



Research Paper

Modeling of infiltration characteristics by modified Kostiakov method on Thuong river's alluvial soil, Langgiang District, Bacgiang Province, Vietnam.

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ABSTRACT

The purpose of this study was to apply modified Kostiakov method in determining soil infiltration and permeated water amount of the alluvial soil of Thuong river for orange plantation in Lang Giang district, Bac Giang province, Vietnam. The particle size ranged from 0.02 to 2.0 mm and composed mainly 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 was medium, while it was 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 0.3 mg per 100 g soil at deepest (5th) horizon. Total and available potassium were very low. A filtration characteristic model was developed using the modified Kostiakov method for alluvial soil. The constant values a; α ; b of the equation $y = at^{\alpha} + b$ was 0.8035, 0.758 và 0.00346, respectively which 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.

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Key words: Soil permeability, rate of infiltration, actual infiltration, accumulated infiltration.

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 duration rainfall increased, the soil permeability reduced (Dagadu and Nmbalkar, 2012), as it becomes saturated and consequently, generate surface flow (Fetter, 2001; Hasan 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. 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; α and b in the mathematical equation to determine the amount of infiltration is assessing and predicting the amount of

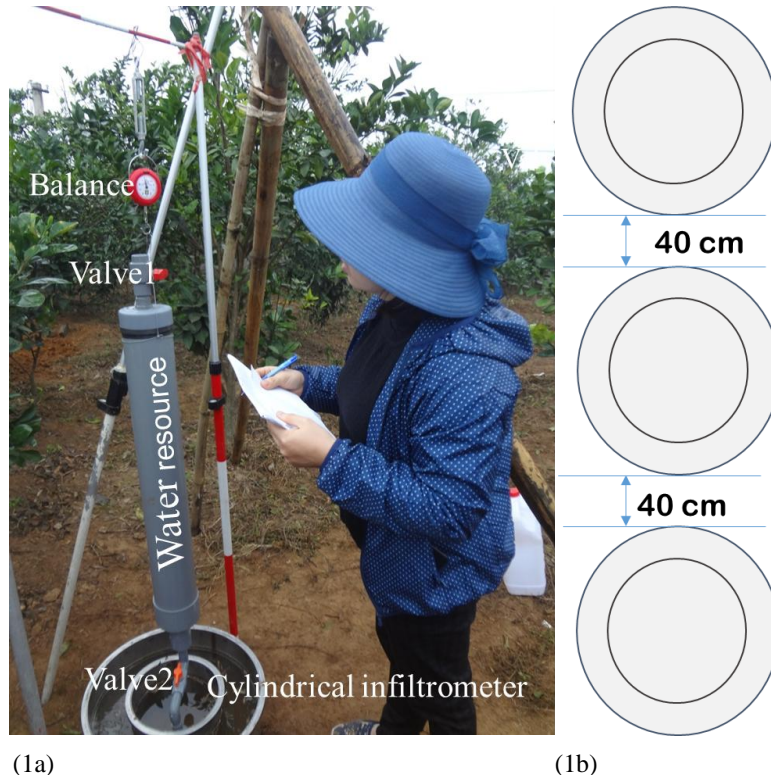


Figure 1: Installation of infiltrmeters in the field and its components.

irrigation water in accordance to the actual water demand of the crop. The objective of this study is to use the modified Kostikov method in calculating rates of permeability and water infiltration on the basis of: (1) Determining the coefficients of Kostikov method; (2) Evaluating the applicability of the model using field data and (3) Determining the error between the actual value and the model calculated value. Therefore, the irrigation plan for the orange zone is determined.

METHODOLOGY

Study site

The study was conducted in Truong Thinh village, Quang Thinh commune, Lang Giang district, Bac Giang province, Vietnam (21°26'28" N; 106°14'26" E) in 2018. This was the area where Bo Ha oranges were planted, Bac Giang province wanted to restore this specialty orange area.

Diagram and instrument for 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 infiltrmometer stable during the measurement process.

This method used 2 infiltration rings, an inner ring with 25 cm diameter 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 infiltrmeters (infiltration rings) were installed lengthwise with distance of 40 cm between them (Figure 1b).

