STUDY OF TWO DIFFERENT FIELD MEASUREMENT METHODS OF INFILTRATION: FALLING HEAD AND CONSTANT HEAD, AT VARIOUS HYDRAULIC HEAD

Wahyu Purwakusuma[1)]*, Sri Malahayati Yusuf[1)] and Enny Dwi Wahjunie[1)]

[1)] Departemen Ilmu Tanah dan Sumberdaya Lahan, Fakultas Pertanian, IPB, Jl. Meranti Kampus IPB Dramaga Bogor 16680

ABSTRACT

Two field measurement of infiltration rate methods had been performed on Latosol (Oxic dystrudept) Dramaga Bogor in order to investigate the opportunity to generate different result due to the different of hydraulic head applied and the different way of water was supplied. They were constant head and falling head methods. Falling head method was done in two different ways, namely within a certain time interval and within a certain water level interval. Hydraulic head used during measurement were of 10 cm, 15 cm, and 20 cm. The falling head and constant head method, clearly, generated different minimum infiltration rate values. The falling head method measured on a fixed time interval generated almost the same values of minimum infiltration rate, respectively of 4.8 cm h^{-1}, 5.5 cm h^{-1}, and 4.8 cm h^{-1} at 10 cm, 15 cm, and 20 cm hydraulic head. The falling head method based on bulk water level interval at 10 cm, 15 cm, and 20 cm generated minimum infiltration rate values respectively of 13.2 cm h^{-1}, 12.8 cm h^{-1}, and 18.8 cm h^{-1}. The constant head method at 10 cm, 15 cm, and 20 cm hydraulic head generated minimum infiltration rate values respectively of 11.0 cm h^{-1}, 18.5 cm h^{-1}, and 19.0 cm h^{-1}. The values were higher than of the fixed time interval based falling head method. Infiltration field measurement using the falling head method either based on time interval or water level interval did not show an increasing trend of minimum infiltration rate values due to the increase of hydraulic head. However, the infiltration field measurement using constant head showed an increasing trend of the minimum infiltration rate values due to the increase of hydraulic head.

Key words: constant head, falling head, hydraulic head, infiltration, time interval

INTRODUCTION

Infiltration is the process by which water arriving at the soil surface enters the soil profile. This process determines surface runoff, determining the fraction of rain water entering the soils, affecting the amount of runoff responsible for subsequent soil erosion, and groundwater recharge (Hillel, 2012). The capability of measuring the surface infiltration rate is necessary in many disciplines. Quantifying the soil infiltration rate is of great importance to understanding and describing the hydrologic analysis and modeling. Infiltration can be quantified by the soil infiltrability, and/or cumulative infiltration expressed in cm/hour and cm respectively. The measurement of infiltration of water into the soil is of important concerning the efficiency of irrigation or drainage, optimizing the availability of water for plants and minimizing erosion (Adeniji *et al*., 2013). Soil properties are one of the important parameters which governs the rate of infiltration.

There are several methods of measuring soil infiltration rate, one of them are using ponding water double ring infiltrometer (ASTM, 2003). Its ease of use causes this method to be widely used and is one of the main methods for measuring infiltration rate. Study of Aronovici (1955) suggested that pressure head is the dominant factor involved in infiltration rates in initially dry or damp soils, and emphasized the influence of the differential hydraulic head in causing a decrease of infiltration rate with time. In water-repellent materials, the higher hydraulic head induces an increase in hydraulic conductivity, which contributes to increased infiltration rate (Feng *et al*., 2001).

The accuracy of infiltration data not only depends on the method of the infiltration test used but also depends on various parameters such as head of ponding or hydraulic head, initial soil moisture content and saturated hydraulic conductivity. Diamond and Shanley (1998) measured the rate of infiltration using double-ring infiltrometer for freely drained, imperfectly drained and poorly drained sites of Irish during summer and winter seasons and reported that 3.5 times higher infiltration rate for summer compared to winter sea. Champatiray *et al*. (2015) measured infiltration using different size of single and double-ring infiltrometer and found that double-ring infiltrometer was better than single ring infiltrometer. Chowdary *et al*. (2006) studied infiltration process under different experimental condition. They found that the length of wetting zone at the central axis of the infiltrometer increases with increasing diameter of infiltrometer and head of ponding. Wu *et al*. (1997) studied the infiltration rate in a single ring infiltrometer using a scaling technique involving saturated hydraulic conductivity, ring insertion depth, ponding depth and ring diameter. They compared the constant and falling head methods with numerical modelling, obtaining similar soil infiltration rates in fine textured soils, although soil infiltration rates decreased more than 30% with the decrease of the water head in coarse soils. Understanding the effect of these parameters on infiltration may provide more accurate infiltration rate data. It may be better to develop an infiltration measurement method with a very thin hydraulic head. Under natural conditions, when it rains, rainwater immediately infiltrates into the soil without waiting for water to pool on the surface of the soil.

