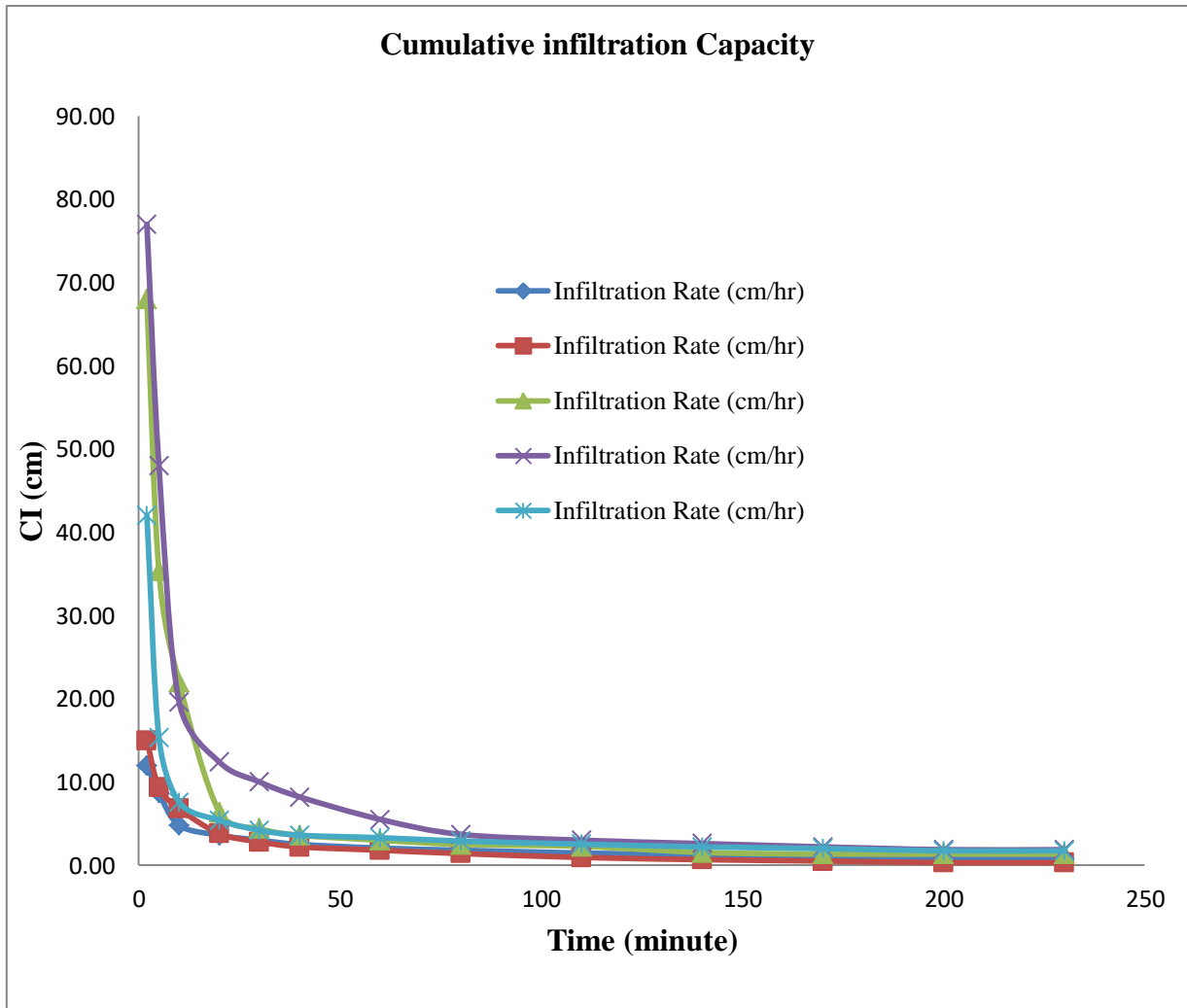


Fig. 5: Infiltration Rate for Vertisol

Similarly, soil infiltration rate and cumulative infiltration of Vertisols were collected from five different samples with three replications from agricultural land of Bishoftu Research Center. The result of this site also showed that, there was different values of infiltration rate from one sample to another. The values of infiltration rate for beginning of first two minutes were 12 cm/hr, 15 cm/hr, 68 cm/hr, 77 cm/hr and 42 cm/hr for sample V1, V2, V3, V4, and V5 respectively. Final steady state infiltration rate of Horton Infiltration ranges from 3 cm/hr to 8 cm/hr respectively. Similarly, there was different values of constant infiltration rate for each sample. Accordingly, there were constant infiltration rate values of V1, V2, V3, V4, and V5 as 0.73 cm/hr, 0.3 cm/hr, 1.33 cm/hr, 1.87 cm/hr, and 1.73 cm/hr.

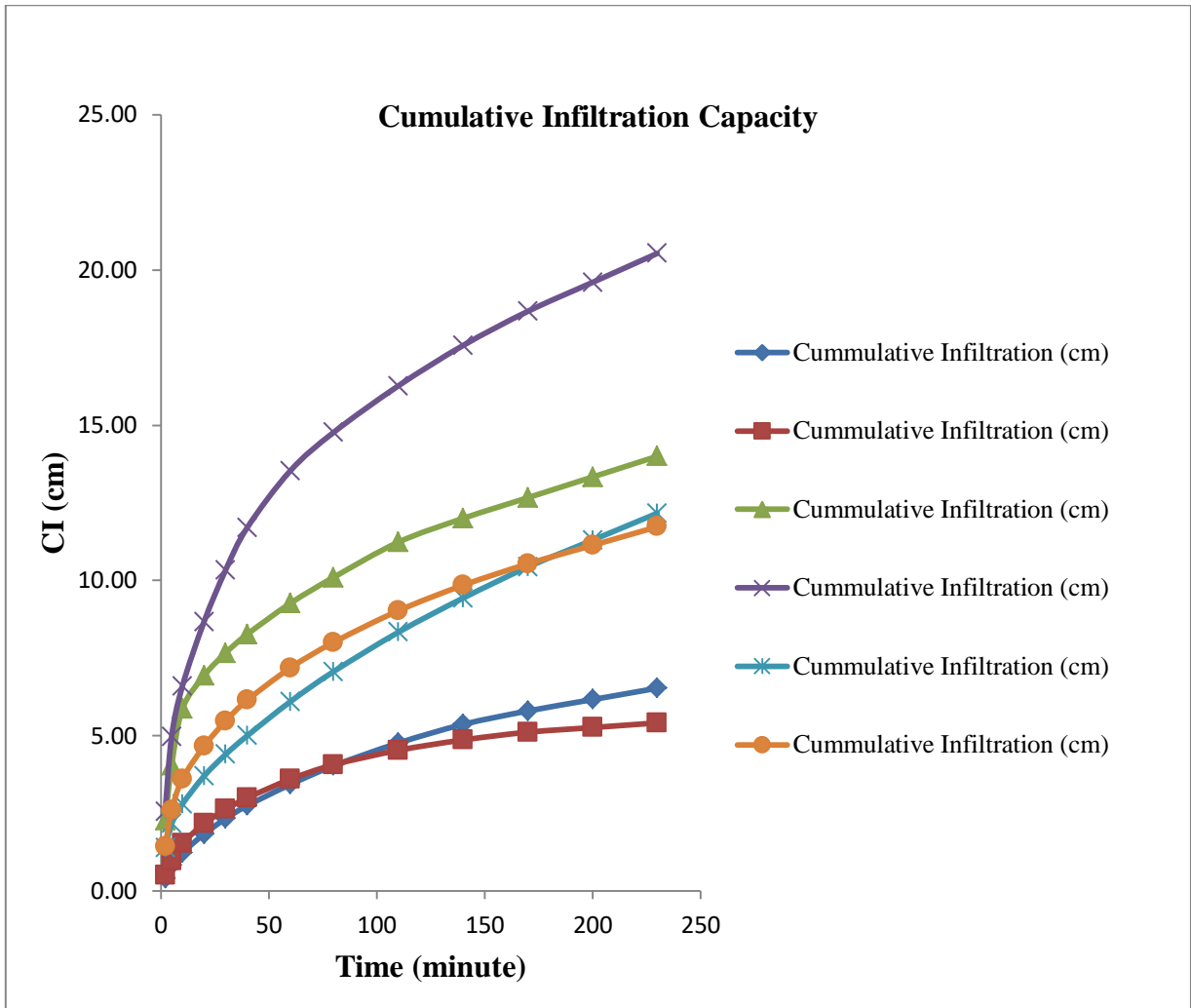


Fig. 6: Cumulative Infiltration Capacity for Vertisol

As infiltration rate, cumulative infiltration capacity was also different from one sample to another. The values of cumulative infiltration capacity of Sample C1, C2, C3, C4, and C5 were 6.53 cm, 5.42 cm, 14 cm, 20.53 cm, 12.17 cm and 11.73 cm.

There is difference in initial infiltration rate, final steady state infiltration rate, and cumulative infiltration capacity for Vertisol. Initial infiltration rate and final steady state infiltration rate ranges from 7.65 cm/hr to 30.19 cm/hr and 0.73 cm/hr to 1.87 cm/hr respectively.

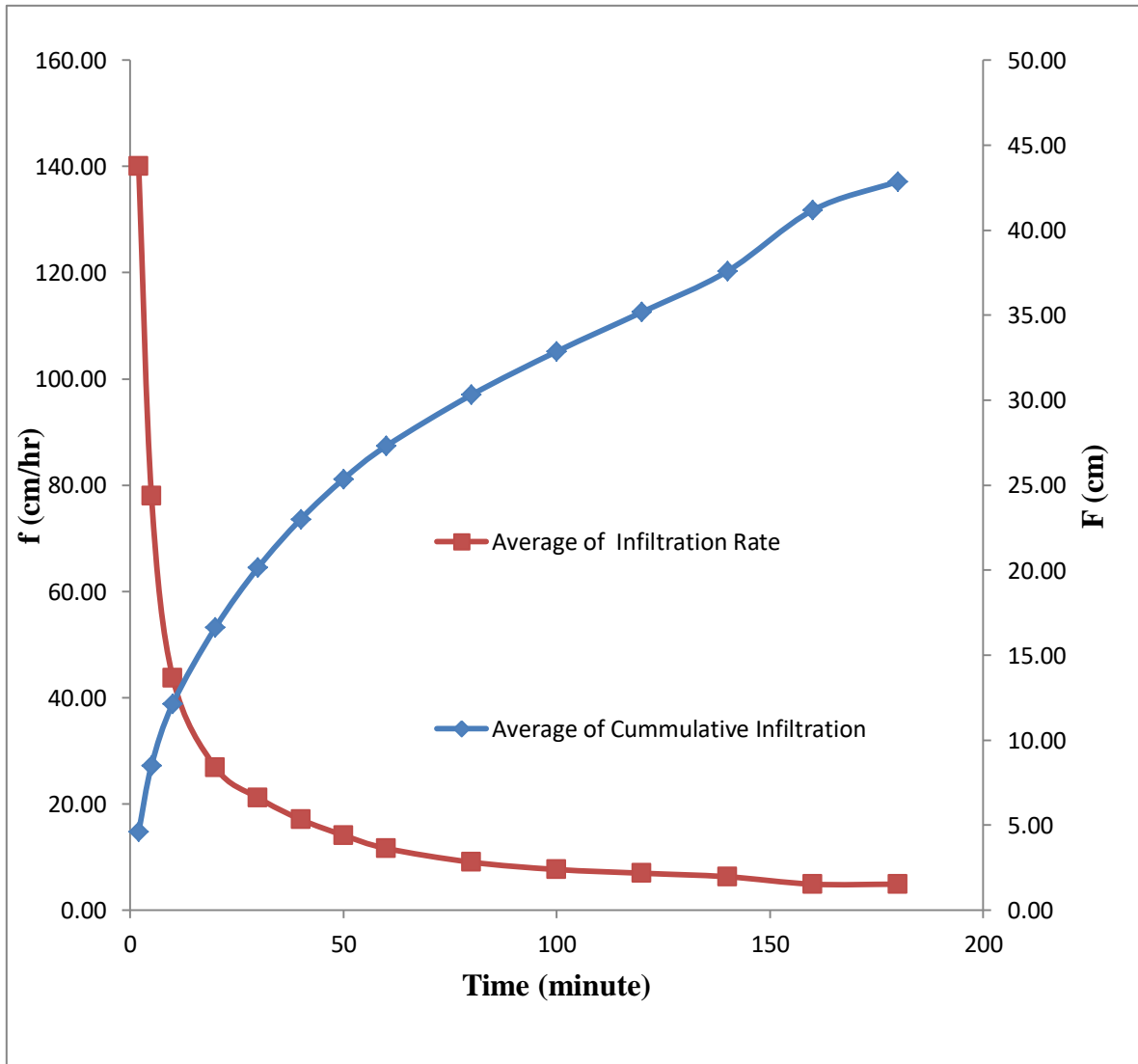


Fig. 7: Average Infiltration Rate and Cumulative Infiltration Capacity for Cambisols

From both dominant soil types of the basin, Cambisols and Vertisol, infiltration rate is different. Cambisols has high infiltration rate, 140 cm/hr, while Vertisol has low infiltration rate, 42.80 cm/hr at the beginning. Final steady state infiltration rate are 4.90 cm/hr and 1.19 cm/hr for Cambisols and Vertisol respectively. But the time needed to reach the final steady state infiltration rate is high for Vertisol compared to Cambisols.

