# Modeling of Infiltration Characteristics by Modified Kostiakov Method on Thuong River's Alluvial Soil, Lang Giang District, Bac Giang Province, Vietnam

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**Abstract**

The purpose of this study is to apply modified Kostiakov method in determining the rate and cumulative infiltration amount in the alluvial soil of Thuong river basin for orange plantation in Lang Giang district, Bac Giang province, Vietnam. The soil with particle size of 0.02 - 2.0 mm is mainly in the surface horizon (>77.7%). The soil was lightly acidic in the surface horizon ($pH_{KCl}$: 5.11), and very acidic in subsurface horizons ($pH_{KCl}$ from 3.42 to 4.79). The organic matter content of the surface horizon is classified as medium, while it is very low in the other horizons. Total nitrogen (N) content was low (0.15%) in surface horizon and very low in subsurface horizons (0.02-0.06%) while the available N was medium. Total phosphorus (P) content in surface horizon was high (0.4%) and medium in the other horizons. Available P in surface horizon was high (18.6 mg per 100 g soil) and largely decreased with depth of up to only 0.3 mg per 100 g soil at the lowest ($5^{th}$) horizon. Total and available potassium were very low. An infiltration characteristic model was developed by using the modified Kostiakov method for this alluvial soil. The constant values a; $\alpha$; b of the equation for accumulated infiltration $y = at^{\alpha} + b$ was 0.8035, 0.758 và 0.00346, respectively which were were smaller than 1. The average percentage difference between the actual and calculated values by the model was only 0.141%, indicating that the calculated value can accurately predict the actual measurement of data in the field. This model will be very helpful for making a good irrigation scheduling and best water management.

***Keywords: soil permeability, rate of inflitration, actual infiltration, acumulated infiltration***

## 1. Introduction

Infiltration is the process of bringing water into the soil profile, the rate of which is dependent on the physical and chemical properties of the water, soil type, soil cover, porosity as well as on the state of soil moisture, ground water table and time of water infiltration (Johnson, 1963; Michael, 1997; Charbeneau, 2000). The amount of water infiltration is an important element of hydrological cycle. As the duration of rainfall increased, the soil permeability reduced (Dagadu and Nmbalkar, 2012), at it becomes saturated and consequently, generate surface flow (Fetter, 2001; Mahbub *et al.*, 2015). The rate of permeability and amount of infiltration are two important components for calculating the water requirements of a crop that can be applied through an irrigation system. In order to operate the irrigation system effectively, two main issues need to be considered: when and how much water to supply in order to generate a water management measures best suitable for crops. So far, the problem of infiltration measurement has not been given much attention in Vietnam and elsewhere.

In terms of the importance and economic benefits of water and irrigation management activities, the determination of the constant values a; $\alpha$ and b in the mathematical equation to determine the amount of infiltration is assessing and predicting the amount of irrigation water in accordance to the actual water demand of the crop. The objective of this study is to use the modified Kostiakov method in calculating rates of permeability and water infiltration on the basis of: (1) Determining the coefficients of Kostiakov equation; (2) Evaluating the applicability of the model by using field data and (3) Determining the error between the actual value and the model calculated value. The study, then, determined the irrigation plan for the orange zone.

## 2. Methodology

### 2.1.Study site

The study was conducted in Truong Thinh village, Quang Thinh commune, Lang Giang district, Bac Giang province, Vietnam ($21^{0}26^{'}28^{''}$ N; $106^{0}14^{'}26^{''}$ E) in 2018. This soil is representative for Thuong River alluvial soil. The soil properties are shown in scetion 3.1. This is the area where a precious local orange specie, Bo Ha, have been planted for generations. Bac Giang province authorities nowadays, intend to restore and expand this special orange area.

### 2.2. Soil permeability determination

Currently, there are several methods of measuring soil permeability, but the most common is by using infiltration rings (Fetter, 2001) which is simple but reliable due to improved water supply to keep the water level in the infiltrometer stable during the measurement process.