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 min 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 1 g 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):

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

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

Where,

m: infiltration water weight, m = a - b (g)

ρ: specific gravity: 1 g/cm³

V: water volume (cm³)

A: cross section area of infiltration ring (cm²)

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 Kostikov method:

$$Y = at^\alpha + b \quad (3)$$

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, 1997). Equation was calculated in 3 steps by: (i) determining Y and t according to real measurements; (ii) selecting couple (t₁y₁) which was the time and amount of infiltration water after 5 min and (t₂y₂) which was the time and amount of infiltration water when soil was finally saturated with water and (iii) calculating a third value for t₃ using the value of t₁ and t₂ via Equation (4).

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

Using t₃ to determine Y₃, then using the equation to calculate b:

$$Y_1 = at_1^\alpha + b; Y_2 = at_2^\alpha + b$$

$$Y_1 Y_2 = (at_1^\alpha + b)(at_2^\alpha + b)$$

$$Y_1 Y_2 = \{a(\sqrt{t_1 t_2})^\alpha\}^2 + ab(t_1^\alpha + t_2^\alpha) + b^2$$

$$Y_1 Y_2 = \{a(\sqrt{t_1 t_2})^\alpha\}^2 + 2ab\sqrt{t_1^\alpha t_2^\alpha} + b^2$$

$$Y_1 Y_2 = \{a(\sqrt{t_1 t_2})^\alpha\}^2 + 2a\sqrt{t_1 t_2}^\alpha b + b^2$$

$$Y_1 Y_2 = \{a\sqrt{t_1 t_2}^\alpha + b\}^2; \text{ Set } Y_3^2 = Y_1 Y_2, \text{ in which}$$

$$Y_3 = \sqrt{Y_1 Y_2} \quad (5)$$

Norms and methods of soil analysis

The soil analysis was done using the following: The pH_{KCl} was measured with a pH meter; OC% was measured following Walkley and Black; total P₂O₅ was measured using the colorimetry method; available P₂O₅ was measured following the methods from Oniani; total K₂O digestion by HClO₄, HF, and HCl acids, measured by flame photometer; available K₂O was measured following the method of Matslova via a flame photometer (Van Reeuwijk, 1986); total N was measured following the methods of Kjeldhal; hydrolysis of N was measured following the methods of Tiurin and Kononova; texture was measured via a pipette following the methods of Robinson; and bulk density was measured using the core method; particle density: picnometer method (10 g of dry soil).

The soil profile was analyzed at Soil Science Central Laboratory of the Land Management Faculty, Vietnam National University of Agriculture. The parameters for analysis followed that of FAO-UNESCO standards (Van Reeuwijk, 1986, ISRIC, 1986).

Soil moisture measurements

In this research, soil moisture is determined by weighing method: Soil water content determination is gravimetric method with oven drying. This method involves weighing a moist sample, oven drying it at 105°C for 48 h, reweighing, and calculating the mass of water lost as a percentage of the mass of the dried soil

RESULTS AND DISCUSSION

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 range of 0.02 to 2.00 mm, in which, the surface layer had 77.7% composition and then decreased to 50% at the 4th and 5th

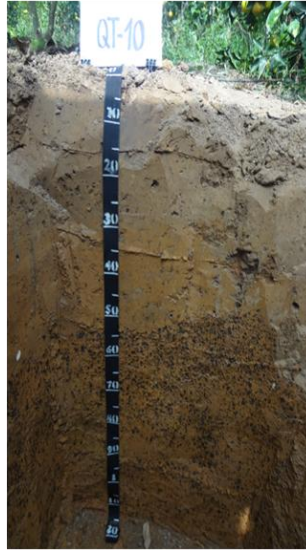


Figure 2: Soil profile at infiltration measurement site.

Table 1: Soil physical chemical properties.

Soil layers	pH _{KCl}	OC	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O	Texture (%)			Particle density (g/cm ³)	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

layers. The average soil particle density was 2.6 g/cm³ 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 was low regardless of the layers.