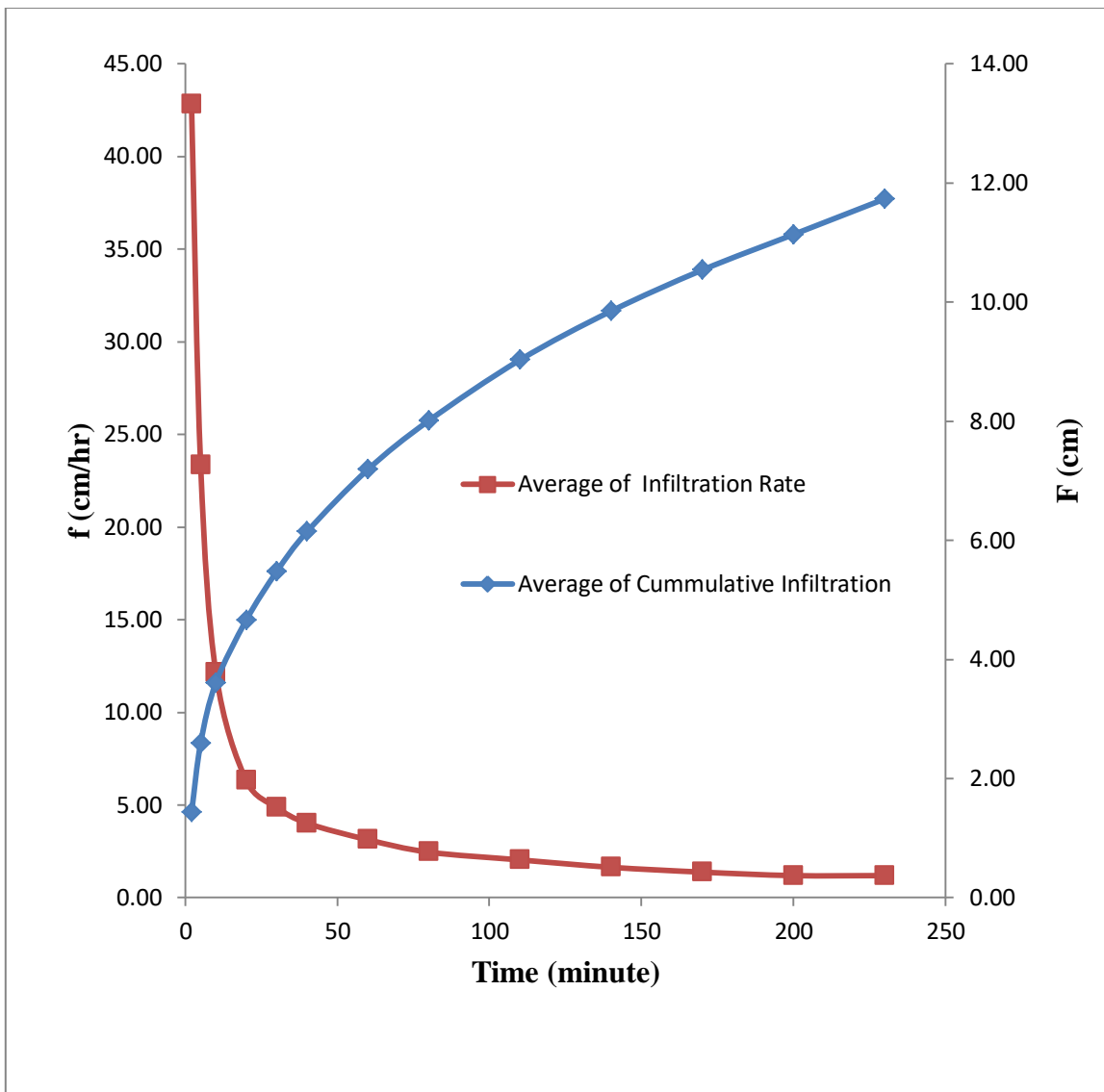


Fig. 8: Average Infiltration Rate and Cumulative Infiltration Capacity for Vertisol

This difference in infiltration capacity of soil is stated by different Authors. Ayu *et al.* (2013) conducted their research to analyze the infiltration rate on a various landuse, and the factors that affect the infiltration rate of dryland areas of Unter Iwes District, Sumbawa regency. They got the results that showed infiltration rate was high as 45.10 cm.h^{-1} for rainfed land use and the infiltration rate as low as 17.70 cm.h^{-1} on ‘Tegalan’ landuse. Patle *et al.* (2018) carried out study on cultivated land and the result showed that the basic infiltration rate was found to be higher in sandy loam soil with minimum value of 2.4 cm/h and maximum value as 16.8 cm/h when compared to loamy sand soil which has minimum and maximum value as 0.30 and 13.80 cm/h , respectively.

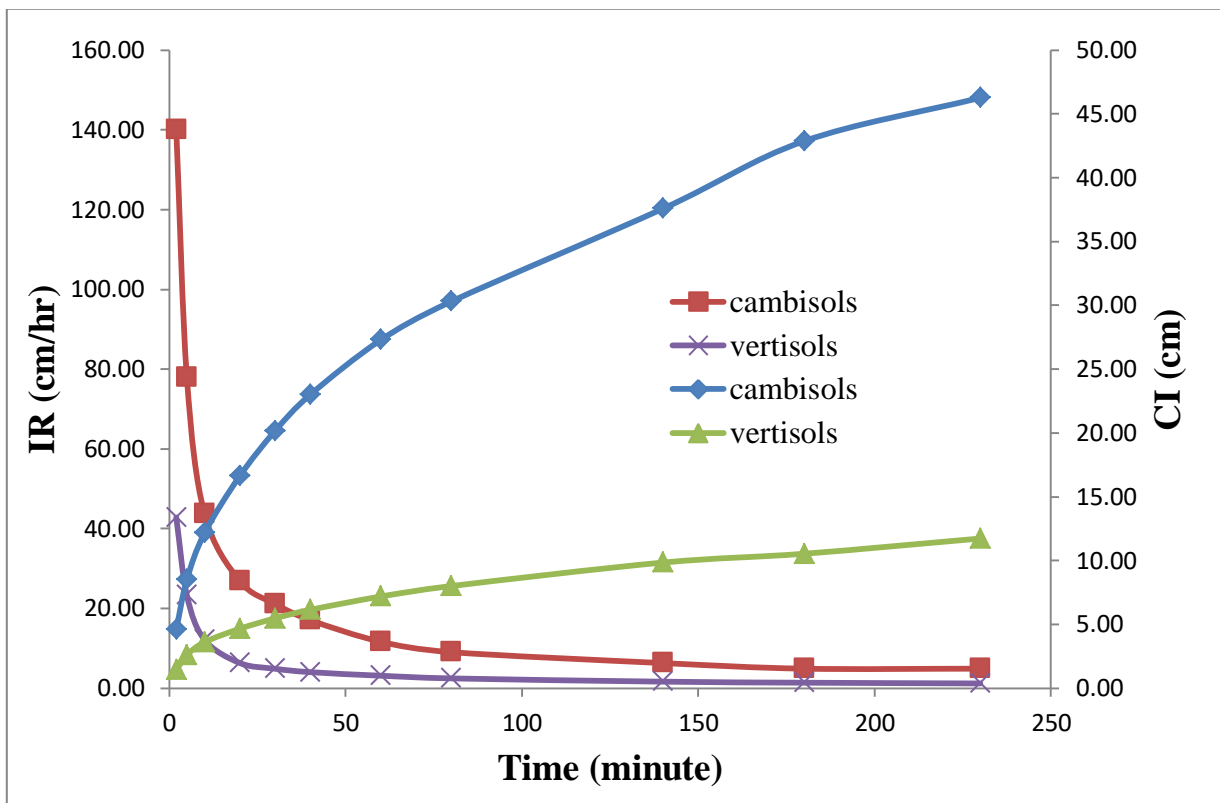


Fig. 9: Average IR and CI for Cambisols and Vertisol

Arshad *et al.* (2016) stated that, the soil condition directly affects the infiltration rate and cumulative infiltration accordingly. The obtained results showed that the constant infiltration rate for unploughed and ploughed sandy loam soils of different tillage operations were found to be 5.34 , 7.83 , 8.09 , and 8.10 cm/hr .

After field infiltration data were collected from the study site for both soil types, data were arranged on excel sheet and graph method was used to determine infiltration parameters of Horton, Kostiakov, Philip and Green_Ampt infiltration models. Then from the graph the values of Horton infiltration model parameters such as initial infiltration rate (f_0) and Horton's decay coefficient (k) were found. Similarly, a and b parameters of Kostiakov infiltration model, soil suction potential or sorptivity (S), hydraulic conductivity (K) infiltration parameters of Philip infiltration model and also m and n parameters of Green_Ampt infiltration model were collected from drawn graph. The graph drawn to get the average infiltration parameters of the four infiltration models for both Cambisols and Vertisols were shown on figure 9 and 10 below and the graph for each five points were shown in annex part. Similarly, the summery of the all model parameters were shown on table 4 below. And using these determined infiltration parameters, infiltration rate of the study sites were estimated using the selected four infiltration models.

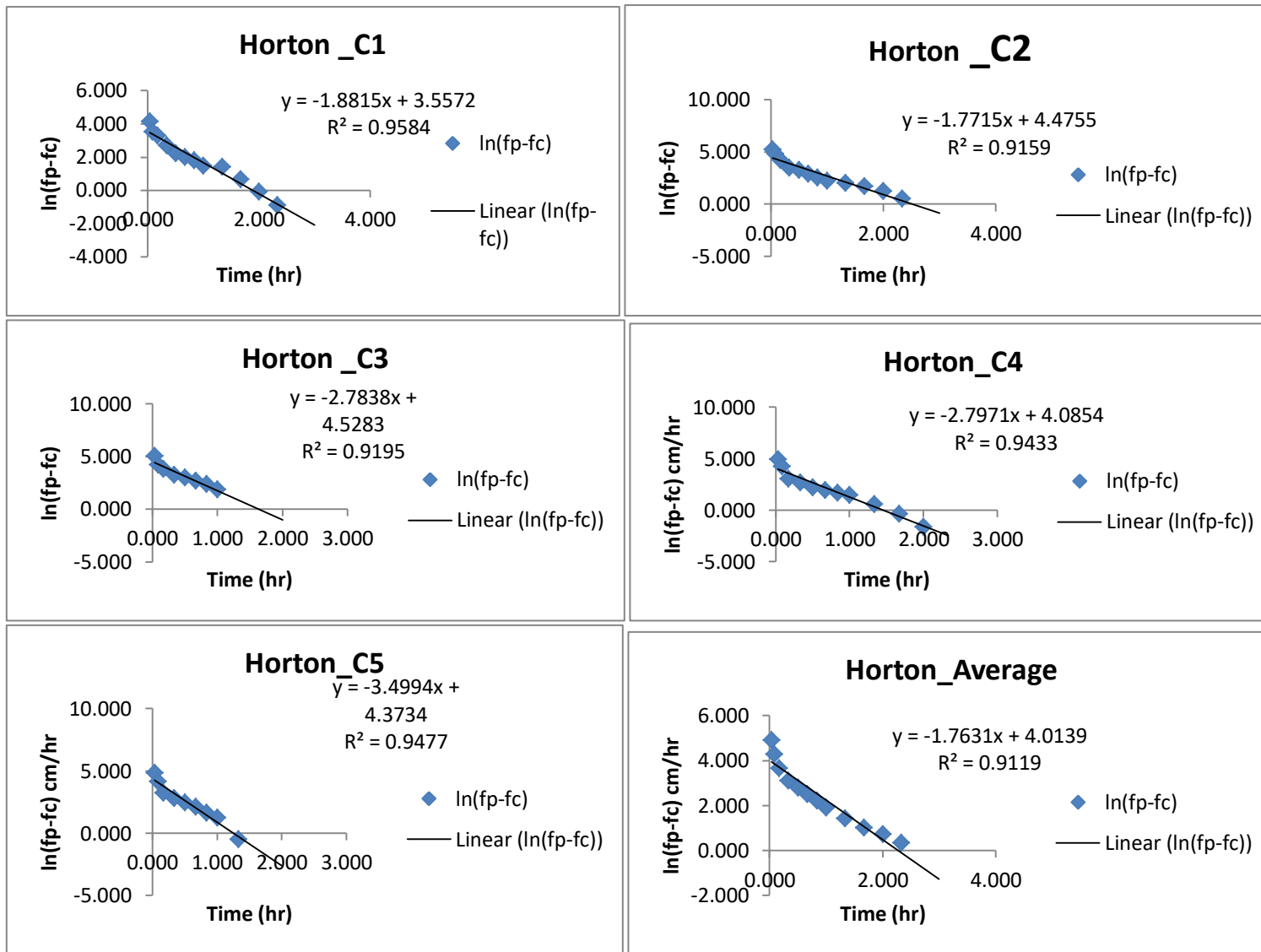


Fig. 10: Graph of Horton for Cambisols (C1, C2, C3, C4, C5 & Average)

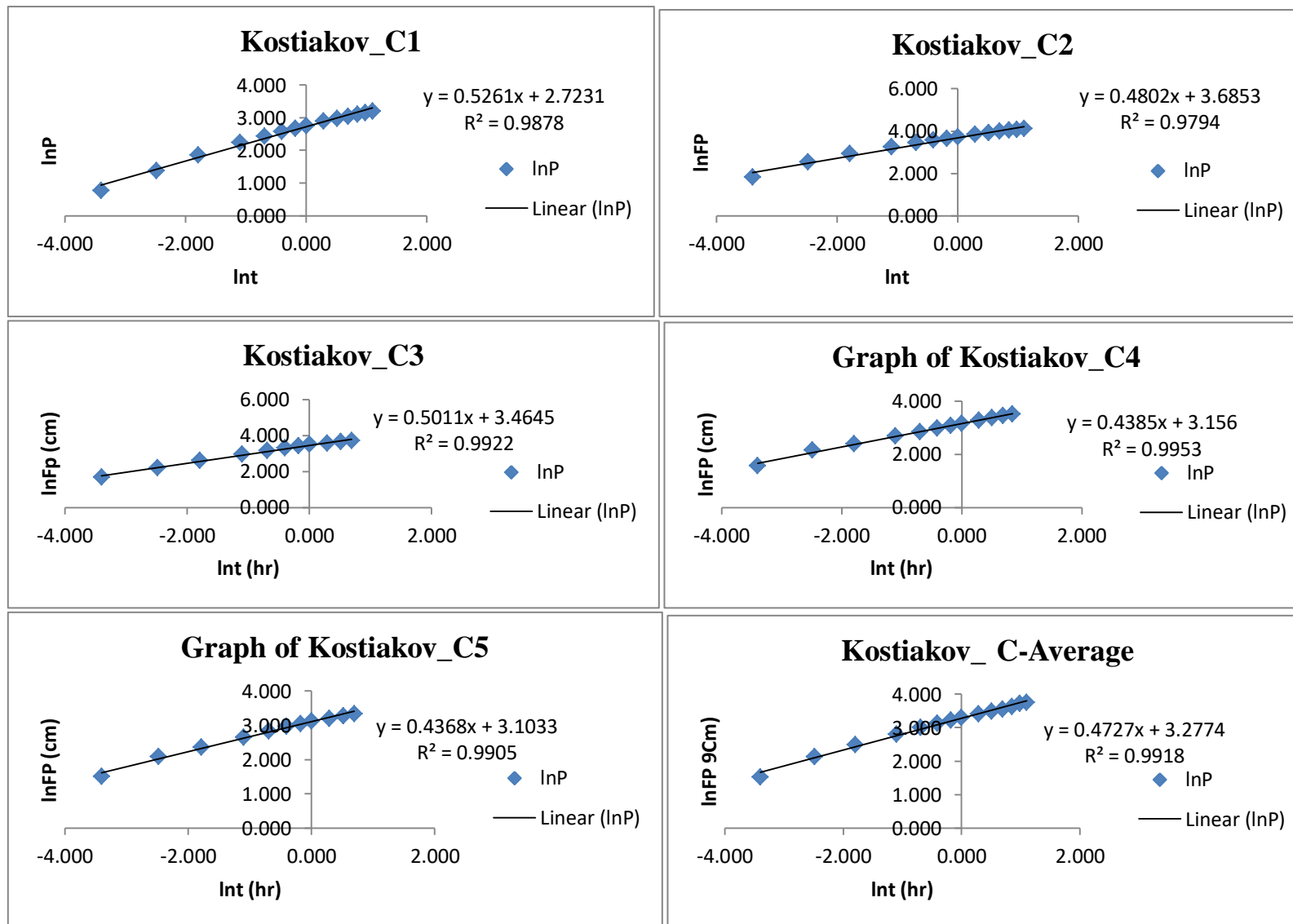


Fig. 11: Graph of Kostiakov for Cambisols (C1, C2, C3, C4, C5 & Average)