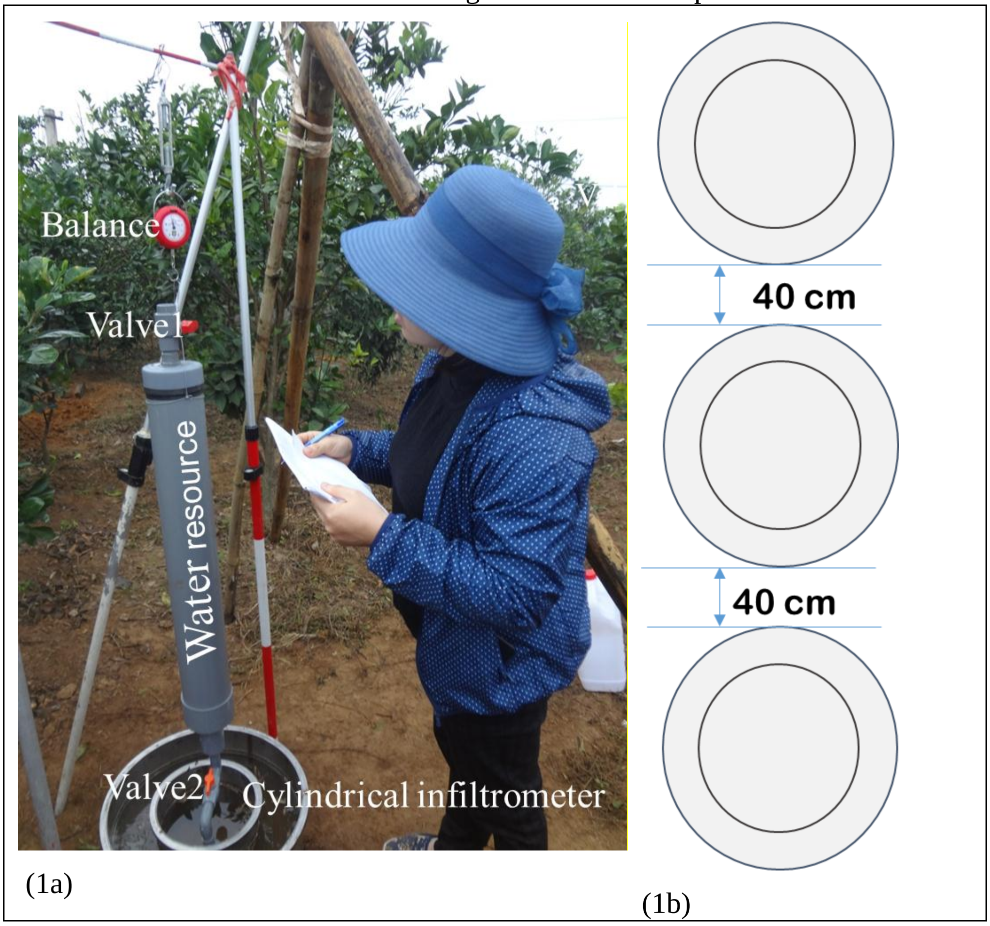


**Figure 1. Installation of infiltrometers in the field and its components.**

This method used 2 infiltration rings, an inner ring with 25 cm diamter and outer ring with 50 cm diameter. The two rings are concentric and driven into the ground to a depth of 15 cm (Figure 1a). The outer ring was used as a buffer pond to avoid the lateral movement of water and to maintain the water within the inner ring with vertical permeability only. The water supply for the infiltration process was a tube filled with water with 2 regulating valves, which were suspended on a scale to determine the water volume in the pipe.

Three infiltrometers (infiltration rings) were installed lenghtwise with distance of 40 cm between them (Figure 1b)

### 2.3. Measurements and calculations

The pipe was filled with water. The pipe had 2 valves. The valve 1 supplied water to pipe while valve 2 supplied water to infiltration rings. For infiltration measurement, valve 1 was closed while the valve 2 was opened. The water inside the pipe only get down to the infiltration rings when valve 2 opening get in contact with air. When the water reached a constant level, valve's opening will not contact with the air and water stop flowing. The amount of water was measured at time 1 (a) and after 5 minute at time 2 (b). The permeated water was calculated as the difference in the amount of water between time 1 and time 2 (a-b).