The objective of the present study was to evaluate the effect of hydraulic head depth or the ponding depth on the minimum infiltration rate. The evaluation was related to two different infiltration measurement methods vi. the falling head dan the constant head.

**) Penulis Korespondensi: Telp. +628561801919; Email. w.purwakusuma@apps.ipb.ac.id* *DOI: http://dx.doi.org/10.29244/jitl.26.1.54-59*

MATERIALS AND METHODS

Site Description

The field experiment was carried out at the Soil Science Depapartment Field Station, Darmaga, Bogor. It is located on the latitude of 6º32'12" - 6º32'58" S and longitude of 106º42'43" - 106º42'49" E. The area is about 50 ha, which is dominated by Latosol (Oxic dystrudept) (Fuady, 2019). The soil has certain soil physical characteristics as described in Table 1. Pore space distribution was calculated based on Hartge and Horn (2009).

Latosol of Darmaga is a clay soil with clay content of about 80% (Fuady, 2019). As indicated by Table 1, soil in the research site has a stable moderate drainage capability (Uhland and O'Neal, 1951; Wischmeier, 1971). This will ensure that the infiltration process at the study area will occur smoothly and will not be an inhibiting factor in the test carried out.

Table 1. Method of analysis of soil physical properties

No	Soil physical parameter	Method
1	Soil bulk density	Gravimetric
2	Soil permeability	Constant Head Permeameter
3	Soil aggregate stability index	Wet and dry sieving
4	Pore space distribution	Pressure plate method

Materials

The research was held on Latosol (Oxic dystrudept) Darmaga, Bogor, at the Soil Science Department Field Station for 6 months. Equipment used consist of a double ring infiltrometer, a metal rammer, measuring gauge, measuring tape, water buckets, water from local well, and Mariote siphon system unit.

Soil samples were collected to determine several physical properties such as: soil bulk density, soil porosity, pore size distribution, soil aggregate stability index, and soil permeability. The soil samples consist of undisturbed soil sample and soil clods. The disturbed soil samples were collected and used to determined initial soil moisture content at the beginning of infiltration measurement.

Methods

The research was carried out at six different locations within the experimental site, which were selected randomly on a certain homogeneous area. Two different infiltration field measurement methods were used, i.e. the constant head and the falling head methods. Infiltration rates were measured by using double-ring infiltrometer which consist of two concentric metal cylindrical ring (Figure 1) as mention in (Bouwer, 1986; Reynold *et al.*, 2002). The diameter of inner and outer ring was 15 cm and 30 cm, respectively, and both have equal height of 25 cm each. Both the rings were placed concentric on the soil surface and was driven into the soil uniformly using a rammer at the depth of 5 cm each. The hydraulic head setting to be evaluated in each method were of 10 cm, 15 cm and 20 cm. In each hydraulic head, infiltration measurements were done based on (1) fixed time interval (FTI), (2) bulk water level interval in line with the hydraulic head (BWI), viz. 10 cm, 15 cm, 20 cm interval, and (3) the constant head (COD) using Mariote siphon system (Figure 2) (Bashyal *et al.*, 2019). Measurements were carried out up to 3 hours or up to a steady infiltration rate was achieved.

Figure 1. Double ring infiltrometer

Figure 2. Mariote siphon developed to maintain a constant head in infiltration ring

Several soil physical properties were analyzed based on Table 2 according to Kurnia *et al*. 2006.

Table 2. Soil physical poperties of study site

Parameter of soil physic	Value
Soil bulk density (g cm^{-3})	1.03
Total soil porosity (% v)	61.2
The very fast drainage pore (% v)	8.7
The fast drainage pore (% v)	6.0
The slow dranage pore (% v)	3.7
Soil aggregate stability index	351.4
Soil permeability (cm h^{-1})	8.2

Analysis of different method

The fitting accuracy of different infiltration method model were used to compare the result of infiltration rate measurement by mean of R^2 values, Bias, and MAE (maximum absolute error) and the closeness of final infiltration rate values to the saturated soil hydraulic conductivity (Song *et al.*, 2021).