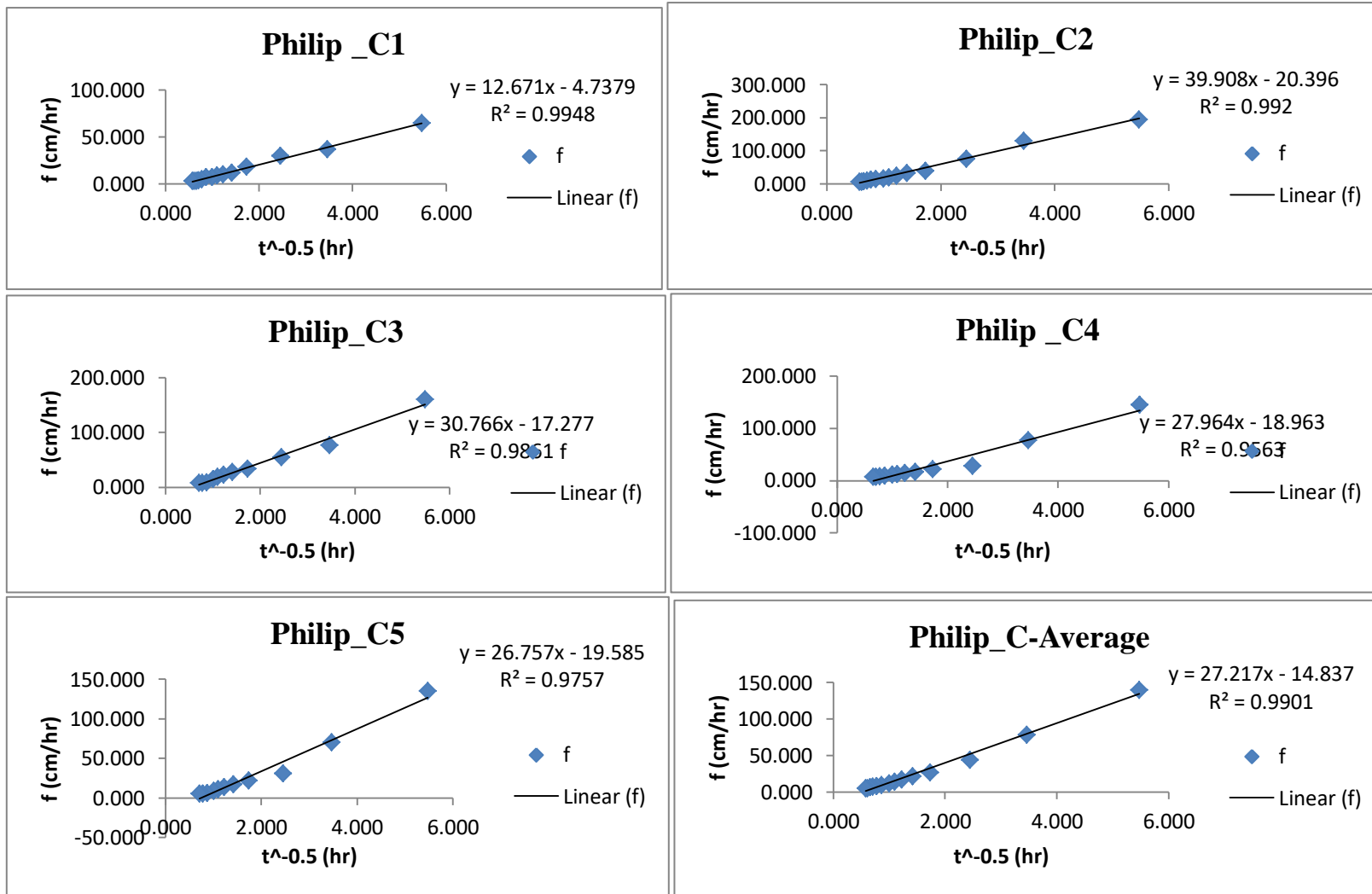


Fig. 12: Graph of Philip for Cambisols (C1, C2, C3, C4, C5 & Average)

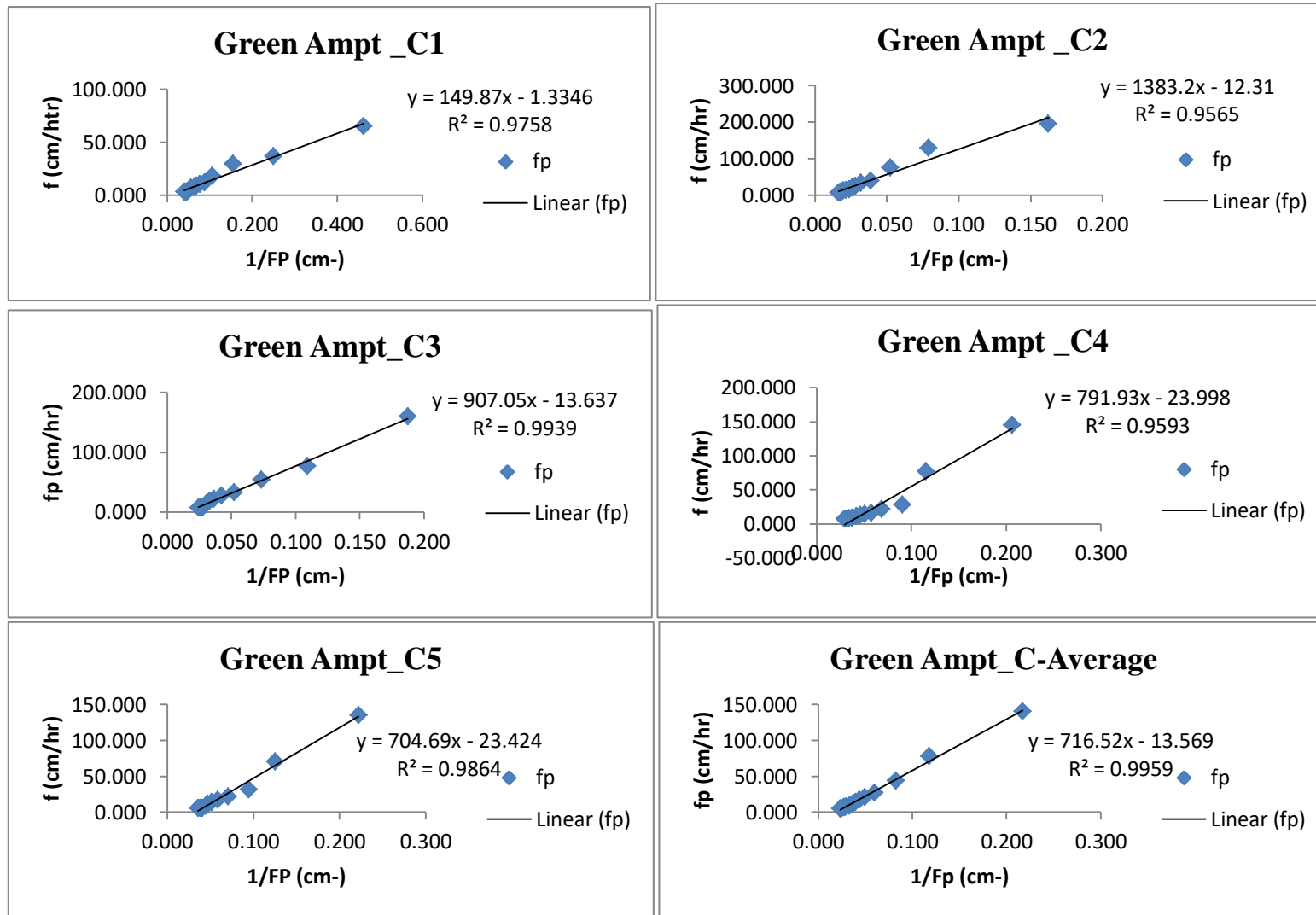


Fig. 13: Graph of Green Ampt for Cambisols (C1, C2, C3, C4, C5 & Average)

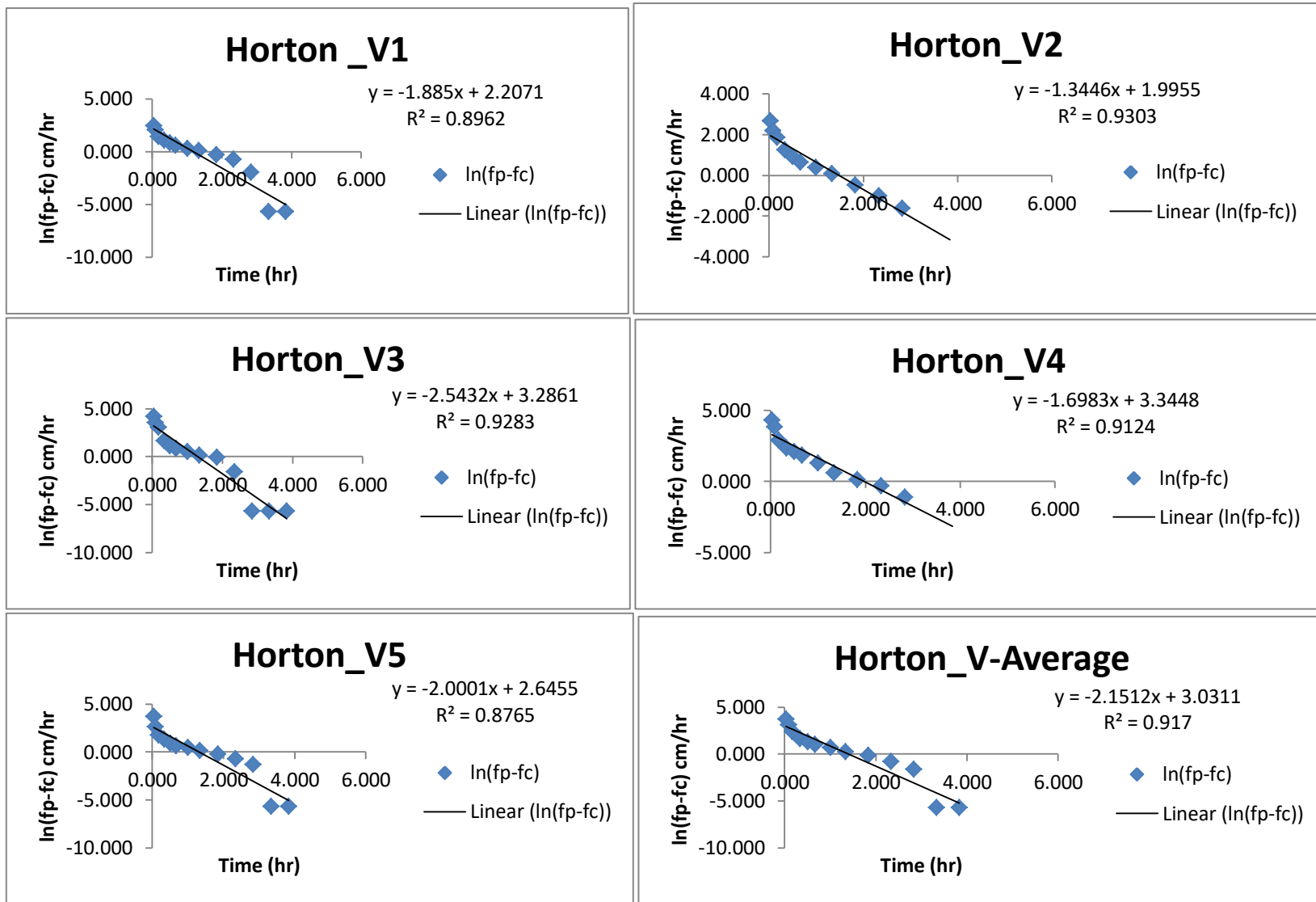


Fig. 14: Graph of Horton for Vertisols (V1, V2, V3, V4, V5 & Average)