The amount of infiltration water was also calculated. The density of water was 1g $cm^{-3}$. The volume of infiltration water was calculated as the weight (amount of water) divided by specific gravity (equation 1). The depth of the permeable water layer was calculated as the volume of water divided by the area of the infiltration ring (equation 2).

$$V = \frac{m}{\partial} \quad (1)$$

$$h = \frac{V}{A}(cm) \quad (2)$$

m: infiltration water weight, m = a - b (g)  V: water volume ($cm^3$)

$\partial$: specific gravity: 1 g/$cm^3$  A: cross section area of infiltration ring ($cm^2$)

*2.4.Determining the coefficient in the permeability equation*

The relationship of accumulated infiltration y with respect to time t was mathematically defined using the following equation from modified Kostiakov method:

$$Y = at^{a} + b \quad (3)$$

Y: accumulated infiltration at time t, (cm),

t: infiltration time (minutes)

Coefficient a, α, and b was calculated following the method of Davis (1943). The values of a, α, and b are usually less than 1 (Michael, A.M. 1997). Equation was calculated in 3 steps by: (i) determining Y and t according to field measurements; (ii) selecting a pair of two values of $t_1$ and $y_1$ which were the time and amount of infiltrated water after 5 minutes and ($t_2$ and $y_2$) which was the time and amount of infiltrated water when soil was finally saturated with water and (iii) calculating a third value for $t_3$ using the value of $t_1$ and $t_2$ via equation (4).

$$t_3 = \sqrt{t_1 t_2} \quad (4)$$

Using $t_3$ to determine $Y_3$, then using the equation to calculate b

$$Y_1 = at_1^{a} + b;\; Y_2 = at_2^{a} + b$$

$$Y_1Y_2 = (at_1^{a} + b) \times (at_2^{a} + b)$$

$$Y_1Y_2 = \left\{a(\sqrt{t_1t_2})^{a}\right\}^2 + ab(t_1^{a} + t_2^{a}) + b^2)$$

$$Y_1Y_2 = \left\{a(\sqrt{t_1t_2})^{a}\right\}^2 + 2ab\sqrt{t_1^{a}t_2^{a}} + b^2$$

$$Y_1Y_2 = \left\{a(\sqrt{t_1t_2})^{a}\right\}^2 + 2a\left[\sqrt{t_1t_2}\right]^{a} b + b^2$$

$$Y_1Y_2 = \left\{a\left[\sqrt{t_1t_2}\right]^{a} + b\right\}^2; \quad \text{Set } Y_3^2 \le Y_1Y_2 \text{, in which } Y_3 = \sqrt{Y_1Y_2} \quad (5)$$

*2.5. Soil analysis*

The $pH_{KCl}$ was measured with a pH meter; OC% was measured Walkley and Black method; total N was measured by Kjeldhal method; total $P_2O_5$ was measured by colorimetry method; total $K_2O$ digestion by $HClO_4$, HF, and HCl acids and K of digestion solusion measured by flame photometer method; hydrolysis N was measured with Tiurin and

Kononova method; available $P_2O_5$ was measured by Oniani methods; available $K_2O$ was measured by Matslova method via a flame photometer; soil texture was measured with pipette methods; particle density was measured by picnometer method and bulk density was measured by core method (L.P.Van Reeuwijk, 1986).

The soil analysis was carried out at Central Laboratory of the Land Management Faculty, Vietnam National University of Agriculture.

*2.6. Soil moisture measurements*

In this research, soil moisture is determined by weighing method: drying soil samples at 105°C for 48 h, weighing, drying and weighing the soil samples until the mass of the samples are constant and then calculating the mass of water lost by percentage of the dried soil.

## 3. RESULTS AND DISCUSSIONS

**Soil properties**

The results showed that soil moisture content before and after measurements were 27.07% and 37.02%, respectively.

Soil profiling showed 5 distinct layers (Figure 2). Generally, the soil had a particle size component ranged from 0.02 mm to 2.00 mm, in which, the surface layer had 77.7% composition and then decreased to 50% at the 4th and 5th layers. The average soil particle density was 2.6 and did not vary among soil layers. The topsoil had an organic content of 1.44%, then gradually decreased with depth to 0.07% in the 5th layer. Furthermore, the soil bulk density ranged from 1.2 to 1.29 g $cm^{-3}$ (Table 1).