RESULTS AND DISCUSSION

Infiltration Characteristics

The high infiltration rate was observed at the beginning of the test and decreased over time. The rate of decrease slowed down exponentially and the infiltration rate gradually reached a steady state, i.e. the final or the minimum infiltration rate. The minimum infiltration rate is approximately similar to the saturated hydraulic conductivity. The minimum infiltration rate is the final rate at which water passes through soil during saturated conditions. For the study area it was 8.2 cm h^{-1} (Table 2). The minimum infiltration rate is usually reached after two to three hours of infiltration process (Chow *et al*., 1988).

Field measurement of infiltration rates of the study area based on evaluated method were presented in Table 3. The minimum infiltration rate varied around the value of soil permeability of the site.

Table3. The minimum soil infiltration rate resulted from the evaluated method

Measurement Method	Hydraulic Head (cm)	Minimum Infiltration Rate (cm h^{-1})
FTI	10	4.8
	15	5.5
	20	4.8
BWI	10	13.2
	15	12.8
	20	18.8
COD	10	11.0
	15	18.5
	20	19.0

Infiltration rate based on FTI

The observed infiltration rate based on FTI at 10 cm, 15 cm and 20 cm showed a rather varied data spread (Figure 3). The value of R^2 was quite weak, that is less than 0.3 at the hydraulic head of 10 cm. It means that less than 30% of infiltration data contribute to the model. The R^2 value slightly better when the hydraulic head increased to 15 cm and 20 cm which means more infiltration data contribute to the model. The R^2 increased to 0.47 and 0.63 respectively due the increase of hydraulic head of 15 cm dan 20 cm (Table 4).

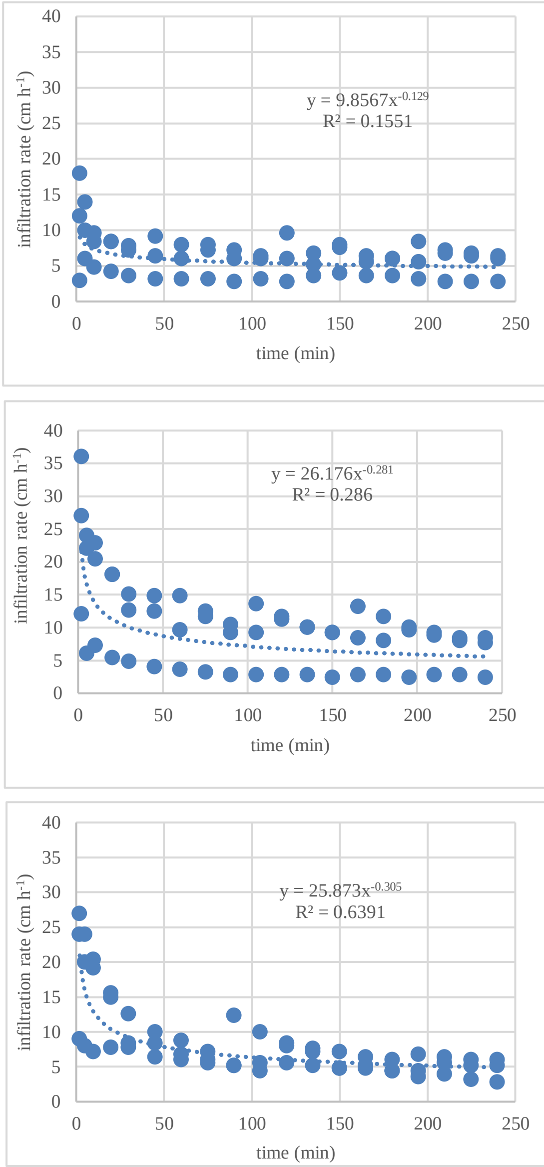

Figure 3. Infiltration rate based on FTI at 10 cm (upper), 15 cm (middle), and 20 cm (lower) initial hydraulic head

Table 4. Fitting results of different infiltration method

Method	R^2			Bias (cm h^{-1})			MAE (cm h^{-1})		
	Hydraulic Head (cm)								
	10	15	20	10	15	20	10	15	20
FTI	0.27	0.47	0.63	2.1	3.5	1.8	11.2	14.5	12.5
BWI	0.70	0.84	0.80	9.4	5.9	9.1	49.4	20.8	23.1
COD	0.70	0.67	0.73	4.7	8.9	10.7	13.6	31.2	45.5

The increase of hydraulic head that increase water pressure in the soil profile seems to be responsible for the development of wetting front as were indicated by Ma *et al.* (2016) which increase the infiltration rate. However, it is not quite clear in this test. The higher the hydraulic head did not correspond to the higher the infiltration rate. The small increment of interval selected during measurement which was capable to capture the small infiltration rate variation (Ravi and Williams, 1998; Bronstert *et al*., 2023) that occurred during infiltration process might be the reason.