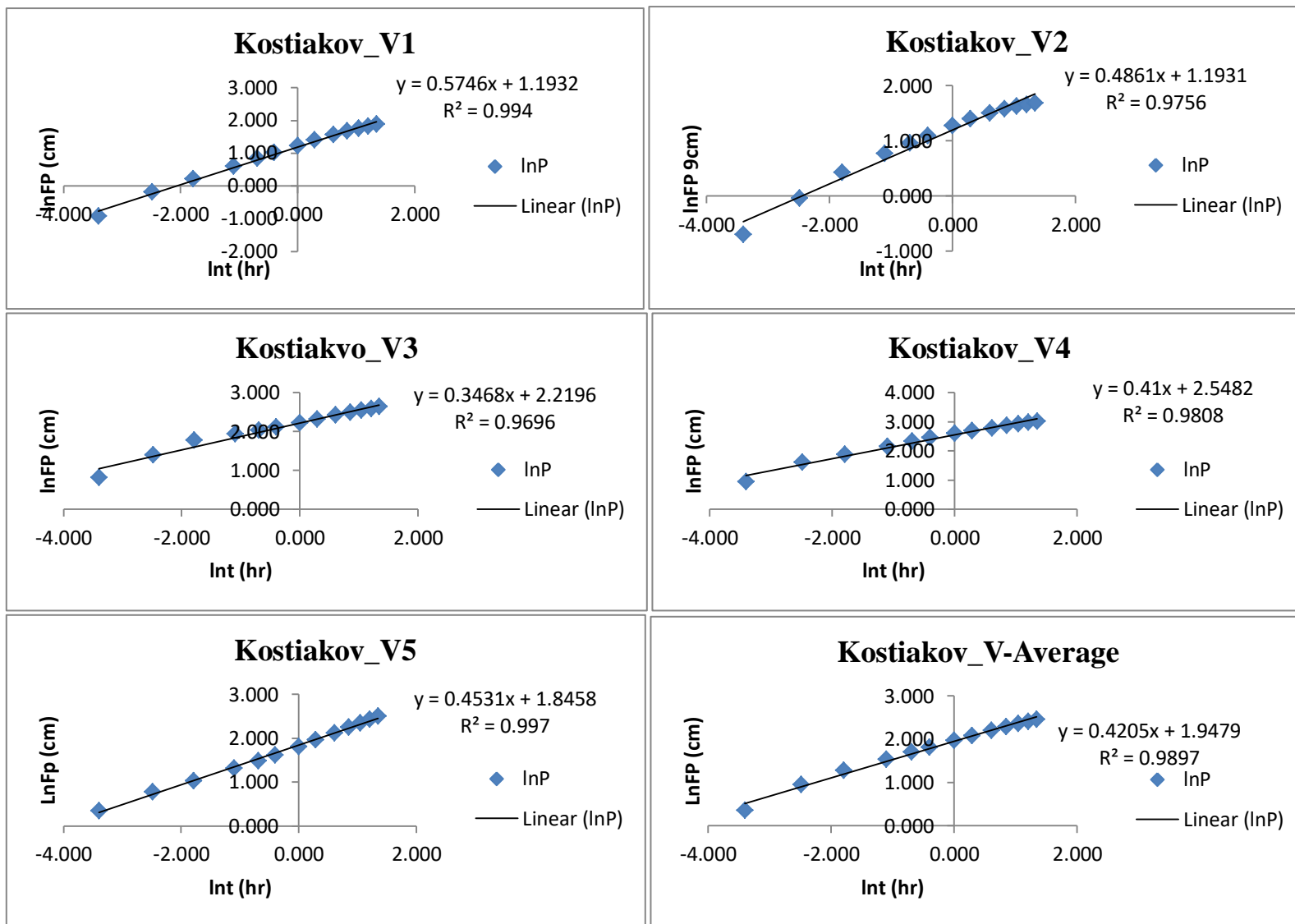


Fig. 15: Graph of Kostiakov for Vertisols (V1, V2, V3, V4, V5 & Average)

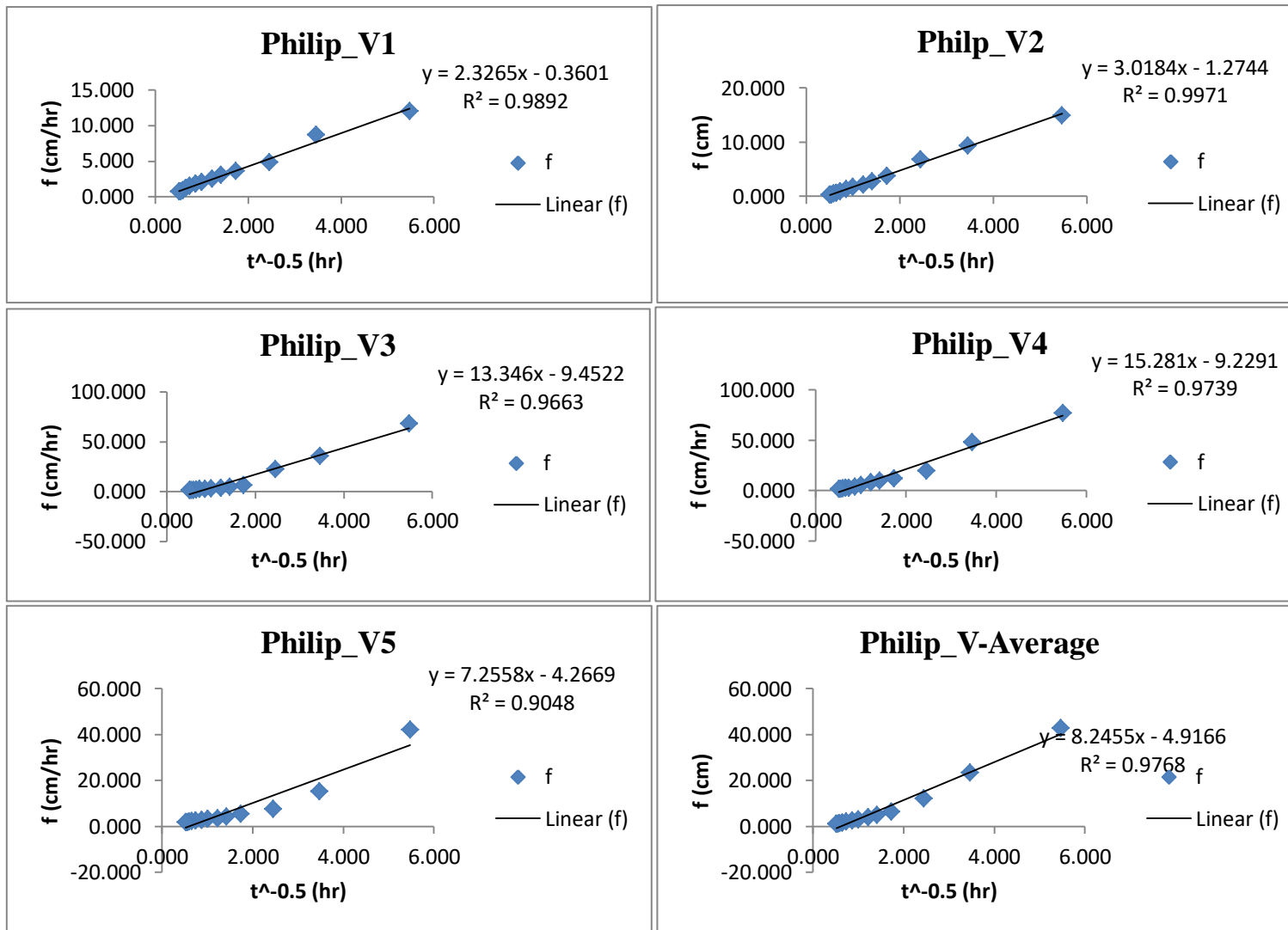


Fig. 16: Graph of Philip for Vertisols (V1, V2, V3, V4, V5 & Average)

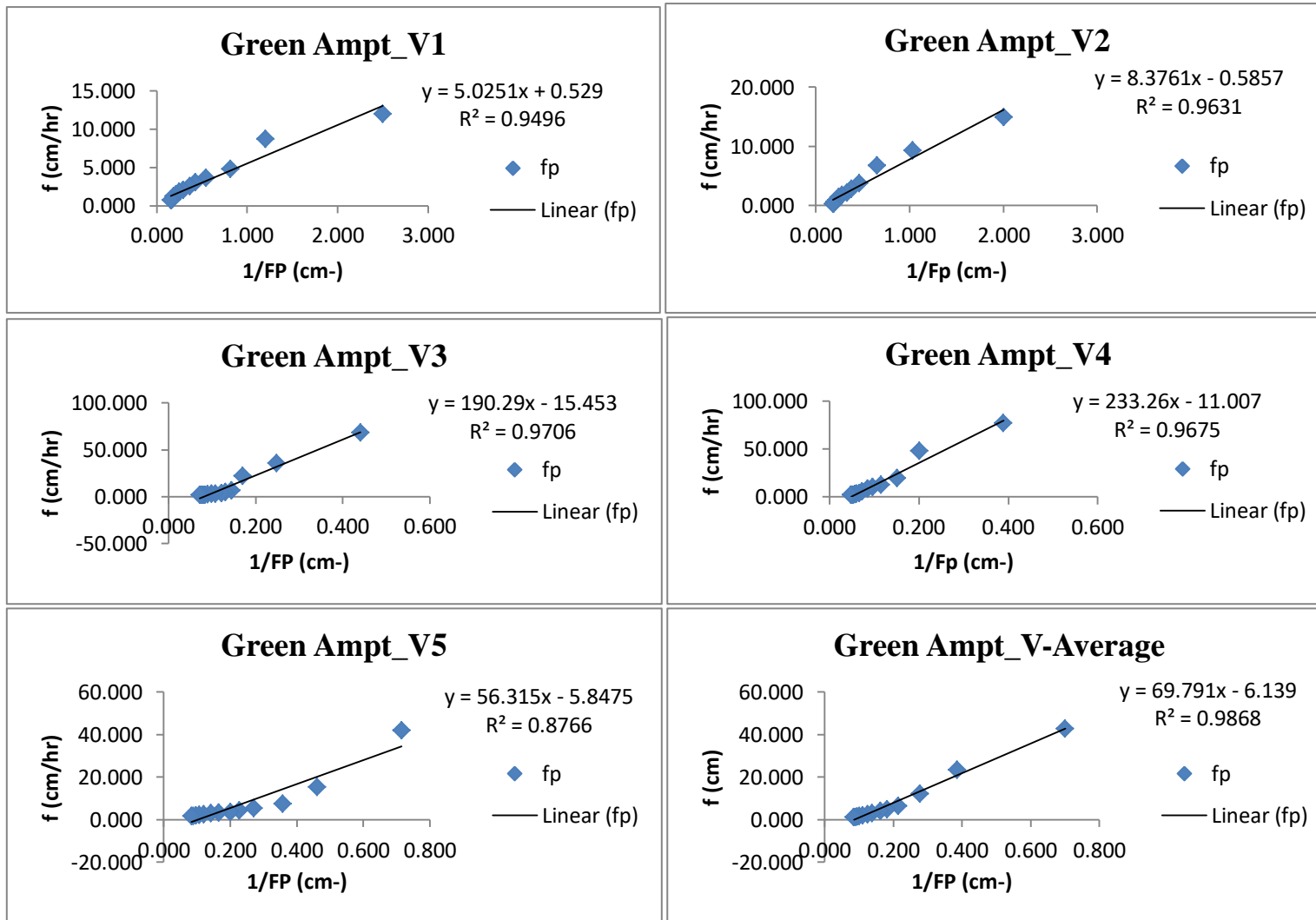


Fig. 17: Graph of Green Ampt for Vertisols (V1, V2, V3, V4, V5 & Average)

Table 4: Calculated Infiltration Parameters of different infiltration models

Soil Type	Points	Kostiakov		Philip		Green Ampt			
		fc	β	a	b	S	K	m	n
Cambisols	C1	3	-1.88	15.22	0.53	25.34	14.74	-1.33	149.8
	C2	6.80	-1.77	39.83	0.48	79.80	20.39	-12.31	1383
	C3	8.00	-2.78	31.93	0.50	61.52	17.27	-13.63	907
	C4	7.00	-2.8	23.47	0.44	55.92	18.96	-23.99	791.9
	C5	5.40	-3.5	22.36	0.44	53.50	19.58	-23.42	704.6
	Average	4.90	-1.76	26.49	0.47	54.42	14.83	13.56	716.5
Vertisol	V1	0.73	-1.89	3.30	0.57	4.65	0.36	0.53	5.03
	V1	0.30	-1.34	3.30	0.49	6.04	1.27	-0.59	8.38
	V3	1.30	-2.54	9.2	0.35	26.68	9.45	-15.45	190.2
	V4	1.87	-1.70	12.78	0.41	30.56	9.23	-11.00	233.20
	V5	1.73	-2.0	6.33	0.45	14.51	4.27	-5.85	56.31
	Average	1.19	-2.15	7.01	0.42	16.49	4.92	-6.14	69.79

The table showed that, there was the variability of steady infiltration rate for both Cambisols and Vertisols at all samples. The values of steady infiltration rate for Cambisols were 3, 6.8, 8, 7 and 5.4 cm/hr which had average value of 4.9 cm/hr. On the other hand, the Vertisol had 0.73, 0.3, 1.3, 1.87 and 1.73 cm/hr. The average value of these steady infiltration rate was 1.19 cm/hr for this soil. This implied that steady infiltration rate of Cambisols was four times steady infiltration rate of Vertisols.

Parameters of kostiakov infiltration models, a and b, for Cambisols were ranged between the criteria set by the model. All values of a are above zero and of b are between 0 and 1. The values of soil suction potential, S, of Philip model were above zero, which implies that, the soil has capacity to suck water at all sample points. The values Hydraulic conductivity of Cambisols were higher than that of Vertisols. This is why infiltration capacity of Cambisols is greater than Vertisol.

After all these parameters of Horton, Kostiakov, Philip and Green Ampt infiltration models were estimated from the graph, infiltration rate of the site was also calculated using these models. When these infiltration models and field infiltration value were compared, the models showed different values. Horton Infiltration Model does not accept initially high increment of infiltration rate and Kostiakov, Philip and Green Ampt underestimate the final steady state infiltration rate. This idea is stated by NP Sonaje (2013), in his Review of Modeling Infiltration process.