The soil was slightly acidic on the first layer to very acidic in sublayers (Table 1). The organic matter content of the surface layer was medium, while it was very low for the rest of the layers. The total N was low in the topsoil and much lower on the sublayers. The available N was medium. The total P was high in the soil surface and medium in the other layers. Available P was high in surface layer but gradually decreased with depths. The total as well as available K were low regardless of the layers.


**Figure 2. Soil profile at infiltration measurement site**

**Table 1. Soil physical chemical properties**

| Soil layers | $pH_{KCl}$ | OC | N | $P_2O_5$ | $K_2O$ | N | $P_2O_5$ | $K_2O$ | Texture (%) | | | Particle density | Bulk density ($g/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | | | | mg/100g | | | <0.002 mm | 0.002-0.02 mm | 0.02-2.0 mm | | |
| **T1** | 5.11 | 1.44 | 0.15 | 0.40 | 0.35 | 6.0 | 18.6 | 7.7 | 9.5 | 12.8 | 77.7 | 2.59 | 1.20 |
| **T2** | 3.42 | 0.42 | 0.06 | 0.08 | 0.38 | 5.6 | 7.4 | 25.8 | 17.1 | 15.1 | 67.8 | 2.65 | 1.21 |
| **T3** | 3.43 | 0.38 | 0.04 | 0.06 | 0.42 | 4.2 | 3.9 | 25.8 | 21.5 | 17.3 | 61.2 | 2.62 | 1.21 |
| **T4** | 3.74 | 0.11 | 0.03 | 0.06 | 0.68 | 5.3 | 1.0 | 11.1 | 36.5 | 13.5 | 50.0 | 2.58 | 1.29 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T5** | 3.79 | 0.07 | 0.02 | 0.05 | 0.76 | 8.1 | 0.3 | 7.7 | 34.3 | 14.9 | 50.8 | 2.58 | 1.29 |

**Calculated coefficients in Kostiakov equation**

*Infiltrations*

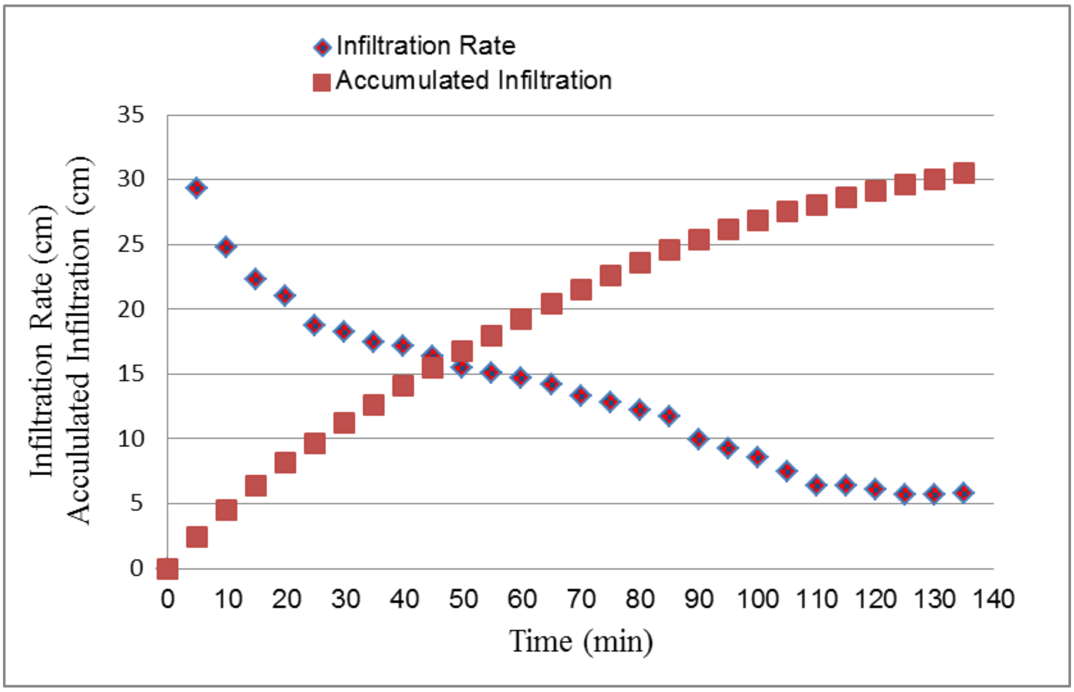


**Figure 3. Average infiltration rate (cm/h) and accumulated infiltration (cm) vs. time (min).**

The observed infiltration rate was low at the beginning and then increased slightly but decreasing at latter stages. The amount of seepage water became stable after 135 minutes and reached about 5.79cm/hour (Figure 3).