Calculated coefficients in Kostiakov equation

Infiltrations

The observed infiltration rate was low and increased slightly but decreasing again. The amount of stable seepage

water after 135 min reached to about 5.79 cm/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 equation:

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

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

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

The calculated value of b was **0.00346** using the Equation (3):

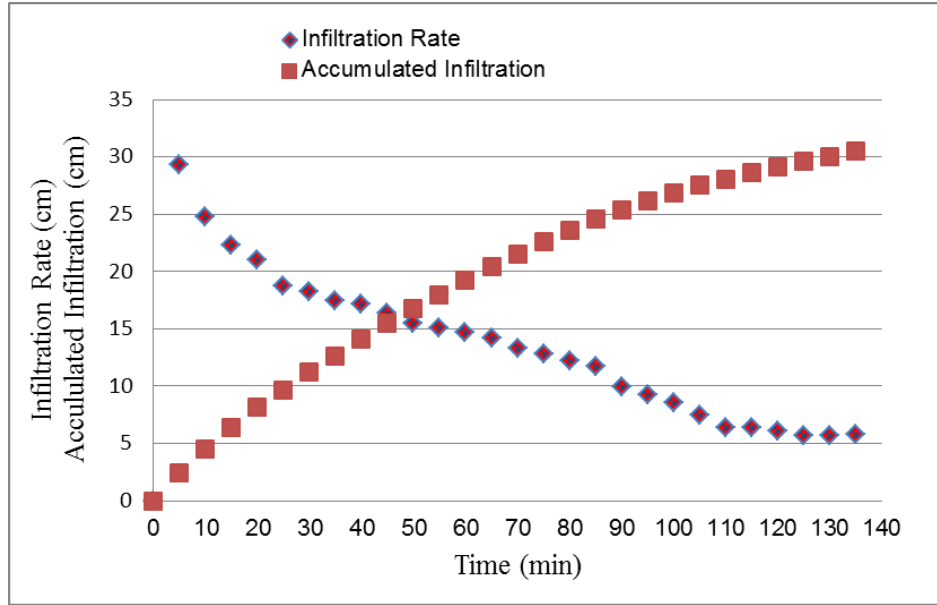


Figure 3: Mean infiltration rate (cm/h) and accumulated infiltration (cm) through time (min).

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

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

The calculated value of a and α

The measurements were done every 5 min, and thus, there were 27 measurements done at the end when the soil is 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 calculate further the value (a). Equation (3) was rearranged and written as: $Y - b = at^\alpha$, get log of two sides with Equation (6)

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

The values of (y) and (t) are shown in Table 2 and value (b) was calculated into Equation (6), get corresponding equations from (7) to (16):

$$\text{Log}(2.44 - 0.00346) = 0.39 = \text{log } a + \alpha \text{log}(5) \quad \text{or } \text{log } a + 0.699 \alpha \quad (7)$$

$$\text{Log}(4.51 - 0.00346) = 0.65 = \text{log } a + \alpha \text{log}(10) \quad \text{or } \text{log } a + 1.000 \alpha \quad (8)$$

$$\text{Log}(6.37 - 0.00346) = 0.80 = \text{log } a + \alpha \text{log}(15) \quad \text{or } \text{log } a + 1.176 \alpha \quad (9)$$

$$\text{Log}(9.68 - 0.00346) = 0.99 = \text{log } a + \alpha \text{log}(25) \quad \text{or } \text{log } a + 1.398 \alpha \quad (10)$$

$$\text{Log}(15.45 - 0.00346) = 1.19 = \text{log } a + \alpha \text{log}(45) \quad \text{or } \text{log } a + 1.653 \alpha \quad (11)$$

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

$$\text{Log}(20.40-0.00346) = 1.31 = \log a + \alpha \log(65) \text{ or } \log a + 1.813 \alpha \quad (12)$$

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

$$\text{Log}(24.57-0.00346) = 1.39 = \log a + \alpha \log(85) \text{ or } \log a + 1.929 \alpha \quad (13)$$

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

$$\text{Log}(27.51-0.00346) = 1.44 = \log a + \alpha \log(105) \text{ or } \log a + 2.021 \alpha \quad (14)$$