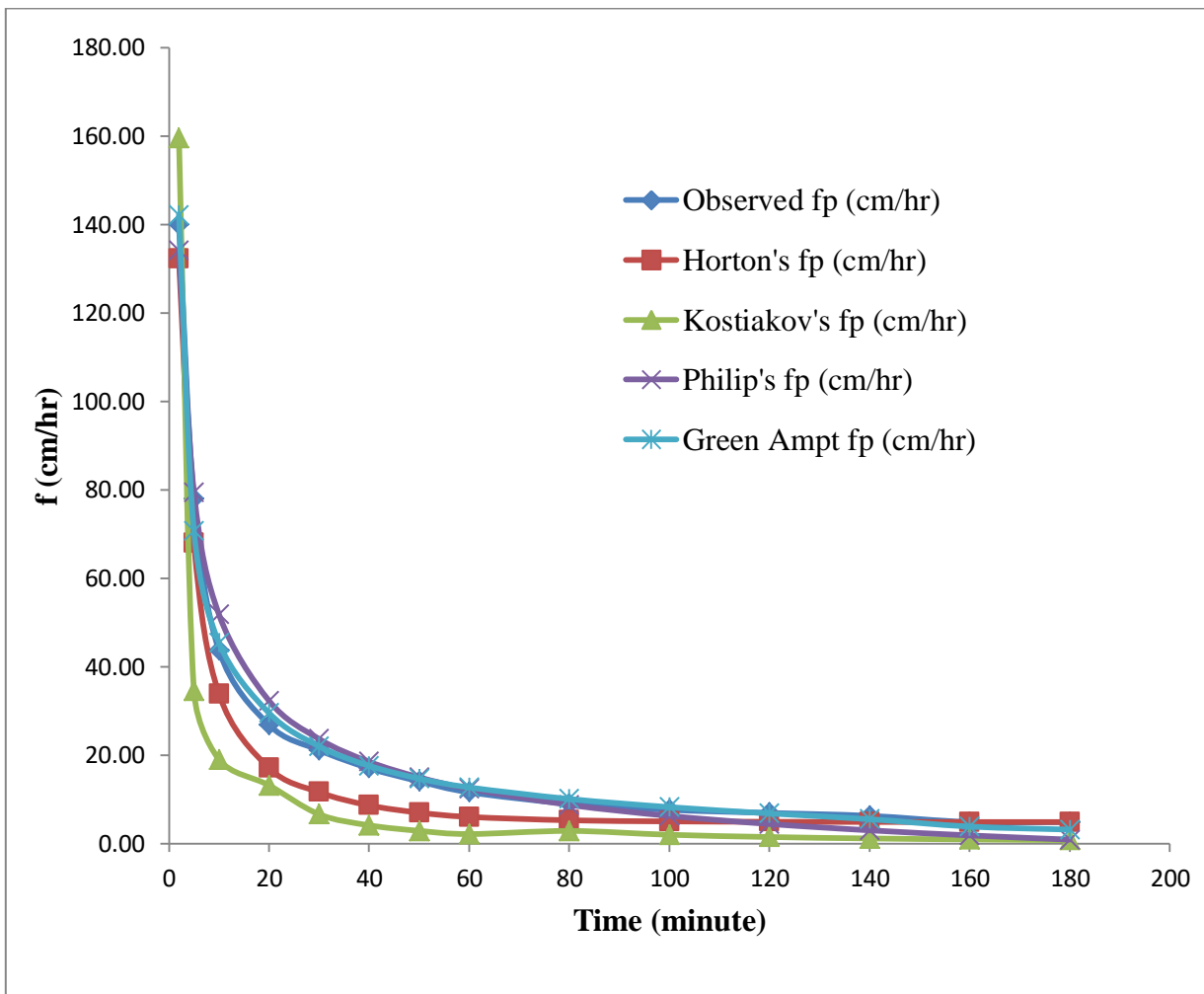
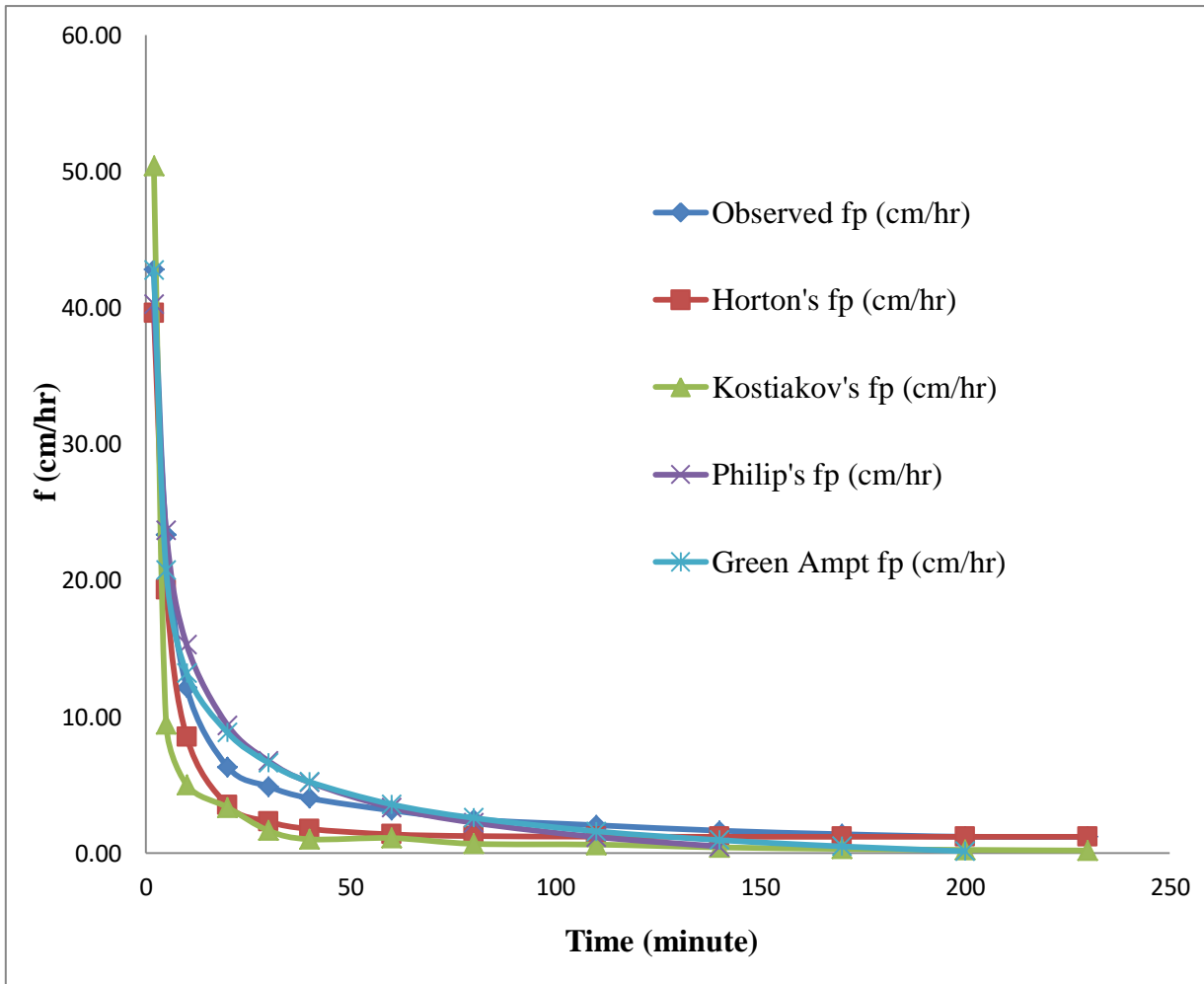


Fig. 18: Observed and Model Infiltration Rate for Cambisols



Graph 19: Observed and Model Infiltration Rate for Vertisol

4.2. Comparing Infiltration rate of Different Infiltration Models

From determined parameters, the values four infiltration models were compared with the values of infiltration rates of field observed one and at any time t . The goodness of fit of each model was tested by both the coefficient of determination (R^2), Nash-Sutcliffe (NS) and the root mean square error (RMSE) to evaluate how closely each model describes the measured infiltration. Even though, all models have good relation with observed values, when compared by R^2 , Green Ampt Model is the best fitting with higher degree R^2 and NS. Similarly this model showed minimum values of RMSE for Cambisols.

The R_2 , NS and RMSE values of Green Ampt infiltration model of Cambisols were 0.995, 0.996 and 2.332 respectively. So, Green Ampt infiltration model was selected for modeling infiltration rate for Cambisols followed by Philip, Horton and Kostiakov.

Table 5: Comparison of Average Observed infiltration and Models Value for Cambisols

Time	Observed fp (cm/hr)	Horton's fp (cm/hr)	Kostiakov's fp (cm/hr)	Philip's fp (cm/hr)	Green Ampt fp (cm/hr)
2	140.00	132.30	159.59	134.16	142.25
5	78.00	68.03	34.54	79.42	70.78
10	43.76	33.88	19.04	51.83	45.48
20	26.88	17.12	13.20	32.32	29.58
30	21.16	11.64	6.65	23.68	22.04
40	17.08	8.67	4.17	18.53	17.64
50	14.12	7.03	2.92	15.02	14.75
60	11.64	6.06	2.18	12.42	12.74
80	9.04	5.30	2.89	8.78	10.13
100	7.66	5.05	2.02	6.29	8.29
120	6.96	4.96	1.51	4.46	6.86
140	6.30	4.92	1.19	3.03	5.56
160	4.90	4.90	0.96	1.88	3.89
180	4.90	4.90	0.80	0.93	3.20
R2		0.991	0.896	0.990	0.995
NS		0.967	0.795	0.990	0.996
RMSE		6.660	16.520	3.632	2.332

Diffirent Scholars recommended different infiltration models for best fit of their study area. Ogbе *et al.* (2011) concluded Horton's models, Sreejani *et al.* (2017) concluded that, Kostiakov's Model, David *et al.* (2018) also concluded that Horton model, Ibrahim et al. (2019) recommended that of Kostiakov's and Horton's infiltration models, Abubakr and Byzedi (2012) recommended that Phillip's model, Sihag *et al.* (2017) concluded novel model, Dagadu and Nimbalkar P. T (2012) concluded that Green – Ampt model is the most suitable amongst other three models for estimation of infiltration rate in specific land use and soil parameters.

Similar to Cambisols, all Infiltration Models have good relation with observed values for Vertisols too. But Green Ampt was best fit model having values of 0.987, 0.987 and 1.312 for R^2 , NS, RMSE. Therefore Green Ampt infiltration model was selected as best fit model followed by Philip, Horton and Kostiakov for Vertisols.

Table 6: Comparison of Average Observed infiltration and Models Value for Vertisol

Time	Observed fp (cm/hr)	Horton's fp (cm/hr)	Kostiakov's fp (cm/hr)	Philip's fp (cm/hr)	Green Ampt fp (cm/hr)
2	42.80	39.60	50.40	40.27	42.78
5	23.33	19.32	9.46	23.66	20.77
10	12.16	8.54	5.01	15.29	13.21
20	6.32	3.50	3.35	9.37	8.84
30	4.88	2.30	1.64	6.75	6.61
40	4.02	1.76	1.01	5.18	5.22
60	3.13	1.37	1.10	3.33	3.57
80	2.46	1.24	0.68	2.22	2.58
110	2.04	1.20	0.62	1.17	1.59
140	1.64	1.19	0.41	0.48	0.95
170	1.38	1.19	0.30	0.48	0.48
200	1.19	1.19	0.23	0.48	0.13
230	1.19	1.19	0.18	0.48	0.13
R2		0.992	0.885	0.980	0.987
NS		0.963	0.805	0.980	0.987
RMSE		2.059	5.142	1.628	1.312

4.3. Equations of Different Infiltration Models for Both Soil Types

Using different equations, those described above, different infiltration parameters of four infiltration models, Horton, Kostiakov, Philip and Green Ampt, were determined. The determined infiltration parameters were inserted in infiltration model equations. Finally, from determined infiltration parameters, infiltration equations for both sites was developed at any time t as follows.

Table 7: Model Equations for Cambisols and Vertisols

Soil Type	Points	Horton	Kostiakov	Philip	Green Ampt
Cambisol	C1	$f_p = 3 + 35.04e^{-1.88t}$	$F_p = 15.22t^{0.53}$	$f_p = 12.67t^{-0.5} + 4.74$	$f_p = \left(\frac{149.8}{F_p}\right) - 1.33$
	C2	$f_p = 6.8 + 94.55e^{-1.77t}$	$F_p = 39.83t^{0.48}$	$f_p = 39.9t^{-0.5} + 20.39$	$f_p = \left(\frac{1383}{F_p}\right) - 12.31$
	C3	$f_p = 8 + 92.53e^{-2.78t}$	$F_p = 31.93t^{0.5}$	$f_p = 30.76t^{-0.5} + 17.27$	$f_p = \left(\frac{907}{F_p}\right) - 13.63$
	C4	$f_p = 7 + 59.42e^{-2.8t}$	$F_p = 23.47t^{0.44}$	$f_p = 27.96t^{-0.5} + 18.96$	$f_p = \left(\frac{791.9}{F_p}\right) - 23.99$
	C5	$f_p = 5.4 + 84.65e^{-3.5t}$	$F_p = 22.26t^{0.44}$	$f_p = 26.75t^{-0.5} + 19.58$	$f_p = \left(\frac{704.6}{F_p}\right) - 23.42$
	Average	$f_p = 4.9 + 60.50e^{-1.76t}$	$F_p = 26.49t^{0.47}$	$f_p = 27.21t^{-0.5} + 14.83$	$f_p = \left(\frac{716.5}{F_p}\right) - 13.56$
Vertisol	V1	$f_p = 0.73 + 9.09e^{-1.89t}$	$F_p = 3.3t^{0.57}$	$f_p = 2.33t^{-0.5} + 0.36$	$f_p = \left(\frac{5.03}{F_p}\right) + 0.53$
	V2	$f_p = 0.3 + 7.35e^{-1.34t}$	$F_p = 3.3t^{0.49}$	$f_p = 3.02t^{-0.5} + 1.27$	$f_p = \left(\frac{8.38}{F_p}\right) - 0.59$
	V3	$f_p = 1.33 + 26.73e^{-2.54t}$	$F_p = 9.2t^{0.35}$	$f_p = 13.34t^{-0.5} + 9.45$	$f_p = \left(\frac{190.2}{F_p}\right) - 15.45$
	V4	$f_p = 1.87 + 28.32e^{-1.7t}$	$F_p = 12.78t^{0.41}$	$f_p = 15.28t^{-0.5} + 9.23$	$f_p = \left(\frac{233.2}{F_p}\right) - 11$
	V5	$f_p = 1.73 + 14.08e^{-2t}$	$F_p = 6.33t^{0.45}$	$f_p = 7.26t^{-0.5} + 4.27$	$f_p = \left(\frac{156.31}{F_p}\right) - 5.85$
	Average	$f_p = 1.19 + 20.71e^{-2.15t}$	$F_p = 7.01t^{0.42}$	$f_p = 8.25t^{-0.5} + 4.92$	$f_p = \left(\frac{69.79}{F_p}\right) - 6.14$

4.4. Accuracy Test for Model Equations

After infiltration equations of each sample were developed, as earlier, it is necessary to check for their validity. This was done by comparing the values of field cumulative infiltration capacity and the result calculated from integrated infiltration rate models using initial time to time required to get steady infiltration rate. When infiltration rate is integrated at any time 't', it gives cumulative infiltration capacity at that time 't'.