*Calculated coefficients in Kostiakov equation*

The calculated third value for $t_3$ using the values of ($t_{1\&}t_2$), with $t_1$=5 and $t_2$=135 minutes, $t_3$ value was 25.98 minutes using the following equation,

$$t_3 = \sqrt{t_1 \times t_2} = \sqrt{5.0 \times 135} = 25.98\,\text{min}$$

The average value of $y_3$: from equation (5) with the measurement of first 5 minutes: $y_1$= 2.44; $y_2$= 30.52 (Table 2) was calculated using the equation.

$$y_3 = \sqrt{y_1 \times y_2} = \sqrt{2.44 \times 30.52} = 8.63cm$$

The calculated value of b was **0.00346** using the equation (3).

$$b = \frac{y_1 \times y_2 - y_3^2}{y_1 + y_2 - 2y_3} = \frac{2.44 \times 30.52 - 8.63^2}{2.44 + 30.52 - 2 \times 8.63} = 0.00346$$

**Table 2. Average values of accumulated infiltration, infiltration rate vs. time for infiltration 1, 2 and 3**

| Time (t: min) | Rate of infiltration (cm/hr) | Accumulated infiltration (y: cm) |
|---|---|---|
| **0** | 0.00 | 0.00 |
| **5** | 29.30 | 2.44 |
| **10** | 24.78 | 4.51 |
| **15** | 22.30 | 6.37 |
| **25** | 18.78 | 9.68 |

| | | |
|---|---|---|
| **45** | 16.38 | 15.45 |
| **65** | 14.15 | 20.40 |
| **85** | 11.70 | 24.57 |
| **105** | 7.47 | 27.51 |
| **120** | 6.12 | 29.09 |
| **135** | 5.79 | 30.52 |

The calculated value of a and α

The measurements were done every 5 minutes, and thus, there were a total of 27 measurements at the end of the experiment when the soil is totally saturated with water. Ten measurements were selected randomly from Table 2 and used for the exclusion (a) to find α. After deriving α, it was used in the equation to further calculate the value of (a). Equation (3) was rearranged and written as: Y - b = $at^{\alpha}$, and then take logarith of two sides as shown in equation (6)

$$\text{Log}(Y - b)= \log(a) + \alpha\log(t) \quad (6)$$

The value of (y) and (t) were filled in in Table 2 and value (b) was calculated using equation (6), to get corresponding equations from (7) to (16):

$\text{Log}\ (2.44-0.00346) = 0.39 = \log a + \alpha\log (5)$ or $\log a+ 0.699\ \alpha$ (7)
$\text{Log}\ (4.51-0.00346) = 0.65 = \log a + \alpha\log (10)$ or $\log a+ 1.000\ \alpha$ (8)
$\text{Log}\ (6.37-0.00346) = 0.80 = \log a + \alpha\log (55)$ or $\log a+ 1.176\ \alpha$ (9)
$\text{Log}\ (9.68-0.00346) = 0.99 = \log a + \alpha\log (25)$ or $\log a+ 1.398\ \alpha$ (10)
$\text{Log}\ (15.45-0.00346) = 1.19 = \log a + \alpha\log (45)$ or $\log a+ 1.653\ \alpha$ (11)
$\text{Log}\ (20.40-0.00346) = 1.31 = \log a + \alpha\log (65)$ or $\log a+ 1.813\ \alpha$ (12)
$\text{Log}\ (24.57-0.00346) = 1.39 = \log a + \alpha\log (85)$ or $\log a+ 1.929\ \alpha$ (13)
$\text{Log}\ (27.51-0.00346) = 1.44 = \log a + \alpha\log (105)$ or $\log a+ 2.021\ \alpha$ (14)
$\text{Log}\ (29.09-0.00346) = 1.46 = \log a + \alpha\log (120)$ or $\log a+ 2.079\ \alpha$ (15)
$\text{Log}\ (30.52-0.00346) = 1.48 = \log a + \alpha\log (135)$ or $\log a+ 2.130\ \alpha$ (16)