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

$$\text{Log}(29.09-0.00346) = 1.46 = \log a + \alpha \log(120) \text{ or } \log a + 2.079 \alpha \quad (15)$$

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

$$\text{Log}(30.52-0.00346) = 1.48 = \log a + \alpha \log(135) \text{ or } \log a + 2.130 \alpha \quad (16)$$

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

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

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

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

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

The sum of the 5 subsequent equations (equations 12 to 16) was used to get Equation 18:

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

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

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

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

$$\text{At } t = 15 \text{ min, } \log(y_{15\text{min}} - 0.00346) = -0.095 + 0.89 = 0.7968; \quad y_{15\text{min}} = 6.2640 \quad (21)$$

Calculated percentage of error

Using Equation (29) to calculate the error between the actual measured value and the value calculated by Kostiakov method, the error value was calculated according to each time interval measured from equations 19 to 28). The calculated values are presented in **Table 3**.

$$\text{Error} = S_{i=1}^n \left| \frac{AI - CI}{AI} \right|, \quad 100 \quad (29)$$

where:

AI: the actual accumulated infiltration

CI: calculated accumulated infiltration by the model and

i is the number of data.

Table 3 shows 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

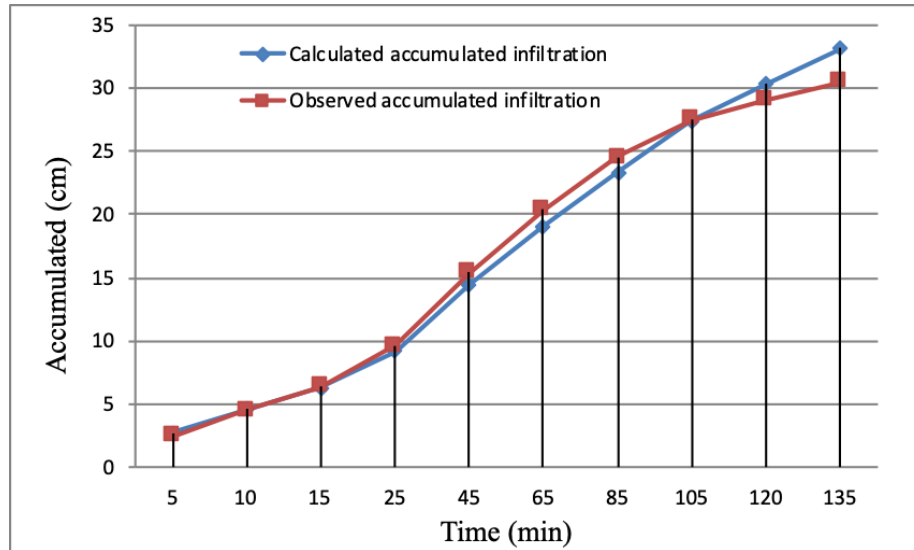


Figure 4: The observed and calculated accumulated infiltration through time (min).

percentage of error between the actual and the calculated values of the accumulated infiltration time is shown. 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 all below 1 and consistent with the previous findings (Michael, 1997; Mahbub et al., 2015).

Figure 4 shows 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 (decide irrigation time, total water amount for each irrigation, number of irrigation in cultivation period).

CONCLUSIONS

In Lang Giang district, Bac Giang province, orange is grown mainly on alluvial soil of Thuong river, with the particle size (0.02-2.0 mm) mainly present in the surface layer (> 77.7%). The soil was slightly acidic on the ($\text{pH}_{\text{KCl}} = 5.11$), and becomes more acidic with depths. The organic matter content of the surface layer was average, while the remaining layers were 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, while 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 using modified Kostiakov equation were 0.8035; 0.758 and 0.00346, respectively which were all less than 1. The percentage error between

the calculated value and the actual measured data was low (0.141%), indicating that these are in acceptable range which can predict accurately the actual field data measurements. Thus, the Kostiakov method is useful in calculating the infiltration rate and the amount of infiltration water into the soil to provide useful information in water management for plants.

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