Table 8: Infiltration Rate and Cumulative Infiltration Capacity Formulas for Models

Models	Infiltration Rate	Cumulative Infiltration Capacity (integrated)	Remark
Horton	$f_p = f_c + (f_0 - f_c)e^{-\beta t}$	$F_p = f_c * t + \frac{(f_0 - f_c) * (1 - e^{-\beta t})}{\beta}$	Integrated
Kostiakov	$F_p = (ab)t^{(b-1)}$	$F_p = at^b$	Integrated
Philip	$f_p = 1/2 st^{-1/2} + k$	$F_p = st^{\frac{1}{2}} + Kt$	Integrated
Green Ampt	$f_p = m + \left(\frac{n}{F_p}\right)$	$F_p = \left(\frac{n}{f_p - m}\right)$	Interchang ed only

By integrating the developed infiltration model between starting and ending time, the cumulative infiltration capacity of the model was calculated and shown in Table 9.

Table 9: Accuracy Test using Field data Vs Model Values for Cambisols

Time	Observed FP (cm)	Horton's FP (cm)	Kostiakov's Fp (cm)	Philip's Fp (cm)	Green Ampt FP (cm)
2	4.60	4.41	5.32	4.47	4.60
5	8.50	7.81	8.20	8.44	8.49
10	12.15	10.63	11.37	12.76	12.14
20	16.63	13.49	15.77	18.15	16.61
30	20.15	15.43	19.10	22.10	20.13
40	23.00	16.87	21.88	25.19	22.96
50	25.35	18.05	24.31	27.69	25.31
60	27.29	19.06	26.49	29.76	27.24
80	30.31	20.82	30.34	32.68	30.24
100	32.86	22.50	33.71	34.78	32.78
120	35.18	24.16	36.74	36.27	35.09
140	37.58	25.80	39.52	37.28	37.48
160	41.17	27.43	42.09	37.90	41.05
180	42.87	29.06	44.49	38.21	42.74
	R ²	0.996	0.995	0.969	0.999
	NS	0.470	0.991	0.972	0.999
	% of Error	32.198	3.792	10.858	0.298

When model cumulative infiltration capacity is compared with field cumulative infiltration capacity, different all models have different values. From the Table 9, Green Ampt infiltration model was accuracy model by predicting the nearest value for field cumulative infiltration capacity. The values of R², NS and percentage of error of this model was 0.999, 0.999 and 0.298 respectively. Generally the accuracy of these model was ranked as Green Ampt > Kostiakov > Philip > Horton.

Table 10: Accuracy Test using Field data Vs Model Values for Vertisol

Time	Observed Fp (cm)	Horton's FP (cm)	Kostiakov's FP (cm)	Philip's Fp (cm)	Green Ampt FP (cm)
2	1.43	1.32	1.68	1.34	1.43
5	2.59	2.29	2.47	2.53	2.59
10	3.61	3.00	3.30	3.80	3.61
20	4.66	3.58	4.42	5.36	4.66
30	5.47	3.96	5.24	6.49	5.47
40	6.14	4.26	5.91	7.35	6.14
60	7.19	4.71	7.01	8.46	7.19
80	8.01	5.13	7.91	9.20	8.01
110	9.03	5.73	9.04	9.79	9.03
140	9.85	6.32	10.01	10.03	9.85
170	10.54	6.92	10.86	10.27	10.54
200	11.13	7.51	11.62	10.51	11.13
230	11.73	8.11	12.33	10.75	11.13
	R ²	0.987	0.996	0.952	0.998
	NS	0.406	0.984	0.956	0.984
	% of Error	30.878	5.081	8.373	5.108

Similar to Cambisols, Green Ampt infiltration model also calculated infiltration capacity of Vertisols. Kostiakov also had similar accuracy with Green Ampt to predict cumulative infiltration capacity. Green Ampt and Kostiakov had Values of 0.998 & 996, 0.984 & 0.984 and 5.1 & 5.1 of R², NS and percentage of error respectively.

5. CONCLUSION AND RECOMMENDATION

Under this section, the results of both Cambisols and Vertisol infiltration capacity, the values of determined infiltration parameters of Horton, Kostiakov, Philip and Green Ampt infiltration models, inter comparison of the models were concluded. The best fit infiltration, the valid developed infiltration model and the use of this valid infiltration model for future use were also recommended.

5.1. Conclusion

The result of the study was showed that, there is a difference in infiltration rate from one point to another at both, Cambisols and vertisol. Constant infiltration rate of Cambisols are 3, 6.8, 8, 7, 5.4 cm/hr for sample C1, C2, C3, C4, and C5 respectively. Similarly, constant infiltration rate for Vertisol are 0.73, 0.3, 1.33, 1.87, 1.73 cm/hr for point V1, V2, V3, V4, and V5 respectively. This result showed that infiltration rate is higher in Cambisols than Vertisol.

Infiltration parameters of four infiltration models, Horton, Kostiakov, Philip and Green Ampt, were determined from field infiltration rate and cumulative infiltration using graph. These infiltration parameters were not similar for different infiltration points and soil types. This result showed that, the highest initial infiltration rate of vertisol is near to the lowest initial infiltration rate of Cambisols. From Kostiakov Infiltration Model, the values of local parameter 'b' are ranged from 0.41 to 0.57 which is above zero and below one at all points and soil types. Similarly local parameter 'a' are ranged from 3.3 to 39.83 which above zero for two soil types. These two conditions satisfy infiltration rule of Kostiakov Model. The function of soil suction potential (S) of Philip Infiltration Model is between 4.65 and 79.80 which is greater than zero. This shows the soil at each point and soil type has potential to suck water. And hydraulic conductivity of soil is different for all points. The lowest and highest hydraulic conductivity is 0.36hr^{-1} and 20.39hr^{-1} . Hydraulic conductivity of Cambisols, which is ranged from 14.74 to 20.39hr^{-1} , is greater than Vertisols which is ranged from 0.36 to 9.45hr^{-1} .

The inter comparison of, Horton, Kostiakov, Philip and Green Ampt infiltration models related to field collected infiltration rate using both R^2 , NS and RMSE, showed that, Green Ampt infiltration model is best fit models followed by Philip, Horton and Kostiakov for both

Cambisols and Vertisols. The Values of R^2 , NS and RMSE of Green Ampt were 0.995, 0.996 and 2.332 respectively for Cambisols. This finding implied that, there is strong relationship between infiltration rate which was collected from the field and calculated values of the models. In similar way, the values of RMSE are 2.332, 3.632, 6.660 and 16.520 for Green Ampt, Philip, Horton and Kostiakov infiltration models respectively. And result of the R^2 , NS and and RMSE values of Green Ampt infiltration model were 0.987, 0.987 and 1.312 for Vertisols, which also implied that, there is strong relationship between infiltration rate which was collected from the field and calculated using this model.

Cumulative infiltration rate collected from field and developed models were compared for validation of the developed infiltration model. From this, the result showed that Green Ampt infiltration model gives the nearest value of field cumulative infiltration capacity of soil. The values of R^2 , NS and percentage of error of this model was 0.999, 0.999 and 0.298 respectively. Similar to Cambisols, Green Ampt infiltration model also calculated infiltration capacity of Vertisols. Kostiakov also had similar accuracy with Green Ampt to predict cumulative infiltration capacity. Green Ampt and Kostiakov had Values of 0.998 & 0.996, 0.984 & 0.984 and 5.1 & 5.1 of R^2 , NS and percentage of error respectively. Generally the accuracy of these model was ranked as Green Ampt > Kostiakov > Philip > Horton. Therefore this model can be used to calculate the infiltration capacity of both Cambisols and Vertisols, which are the most dominant soil types of Upper Awash Basin.

5.2. Recommendation

Even though, all models have good relation with observed values, Green Ampt Model is the best fitting model for both soils showing highest degree of R^2 and NS and minimum RMSE. Therefore, Green Ampt infiltration model is recommended that it is best model to calculate infiltration rate of both Cambisols and Vertisols for dry season. Since infiltration behavior of the soil directly determines the essential variables such as inflow rate, length of run, application time, depth of percolation, and tail water run-off in irrigation systems, this model is also useful to design, operation, management, and hydraulic evaluation of on-farm water applications. But further study is necessary to identify other hydrologic processes by addressing additional land use/covers, and both dry and wet season.

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ANNEXES

1. Pictures of Field Infiltration Data Collection



Picture 2: Field Data Collection



Picture 3: Laboratory Soil Moisture Content Identification

2. Lists of Infiltration Tables

Table 11: Soil Infiltration Rate Test of Cambisols

Time (min)	Infiltration Rate (cm/hr)					
	C1	C2	C3	C4	C5	Average
2	65.00	195.00	160.00	145.00	135	140.00
5	36.67	130.00	76.67	76.67	70	78.00
10	29.60	76.00	54.00	28.00	31.2	43.76
20	18.00	40.00	33.20	21.40	21.8	26.88
30	12.00	33.00	27.40	16.20	17.2	21.16
40	10.20	25.00	22.40	14.00	13.8	17.08
50	9.00	20.00	18.60	12.40	10.6	14.12
60	7.40	16.20	14.40	11.40	8.8	11.64
80	7.00	14.50	8.90	8.80	6	9.04
100	4.90	12.30	8.00	7.70	5.4	7.66
120	3.90	10.30	8.00	7.20	5.4	6.96
140	3.40	8.50		7.00		6.30
160	3.00	6.80				4.90
180	3.00	6.80				4.90

Table 12: Cumulative Infiltration Capacity of Cambisols

Time	Cumulative Infiltration (cm)					
	C1	C2	C3	C4	C5	Average
2	2.17	6.17	5.33	4.83	4.50	4.60
5	4.00	12.67	9.17	8.67	8.00	8.50
10	6.47	19.00	13.67	11.00	10.60	12.15
20	9.47	25.67	19.20	14.57	14.23	16.63
30	11.47	31.17	23.77	17.27	17.10	20.15
40	13.17	35.33	27.50	19.60	19.40	23.00
50	14.67	38.67	30.60	21.67	21.17	25.35
60	15.90	41.37	33.00	23.57	22.63	27.29
80	18.23	46.20	35.97	26.50	24.63	30.31
100	19.87	50.30	38.63	29.07	26.43	32.86
120	21.17	53.73	41.30	31.47	28.23	35.18
140	22.30	56.57		33.80		37.56
160	23.30	58.83				41.07
180	24.30	61.10				42.70

Table 13: Soil Infiltration Rate Test of Vertisol

Time (min)	Infiltration Rate (cm/hr)					Average
	V1	V2	V3	V4	V5	
2	12.00	15.00	68.00	77.00	42.00	42.80
5	8.67	9.33	35.33	48.00	15.33	23.33
10	4.80	6.80	22.00	19.60	7.60	12.16
20	3.60	3.80	6.40	12.40	5.40	6.32
30	3.00	2.80	4.40	10.00	4.20	4.88
40	2.50	2.20	3.60	8.20	3.60	4.02
60	2.05	1.80	3.00	5.50	3.30	3.13
80	1.80	1.40	2.50	3.70	2.90	2.46
110	1.47	0.93	2.27	3.00	2.53	2.04
140	1.20	0.67	1.53	2.60	2.20	1.64
170	0.87	0.50	1.33	2.20	2.00	1.38
200	0.73	0.30	1.33	1.87	1.73	1.19
230	0.73	0.30	1.33	1.87	1.73	1.19

Table 14: Cumulative Infiltration Capacity of Vertisol

Time	Cummulative Infiltration (cm)					Average
	V1	V2	V3	V4	V5	
2	0.40	0.50	2.27	2.57	1.40	1.43
5	0.83	0.97	4.03	4.97	2.17	2.59
10	1.23	1.53	5.87	6.60	2.80	3.61
20	1.83	2.17	6.93	8.67	3.70	4.66
30	2.33	2.63	7.67	10.33	4.40	5.47
40	2.75	3.00	8.27	11.70	5.00	6.14
60	3.43	3.60	9.27	13.53	6.10	7.19
80	4.03	4.07	10.10	14.77	7.07	8.01
110	4.77	4.53	11.23	16.27	8.33	9.03
140	5.37	4.87	12.00	17.57	9.43	9.85
170	5.80	5.12	12.67	18.67	10.43	10.54
200	6.17	5.27	13.33	19.60	11.30	11.13
230	6.53	5.42	14.00	20.53	12.17	11.73

Table 15: Average Values of five points of Cambisols

Time (min)	Average of Cumulative Infiltration	Average of Infiltration Rate
2	4.60	140.00
5	8.50	78.00
10	12.15	43.76
20	16.63	26.88
30	20.15	21.16
40	23.00	17.08
50	25.35	14.12
60	27.29	11.64
80	30.31	9.04
100	32.86	7.66
120	35.18	6.96
140	37.58	6.30
160	41.17	4.90
180	42.87	4.90

Table 16: Average Values of five points of Vertisol

Time (min)	Average of Cumulative Infiltration	Average of Infiltration Rate
2	1.43	42.80
5	2.59	23.33
10	3.61	12.16
20	4.66	6.32
30	5.47	4.88
40	6.14	4.02
60	7.19	3.13
80	8.01	2.46
110	9.03	2.04
140	9.85	1.64
170	10.54	1.38
200	11.13	1.19
230	11.73	1.19

Table 17: Observed and Calculated Infiltration Rate of Cambisols Using Infiltration Models

Time (min)	Observed fp (cm/hr)	Horton's fp (cm/hr)	Kostiakov's fp (cm/hr)	Philip's fp (cm/hr)	Green Ampt fp (cm/hr)
2	140.00	132.30	159.59	134.16	142.14
5	78.00	68.03	34.54	79.42	70.73
10	43.76	33.88	19.04	51.83	45.44
20	26.88	17.12	13.20	32.32	29.55
30	21.16	11.64	6.65	23.68	22.02
40	17.08	8.67	4.17	18.53	17.62
50	14.12	7.03	2.92	15.02	14.73
60	11.64	6.06	2.18	12.42	12.72
80	9.04	5.30	2.89	8.78	10.12
100	7.66	5.05	2.02	6.29	8.28
120	6.96	4.96	1.51	4.46	6.84
140	6.30	4.92	1.19	3.03	5.54
160	4.90	4.90	0.96	1.88	3.88
180	4.90	4.90	0.80	0.93	3.19

Table 18: Observed and Calculated Infiltration Rate of Vertisol Using Infiltration Models