The sum of 5 first equations (equations 7 to 11) was used to get equation 17:

$5\log a + 5.926\ \alpha = 4.019$ (17)

The sum of the 5 subsequent equations (equations 12 to16) was used to get equation 18:

$5\log a + 9.973\ \alpha = 7.088$ (18)

To calculate equations 17 and 18, the α was substituted with **0.758** while value of log (a) was -0.095 and a =**0.8035**. Thereafter, a, b, and α was replaced with values in the equation for individual elapsed times: **log(y - b) = loga + αlog(t)** got more 10 equations (from equation (19) to equation (28), determine the value of y (from $y_{5min}$ to $y_{135\ min}$)

At t = 5 min, $\log(y_{5min} - 0.00346) = -0.095+0.5301 = 0.4350$; $y_{5min} = 2.7229$ (19)

At t = 10 min, $\log(y_{10min} - 0.00346) = -0.095+0.7583 = 0.6633$; $y_{10min} = 4.6059$ (20)

At t = 15 min, $\log(y_{15min} - 0.00346) = -0.095+0.8919 = 0.7968$; $y_{15min} = 6.2640$ (21)

At t = 25 min, $\log(y_{25min} - 0.00346) = -0.095+1.2537 = 0.9651$; $y_{25min} = 9.2275$ (22)

At t = 45 min, $\log(y_{45min} - 0.00346) = -0.095+1.3748 = 1.1587$; $y_{45min} = 14.4101$ (23)

At t = 65 min, $\log(y_{65min} - 0.00346) = -0.095+1.4631 = 1.2798$; $y_{65min} = 19.0447$ (24)

At t = 85 min, $\log(y_{105min} - 0.00346) = -0.095+1.5327 = 1.3681$; $y_{105min} = 23.3413$ (25)

At t = 105 min, $\log(y_{105min} - 0.00346) = -0.095+1.5327 = 1.4377$; $y_{105min} = 27.3979$ (26)

At t = 120 min, $\log(y_{120min} - 0.00346) = -0.095+1.5767 = 1.4817$; $y_{120min} = 30.3176$ (27)

At t = 135 min, $\log(y_{135min} - 0.00346) = -0.095+1.6155 = 1.5205$; $y_{135min} = 33.1502$ (28)

*Calculated percentage of error*

Equation (29) was used to calculate the error between the actual measured value and the value calculated by Kostiakov method. The error value was calculated for each time interval as shown in equations 19 to 28. The calculated values are presented in Table 3.

$$Error = \Sigma_{i=1}^{n} \left| \frac{AI - CI}{AI} \right| \times 100 \qquad (29)$$

where:

AI: the actual accumulated infiltration

CI: calculated accumulated infiltration by the model and

i is the number of data.

**Table 3. The calculated percentage of error between the actual and caculated values of accumulated infiltration vs time**

| Time (min) | Observed calculated infiltration (cm) | Calculated accumulated infiltration (cm) | Percent of error (%) |
|---|---|---|---|
| **5** | 2.442 | 2.7229 | 11.517 |
| **10** | 4.507 | 4.6059 | 2.195 |
| **15** | 6.365 | 6.2640 | -1.590 |
| **25** | 9.684 | 9.2275 | -4.711 |
| **45** | 15.451 | 14.4101 | -6.737 |
| **65** | 20.404 | 19.0447 | -6.660 |
| **85** | 24.574 | 23.3413 | -5.015 |
| **105** | 27.511 | 27.3979 | -0.410 |
| **120** | 29.091 | 30.3176 | 4.216 |
| **135** | 30.525 | 33.1502 | 8.602 |
| | | **Average** | **0.141** |

Table 3 showed the calculated values against actual values within the allowed range. The lowest error value was -6.737% while the highest error value was 11.517%. The percentage of error between the actual and the calculated values of the accumulated infiltration time. The average value of percent of error was 0.141, which was in the range of acceptable values. The results of log (a), α and b were -0.095, 0.758, and 0.00346, respectively which were were all below 1 and consistent with the previous findings (Michael,1997; Mahbub *et al.* 2015).