Time (min)	Observed fp (cm/hr)	Horton's fp (cm/hr)	Kostiakov's fp (cm/hr)	Philip's fp (cm/hr)	Green Ampt fp (cm/hr)
2	42.80	39.60	50.40	40.27	42.78
5	23.33	19.32	9.46	23.66	20.77
10	12.16	8.54	5.01	15.29	13.21
20	6.32	3.50	3.35	9.37	8.84
30	4.88	2.30	1.64	6.75	6.61
40	4.02	1.76	1.01	5.18	5.22
60	3.13	1.37	1.10	3.33	3.57
80	2.46	1.24	0.68	2.22	2.58
110	2.04	1.20	0.62	1.17	1.59
140	1.64	1.19	0.41	0.48	0.95
170	1.38	1.19	0.30		0.48
200	1.19	1.19	0.23		0.13
230	1.19	1.19	0.18		

3. Field Infiltration Rate Data Collection Format

Site Location: ASTU

Point: A1

Soil Type: Cambisols

Date: 20/04/2012

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
1:55	Start		0	17				
1:57	2	2	15		2	1.00	60.00	2
2:00	3	5	14.5		0.5	0.17	10.00	2.5
2:05	5	10	13.8		0.7	0.14	8.40	3.2
2:15	10	20	12.6		1.2	0.12	7.20	4.4
2:25	10	30	11.7		0.9	0.09	5.40	5.3
2:35	10	40	10.9		0.8	0.08	4.80	6.1
2:45	10	50	10.2		0.7	0.07	4.20	6.8
2:55	10	60	9.6	15.8	0.6	0.06	3.60	7.4
3:15	20	80	14.6		1.2	0.06	3.60	8.6
3:35	20	100	13.6		1	0.05	3.00	9.6
3:55	20	120	12.7		0.9	0.05	2.70	10.5
4:15	20	140	11.9		0.8	0.04	2.40	11.3
4:35	20	160	11.2		0.7	0.04	2.10	12
4:55	20	180	10.5		0.7	0.04	2.10	12.7

Site Location: ASTU

Point: A2

Soil Type: Cambisols

Date: 20/04/2012

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
5:20	Start		0	8				
5:22	2	2	6.5		1.5	0.75	45.00	1.5
5:25	3	5	5.5		1	0.33	20.00	2.5
5:30	5	10	4.3		1.2	0.24	14.40	3.7
5:40	10	20	3.4		0.9	0.09	5.40	4.6
5:50	10	30	2.6		0.8	0.08	4.80	5.4
6:00	10	40	1.9		0.7	0.07	4.20	6.1
6:10	10	50	1.3		0.6	0.06	3.60	6.7
6:20	10	60	0.8	9.5	0.5	0.05	3.00	7.2
6:40	20	80	8.2		1.3	0.07	3.90	8.5
7:00	20	100	7.3		0.9	0.05	2.70	9.4
7:20	20	120	6.3		1	0.05	3.00	10.4
7:40	20	140	5.4		0.9	0.05	2.70	11.3
8:00	20	160	4.6		0.8	0.04	2.40	12.1
8:20	20	180	3.8		0.8	0.04	2.40	12.9

Site Location: ASTU

Point: A3

Soil Type: Cambisols

Date: 20/04/2012

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
8:40	Start		0	20				
8:42	2	2	17		3	1.50	90.00	3
8:45	3	5	13		4	1.33	80.00	7
8:50	5	10	7.5	21	5.5	1.10	66.00	12.5
9:00	10	20	14.1		6.9	0.69	41.40	19.4
9:10	10	30	9.8		4.3	0.43	25.80	23.7
9:20	10	40	6.2	21	3.6	0.36	21.60	27.3
9:30	10	50	17.8		3.2	0.32	19.20	30.5
9:40	10	60	15.2		2.6	0.26	15.60	33.1
10:00	20	80	10.7		4.5	0.23	13.50	37.6
10:20	20	100	7.7		3	0.15	9.00	40.6
10:40	20	120	5.7	10	2	0.10	6.00	42.6
11:00	20	140	8.3		1.7	0.09	5.10	44.3
11:20	20	160	6.8		1.5	0.08	4.50	45.8
11:40	20	180	5.3		1.5	0.08	4.50	47.3

Site Location: ASTU

Point: B1

Soil Type: Cambisols

Date: 21/04/2012

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
2:00	Start		0	20				
2:02	2	2	13		7	3.50	210.00	7
2:05	3	5	4	20	9	3.00	180.00	16
2:10	5	10	12		8	1.60	96.00	24
2:20	10	20	5	20	7	0.70	42.00	31
2:30	10	30	15		5	0.50	30.00	36
2:40	10	40	12		3	0.30	18.00	39
2:50	10	50	10		2	0.20	12.00	41
3:00	10	60	8.5		1.5	0.15	9.00	42.5
3:20	20	80	6		2.5	0.13	7.50	45
3:40	20	100	4	15	2	0.10	6.00	47
4:00	20	120	13.3	10	1.7	0.09	5.10	48.7
4:20	20	140	11.8		1.5	0.08	4.50	50.2
4.40	20	160	10.5		1.3	0.06	3.90	51.5

5:00	20	180	9.2		1.3	0.06	3.90	52.8
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Site Location: ASTU

Point: B2

Soil Type: Cambisols

Date: 21/04/2012

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
2:00	Start		0	20				
2:02	2	2	13.5		6.5	3.25	195.00	6.5
2:05	3	5	6	20	7.5	2.50	150.00	14
2:10	5	10	13		7	1.40	84.00	21
2:20	10	20	5	20	8	0.80	48.00	29
2:30	10	30	13		7	0.70	42.00	36
2:40	10	40	7	20	6	0.60	36.00	42
2:50	10	50	15		5	0.50	30.00	47
3:00	10	60	11		4	0.40	24.00	51
3:20	20	80	4	20	7	0.35	21.00	58
3:40	20	100	14		6	0.30	18.00	64
4:00	20	120	9		5	0.25	15.00	69
4:20	20	140	5	10	4	0.20	12.00	73

4.40	20	160	7.2		2.8	0.14	8.40	75.8
5:00	20	180	4.4		2.8	0.14	8.40	78.6

Site Location: ASTU

Point: B3

Soil Type: Cambisols

Date: 21/04/2012

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
5:30	Start		0	20				
5:32	2	2	13.5		6.5	3.25	195.00	6.5
5:35	3	5	12		1.5	0.50	30.00	8
5:40	5	10	8	20	4	0.80	48.00	12
5:50	10	20	15		5	0.50	30.00	17
6:00	10	30	10.5		4.5	0.45	27.00	21.5
6:10	10	40	7	20	3.5	0.35	21.00	25
6:20	10	50	17		3	0.30	18.00	28
6:30	10	60	14.4		2.6	0.26	15.60	30.6
6:50	20	80	9.4		5	0.25	15.00	35.6
7:10	20	100	5.1	15	4.3	0.22	12.90	39.9

7:30	20	120	11.4		3.6	0.18	10.80	43.5
7:50	20	140	8.4		3	0.15	9.00	46.5
8:10	20	160	5.7		2.7	0.14	8.10	49.2
8:30	20	180	3		2.7	0.14	8.10	51.9

Site Location: ASTU

Point: C1

Soil Type: Cambisols

Date: 22/04/2012

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
1:30	Start		0	20				
1:32	2	2	15		5	2.50	150.00	5
1:35	3	5	11		4	1.33	80.00	9
1:40	5	10	6	20	5	1.00	60.00	14
1:50	10	20	14.4		5.6	0.56	33.60	19.6
2:00	10	30	9		5.4	0.54	32.40	25
2:10	10	40	4.5	20	4.5	0.45	27.00	29.5
2:20	10	50	16		4	0.40	24.00	33.5
2:30	10	60	13.4		2.6	0.26	15.60	36.1

2:50	20	80	11.5		1.9	0.09	5.70	38
3:10	20	100	9		2.5	0.13	7.50	40.5
3:30	20	120	6.5		2.5	0.13	7.50	43

Site Location: ASTU

Point: C2

Soil Type: Cambisols

Date: 22/04/2012

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
5:30	Start		0	15				
5:32	2	2	9		6	3.00	180.00	6
5:35	3	5	6		3	1.00	60.00	9
5:40	5	10	3	15	3	0.60	36.00	12
5:50	10	20	11		4	0.40	24.00	16
6:00	10	30	8.2		2.8	0.28	16.80	18.8

6:10	10	40	5.7		2.5	0.25	15.00	21.3
6:20	10	50	3.4	15	2.3	0.23	13.80	23.6
6:30	10	60	13		2	0.20	12.00	25.6
6:50	20	80	9.5		3.5	0.18	10.50	29.1
7:10	20	100	6.8		2.7	0.14	8.10	31.8
7:30	20	120	4.1		2.7	0.14	8.10	34.5

Site Location: ASTU

Point: C3

Soil Type: Cambisols

Date: 22/04/2012

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
8:30	Start		0	20				
8:32	2	2	15		5	2.50	150.00	5
8:35	3	5	10.5		4.5	1.50	90.00	9.5
8:40	5	10	5	18	5.5	1.10	66.00	15

8:50	10	20	11		7	0.70	42.00	22
9:00	10	30	5.5	16	5.5	0.55	33.00	27.5
9:10	10	40	11.8		4.2	0.42	25.20	31.7
9:20	10	50	8.8		3	0.30	18.00	34.7
9:30	10	60	6.2	15	2.6	0.26	15.60	37.3
9:50	20	80	11.5		3.5	0.18	10.50	40.8
10:10	20	100	8.7		2.8	0.14	8.40	43.6
10:30	20	120	5.9		2.8	0.14	8.40	46.4

Site Location: ASTU

Point: D1

Soil Type: Cambisols

Date: 23/04/2012

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
2:00	Start		0	20				
2:02	2	2	17.5		2.5	1.25	75.00	2.5

2:05	3	5	15.5		2	0.67	40.00	4.5
2:10	5	10	14.5		1	0.20	12.00	5.5
2:20	10	20	13.8		0.7	0.07	4.20	6.2
2:30	10	30	13.2		0.6	0.06	3.60	6.8
2:40	10	40	12.7		0.5	0.05	3.00	7.3
2:50	10	50	12.3		0.4	0.04	2.40	7.7
3:00	10	60	12		0.3	0.03	1.80	8
3:20	20	80	11.4		0.6	0.03	1.80	8.6
3:40	20	100	10.8		0.6	0.03	1.80	9.2
4:00	20	120	10.2		0.6	0.03	1.80	9.8
4:20	20	140	9.6		0.6	0.03	1.80	10.4

Site Location: ASTU

Point: D2

Soil Type: Cambisols

Date: 23/04/2012

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
4:40	Start		0	16				

4:42	2	2	10		6	3.00	180.00	6
4:45	3	5	5.5		4.5	1.50	90.00	10.5
4:50	5	10	2.5	15	3	0.60	36.00	13.5
5:00	10	20	10		5	0.50	30.00	18.5
5:10	10	30	6		4	0.40	24.00	22.5
5:20	10	40	2.5	15	3.5	0.35	21.00	26
5:30	10	50	11.8		3.2	0.32	19.20	29.2
5:40	10	60	8.8		3	0.30	18.00	32.2
6:00	20	80	3.6	18	5.2	0.26	15.60	37.4
6:20	20	100	13.2		4.8	0.24	14.40	42.2
6:40	20	120	8.6		4.6	0.23	13.80	46.8
7:00	20	140	4.1		4.5	0.23	13.50	51.3

Site Location: ASTU

Point: D3

Soil Type: Cambisols

Date: 23/04/2012

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				

7:50	Start		0	18				
7:52	2	2	12		6	3.00	180.00	6
7:55	3	5	7		5	1.67	100.00	11
8:00	5	10	4	18	3	0.60	36.00	14
8:10	10	20	13		5	0.50	30.00	19
8:20	10	30	9.5		3.5	0.35	21.00	22.5
8:30	10	40	6.5	20	3	0.30	18.00	25.5
8:40	10	50	17.4		2.6	0.26	15.60	28.1
8:50	10	60	15		2.4	0.24	14.40	30.5
9:10	20	80	12		3	0.15	9.00	33.5
9:30	20	100	9.7		2.3	0.12	6.90	35.8
9:50	20	120	7.7		2	0.10	6.00	37.8
10:10	20	140	5.8		1.9	0.09	5.70	39.7

Site Location: ASTU

Point: E1

Soil Type: Cambisols

Date: 24/04/2012

Reading On Clock	Time Difference	Cumulative Time (min)	Water Level Reading	Infiltration(cm)	Infiltration Rate	Infiltration Rate	Cumulative Infiltration(cm)
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	(min)		Decreased depth (cm)	Depth of Filling (cm)		(cm/min)	(cm/hr)	
2:30	Start		0	15				
2:32	2	2	12.5		2.5	1.25	75.00	2.5
2:35	3	5	10.5		2	0.67	40.00	4.5
2:40	5	10	9.5		1	0.20	12.00	5.5
2:50	10	20	8.8		0.7	0.07	4.20	6.2
3:00	10	30	8.2		0.6	0.06	3.60	6.8
3:10	10	40	7.7		0.5	0.05	3.00	7.3
3:20	10	50	7.3		0.4	0.04	2.40	7.7
3:30	10	60	7		0.3	0.03	1.80	8
3:50	20	80	6.4		0.6	0.03	1.80	8.6
4:10	20	100	5.8		0.6	0.03	1.80	9.2
4:30	20	120	5.2		0.6	0.03	1.80	9.8

Site Location: ASTU

Point: E2

Soil Type: Cambisols

Date: 24/04/2012

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
5:10	Start		0	20				
5:12	2	2	14		6	3.00	180.00	6
5:15	3	5	9.5		4.5	1.50	90.00	10.5
5:20	5	10	6	20	3.5	0.70	42.00	14
5:30	10	20	15		5	0.50	30.00	19
5:40	10	30	11		4	0.40	24.00	23
5:50	10	40	7.6		3.4	0.34	20.40	26.4
6:00	10	50	5.2	15	2.4	0.24	14.40	28.8
6:10	10	60	13		2	0.20	12.00	30.8
6:30	20	80	10.6		2.4	0.12	7.20	33.2
6:50	20	100	8.6		2	0.10	6.00	35.2
7:10	20	120	6.6		2	0.10	6.00	37.2

Site Location: ASTU

Point: E3

Soil Type: Cambisols

Date: 24/04/2012

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
8:25	Start		0	18				
8:27	2	2	13		5	2.50	150.00	5
8:30	3	5	9		4	1.33	80.00	9
8:35	5	10	5.7	20	3.3	0.66	39.60	12.3
8:45	10	20	14.8		5.2	0.52	31.20	17.5
8:55	10	30	10.8		4	0.40	24.00	21.5
9:05	10	40	7.8		3	0.30	18.00	24.5
9:15	10	50	5.3	15	2.5	0.25	15.00	27
9:25	10	60	12.9		2.1	0.21	12.60	29.1
9:45	20	80	9.9		3	0.15	9.00	32.1
10:05	20	100	7.1		2.8	0.14	8.40	34.9
10:25	20	120	4.3		2.8	0.14	8.40	37.7

Site Location: **Bishoftu**

Point: **A1**

Soil Type: **Vertisols**

Date: **06/05/2012**

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
1:30	Start		0	19				
1:32	2	2	18.5		0.5	0.25	15.00	0.5
1:35	3	5	18.1		0.4	0.13	8.00	0.9
1:40	5	10	17.8		0.3	0.06	3.60	1.2
1:50	10	20	17.3		0.5	0.05	3.00	1.7
2:00	10	30	16.9		0.4	0.04	2.40	2.1
2:10	10	40	16.6		0.3	0.03	1.80	2.4
2:30	20	60	16.2		0.4	0.02	1.20	2.8
2:50	20	80	15.9		0.3	0.02	0.90	3.1
3:20	30	110	15.5		0.4	0.01	0.80	3.5
3:50	30	140	15.2		0.3	0.01	0.60	3.8
4:20	30	170	15		0.2	0.01	0.40	4
4:50	30	200	14.8		0.2	0.01	0.40	4.2
5:20	30	230	14.6		0.2	0.01	0.40	4.4

Site Location: **Bishoftu**

Point: **A2**

Soil Type: **Vertisols**

Date: **06/05/2012**

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
5:35	Start		0	16				
5:37	2	2	15.7		0.3	0.15	9.00	0.3
5:40	3	5	15.3		0.4	0.13	8.00	0.7
5:45	5	10	14.7		0.6	0.12	7.20	1.3
5:55	10	20	13.9		0.8	0.08	4.80	2.1
6:05	10	30	13.2		0.7	0.07	4.20	2.8
6:15	10	40	12.6		0.6	0.06	3.60	3.4
6:35	20	60	11.6		1	0.05	3.00	4.4
6:55	20	80	10.7		0.9	0.05	2.70	5.3
7:25	30	110	9.7		1	0.03	2.00	6.3
7:55	30	140	8.9		0.8	0.03	1.60	7.1
8:25	30	170	8.3		0.6	0.02	1.20	7.7
8:55	30	200	7.8		0.5	0.02	1.00	8.2
9:25	30	230	7.3		0.5	0.02	1.00	8.7

Site Location: **Bishoftu**

Point: **A3**

Soil Type: **Vertisols**

Date: **06/05/2012**

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
9:30	Start		0	15				
9:32	2	2	14.6		0.4	0.20	12.00	0.4
9:35	3	5	14.1		0.5	0.17	10.00	0.9
9:40	5	10	13.8		0.3	0.06	3.60	1.2
9:50	10	20	13.3		0.5	0.05	3.00	1.7
10:00	10	30	12.9		0.4	0.04	2.40	2.1
10:10	10	40	12.55		0.35	0.04	2.10	2.45
10:30	20	60	11.9		0.65	0.03	1.95	3.1
10:50	20	80	11.3		0.6	0.03	1.80	3.7
11:20	30	110	10.5		0.8	0.03	1.60	4.5
11:50	30	140	9.8		0.7	0.02	1.40	5.2
12:20	30	170	9.3		0.5	0.02	1.00	5.7
12:50	30	200	8.9		0.4	0.01	0.80	6.1
1:20	30	230	8.5		0.4	0.01	0.80	6.5

Site Location: **Bishoftu**

Point: **B1**

Soil Type: **Vertisols**

Date: **07/05/2012**

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
1:20	Start		0	16				
1:22	2	2	15.6		0.4	0.20	12.00	0.4
1:25	3	5	15.1		0.5	0.17	10.00	0.9
1:30	5	10	14.6		0.5	0.10	6.00	1.4
1:40	10	20	14		0.6	0.06	3.60	2
1:50	10	30	13.6		0.4	0.04	2.40	2.4
2:00	10	40	13.3		0.3	0.03	1.80	2.7
2:20	20	60	12.8		0.5	0.03	1.50	3.2
2:40	20	80	12.4		0.4	0.02	1.20	3.6
3:10	30	110	11.9		0.5	0.02	1.00	4.1
3:40	30	140	11.6		0.3	0.01	0.60	4.4
4:10	30	170	11.35		0.25	0.01	0.50	4.65

4:40	30	200	11.2		0.15	0.00	0.30	4.8
5:10	30	230	11.05		0.15	0.01	0.30	4.95

Site Location: **Bishoftu**

Point: **B2**

Soil Type: **Vertisols**

Date: **07/05/2012**

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
5:20	Start		0	15				
5:22	2	2	14.5		0.5	0.25	15.00	0.5
5:25	3	5	14.1		0.4	0.13	8.00	0.9
5:30	5	10	13.6		0.5	0.10	6.00	1.4
5:40	10	20	13.1		0.5	0.05	3.00	1.9
5:50	10	30	12.7		0.4	0.04	2.40	2.3
6:00	10	40	12.4		0.3	0.03	1.80	2.6
6:20	20	60	11.9		0.5	0.03	1.50	3.1
6:40	20	80	11.5		0.4	0.02	1.20	3.5
7:10	30	110	11		0.5	0.02	1.00	4
7:40	30	140	10.6		0.4	0.01	0.80	4.4

8:10	30	170	10.3		0.3	0.01	0.60	4.7
8:40	30	200	10.1		0.2	0.01	0.40	4.9
9:10	30	230	9.9		0.2	0.01	0.40	5.1

Site Location: **Bishoftu**

Point: **B3**

Soil Type: **Vertisols**

Date: **07/05/2012**

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
9:20	Start		0	14				
9:22	2	2	13.4		0.6	0.30	18.00	0.6
9:25	3	5	12.9		0.5	0.17	10.00	1.1
9:30	5	10	12.2		0.7	0.14	8.40	1.8
9:40	10	20	11.4		0.8	0.08	4.80	2.6
9:50	10	30	10.8		0.6	0.06	3.60	3.2
10:00	10	40	10.3		0.5	0.05	3.00	3.7
10:20	20	60	9.5		0.8	0.04	2.40	4.5
10:40	20	80	8.9		0.6	0.03	1.80	5.1
11:10	30	110	8.5		0.4	0.01	0.80	5.5

11:40	30	140	8.2		0.3	0.01	0.60	5.8
0:10	30	170	8		0.2	0.01	0.40	6
0:40	30	200	7.9		0.1	0.00	0.20	6.1
1:10	30	230	7.8		0.1	0.00	0.20	6.2

Site Location: **Bishoftu**

Point: **C1**

Soil Type: **Vertisols**

Date: **08/05/2012**

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
1:20	Start		0	17				
1:22	2	2	15		2	1.00	60.00	2
1:25	3	5	14		1	0.33	20.00	3
1:30	5	10	13.2		0.8	0.16	9.60	3.8
1:40	10	20	12.5		0.7	0.07	4.20	4.5
1:50	10	30	11.9		0.6	0.06	3.60	5.1
2:00	10	40	11.4		0.5	0.05	3.00	5.6
2:20	20	60	10.4		1	0.05	3.00	6.6

2:40	20	80	9.6		0.8	0.04	2.40	7.4
3:10	30	110	8.5		1.1	0.04	2.20	8.5
3:40	30	140	7.7		0.8	0.03	1.60	9.3
4:10	30	170	7		0.7	0.02	1.40	10
4:40	30	200	6.3		0.7	0.02	1.40	10.7
5:10	30	230	5.6		0.7	0.02	1.40	11.4

Site Location: **Bishoftu**

Point: **C2**

Soil Type: **Vertisols**

Date: **08/05/2012**

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
5:20	Start		0	15				
5:22	2	2	12		3	1.50	90.00	3
5:25	3	5	9.3		2.7	0.90	54.00	5.7
5:30	5	10	6.5		2.8	0.56	33.60	8.5
5:40	10	20	5.2		1.3	0.13	7.80	9.8
5:50	10	30	4.5		0.7	0.07	4.20	10.5

6:00	10	40	3.9		0.6	0.06	3.60	11.1
6:20	20	60	2.8	10	1.1	0.06	3.30	12.2
6:40	20	80	9.1		0.9	0.05	2.70	13.1
7:10	30	110	7.9		1.2	0.04	2.40	14.3
7:40	30	140	7.1		0.8	0.03	1.60	15.1
8:10	30	170	6.4		0.7	0.02	1.40	15.8
8:40	30	200	5.7		0.7	0.02	1.40	16.5
9:10	30	230	5		0.7	0.02	1.40	17.2

Site Location: **Bishoftu**

Point: **C3**

Soil Type: **Vertisols**

Date: **08/05/2012**

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
9:20	Start		0	14				
9:22	2	2	12.2		1.8	0.90	54.00	1.8
9:25	3	5	10.6		1.6	0.53	32.00	3.4
9:30	5	10	8.7		1.9	0.38	22.80	5.3
9:40	10	20	7.5		1.2	0.12	7.20	6.5

9:50	10	30	6.6		0.9	0.09	5.40	7.4
10:00	10	40	5.9		0.7	0.07	4.20	8.1
10:20	20	60	5	10	0.9	0.05	2.70	9
10:40	20	80	9.2		0.8	0.04	2.40	9.8
11:10	30	110	8.1		1.1	0.04	2.20	10.9
11:40	30	140	7.4		0.7	0.02	1.40	11.6
0:10	30	170	6.8		0.6	0.02	1.20	12.2
0:40	30	200	6.2		0.6	0.02	1.20	12.8
1:10	30	230	5.6		0.6	0.02	1.20	13.4

Site Location: **Bishoftu**

Point: **D1**

Soil Type: **Vertisols**

Date: **09/05/2012**

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
1:20	Start		0	17				
1:22	2	2	14		3	1.50	90.00	3
1:25	3	5	9.8		4.2	1.40	84.00	7.2

1:30	5	10	7.3		2.5	0.50	30.00	9.7
1:40	10	20	4.2	15	3.1	0.31	18.60	12.8
1:50	10	30	12.5		2.5	0.25	15.00	15.3
2:00	10	40	10.5		2	0.20	12.00	17.3
2:20	20	60	8		2.5	0.13	7.50	19.8
2:40	20	80	6.8		1.2	0.06	3.60	21
3:10	30	110	5.5	10	1.3	0.04	2.60	22.3
3:40	30	140	9		1	0.03	2.00	23.3
4:10	30	170	8.2		0.8	0.03	1.60	24.1
4:40	30	200	7.5		0.7	0.02	1.40	24.8
5:10	30	230	6.8		0.7	0.02	1.40	25.5

Site Location: **Bishoftu**

Point: **D2**

Soil Type: **Vertisols**

Date: **09/05/2012**

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
5:20	Start		0	15				

5:22	2	2	12.8		2.2	1.10	66.00	2.2
5:25	3	5	11.6		1.2	0.40	24.00	3.4
5:30	5	10	10.6		1	0.20	12.00	4.4
5:40	10	20	9.5		1.1	0.11	6.60	5.5
5:50	10	30	8.5		1	0.10	6.00	6.5
6:00	10	40	7.6		0.9	0.09	5.40	7.4
6:20	20	60	6.2	15	1.4	0.07	4.20	8.8
6:40	20	80	13.7		1.3	0.07	3.90	10.1
7:10	30	110	12		1.7	0.06	3.40	11.8
7:40	30	140	10.4		1.6	0.05	3.20	13.4
8:10	30	170	8.9		1.5	0.05	3.00	14.9
8:40	30	200	7.7		1.2	0.04	2.40	16.1
9:10	30	230	6.5		1.2	0.04	2.40	17.3

Site Location: **Bishoftu**

Point: **D3**

Soil Type: **Vertisols**

Date: **09/05/2012**

Reading On	Time Difference	Cumulative Time (min)	Water Level Reading	Infiltration(cm)	Infiltration Rate	Infiltration Rate	Cumulative Infiltration(cm)
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Clock	(min)		Decreased depth (cm)	Depth of Filling (cm)		(cm/min)	(cm/hr)	
9:20	Start		0	16				
9:22	2	2	13.5		2.5	1.25	75.00	2.5
9:25	3	5	11.7		1.8	0.60	36.00	4.3
9:30	5	10	10.3		1.4	0.28	16.80	5.7
9:40	10	20	8.3		2	0.20	12.00	7.7
9:50	10	30	6.8		1.5	0.15	9.00	9.2
10:00	10	40	5.6		1.2	0.12	7.20	10.4
10:20	20	60	4	14	1.6	0.08	4.80	12
10:40	20	80	12.8		1.2	0.06	3.60	13.2
11:10	30	110	11.3		1.5	0.05	3.00	14.7
11:40	30	140	10		1.3	0.04	2.60	16
0:10	30	170	9		1	0.03	2.00	17
0:40	30	200	8.1		0.9	0.03	1.80	17.9
1:10	30	230	7.2		0.9	0.03	1.80	18.8

Site Location: **Bishoftu**

Point: **E1**

Soil Type: **Vertisols**

Date: **10/05/2012**

Reading On Clock	Time Difference (min)	Cumulative Time (min)	Water Level Reading		Infiltration(cm)	Infiltration Rate (cm/min)	Infiltration Rate (cm/hr)	Cumulative Infiltration(cm)
			Decreased depth (cm)	Depth of Filling (cm)				
1:20	Start		0	15				
1:22	2	2	13.5		1.5	0.75	45.00	1.5
1:25	3	5	12.7		0.8	0.27	16.00	2.3
1:30	5	10	12		0.7	0.14	8.40	3
1:40	10	20	11	15	1	0.10	6.00	4
1:50	10	30	10.2		0.8	0.08	4.80	4.8
2:00	10	40	9.5		0.7	0.07	4.20	5.5
2:20	20	60	8.2		1.3	0.07	3.90	6.8
2:40	20	80	7.1		1.1	0.06	3.30	7.9
3:10	30	110	5.6	12	1.5	0.05	3.00	9.4
3:40	30	140	10.7		1.3	0.04	2.60	10.7
4:10	30	170	9.5		1.2	0.04	2.40	11.9
4:40	30	200	8.5		1	0.03	2.00	12.9
5:10	30	230	7.5		1	0.03	2.00	13.9