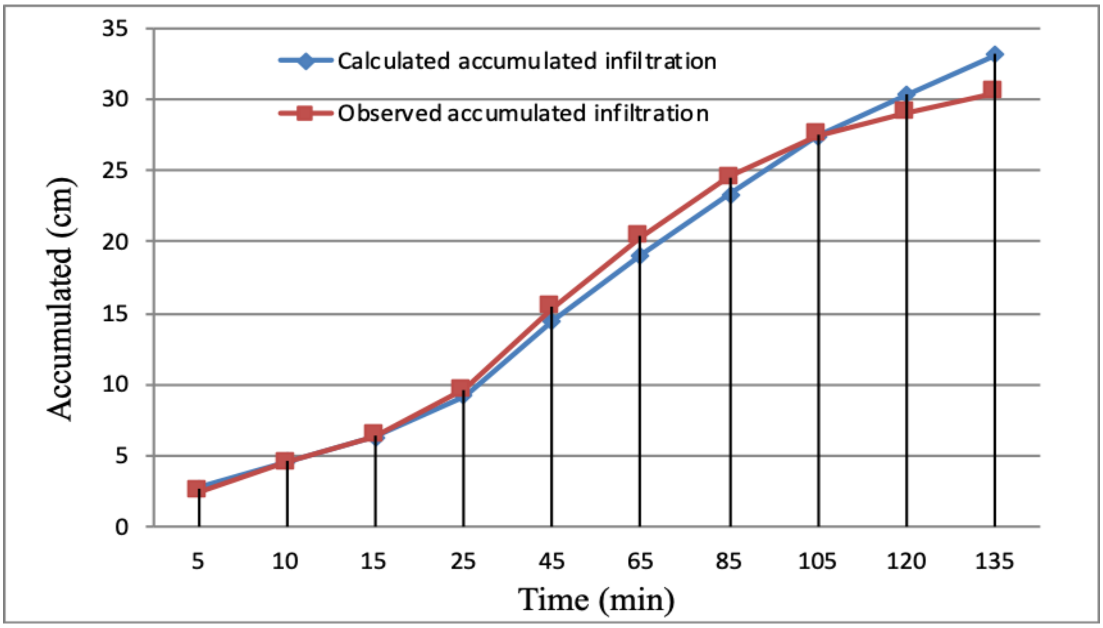


**Figure 4. The observed and calculated accumulated infiltration through time (min)**

Figure 4 showed that values calculated from Kostiakov method can accurately predict the actual field data measurement. Therefore, this model provide an accurate and useful basis for determining the infiltration rate and calculating the amount of infiltration water in the field. Simultaneously, the research results can provide basis for irrigation scheduling for plants to achieve high water use efficiency (determination of irrigation time, total water amount for each irrigation, number of irrigation in cultivation period)

## 4. Conclusions

In Lang Giang district, Bac Giang province, orange is grown mainly on alluvial soil of Thuong river, with the particle size of 0.02-2.0 mm mainly present in the surface layer (> 77.7%). The soil was slightly acidic on the ($pH_{KCl}$ = 5.11), and becomes more acidic with depths The organic matter content of the surface layer is average, while the remaining layers are very low. The total N was poor in the topsoil and gradually decreased to very poor level in the sub-layers while the available N was medium. The total P was high in the surface (0.4%), medium in sub surface whole the available P was high at surface layer but gradually reduced with depth. The total available K was poor.

The values of a, α and b determined using modified Kostiakov equation were 0.8035; 0.758 and 0.00346, respectively, all of which were all less than 1. The percentage error between the calculated value and the actual measured data of 0.141% was low indicating that these are in acceptable range which can predict accurately the actual field data measurements. Thus, the Kostiakov method in useful in calculating the infiltration rate and the amount of infiltration water into the soil to provide a useful information in water management for plants.

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