Infiltration rate based on BWI

The infiltration rate measurement based on BWI was done at water level increment of 10 cm, 15 cm and 20 cm according to the initial hydraulic head. The result showed that the R^2 of the infiltration rate obtained was better than that based on FTI (Figure 4). This indicates that the measurement which was carried out at longer water level interval in line with the initial hydraulic head might eliminate the variations found in measurement based on FTI. The R^2 values now are 0.70, 0.84, and 0.80 respectively at 10 cm, 15 cm, and 20 cm initial hydraulic head and the values of minimum infiltration rate are 13.2 cm h^{-1}, 12.8 cm h^{-1}, and 18.8 cm h^{-1} (Table 3). The values were higher than that based on FTI and slightly higher than the soil permeability. The test result did not show any tendency of increasing the minimum infiltration rate as the consequence of increasing the hydraulic head inside the infiltrometer.

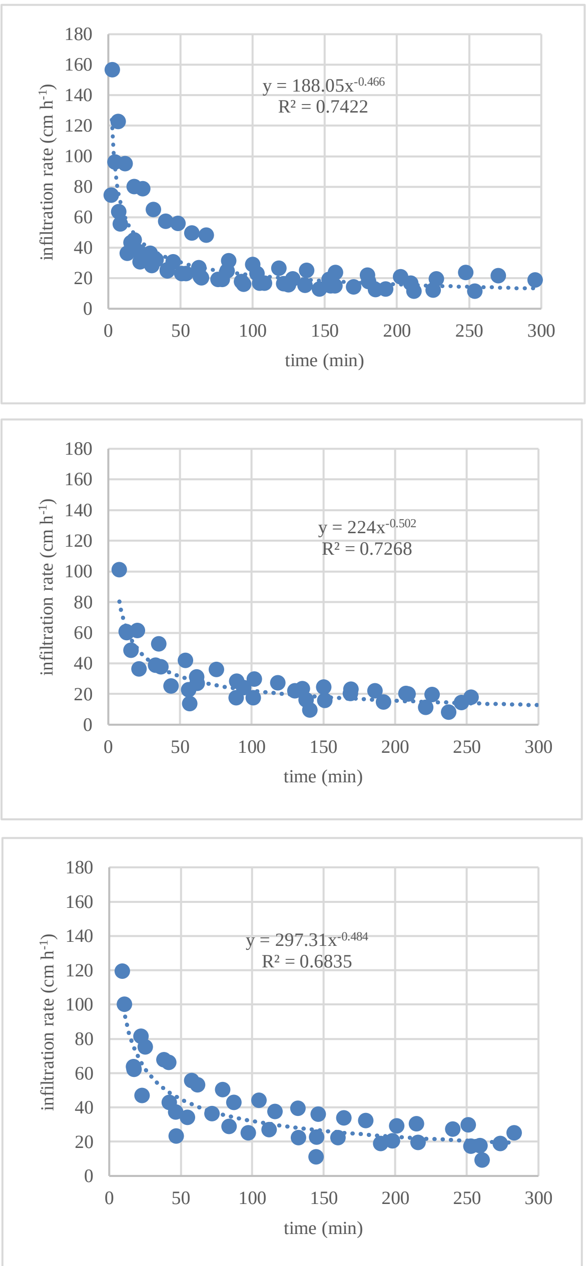

Figure 4. Infiltration rate based of BWI at 10 cm (upper), 15 cm (middle), and 20 cm (lower) initial hydraulic head

The initial infiltration rate base on BWI (>100 cm h^{-1}) was much higher than the initial infiltration rate base on FTI (<30 cm h^{-1}) (figures 3 and 4). The differences in data are clearly not caused by differences in measurement methods. The characteristics of landuse and soil type for the location are the same, while the differences only came from the initial condition of soil water content. The differentiator is not a determining factor because the measured parameter is the minimum infiltration rate, when the movement of water is constant. The difference in moisture content will determine the length of constant time is reached.

Infiltration rate based on COD

The infiltration rate measurement based on COD was carried out by maintaining a certain level of water ponding inside the infiltrometer during measurement vi. 10 cm, 15 cm and 20 cm. This will create a constant pressure on the surface of soil during measurement being conducted and might affect the infiltrability of the soil. Measurement have shown that there was an increase in the minimum infiltration rate value in line with the increase in the hydraulic head (Table 3). The minimum infiltration rate, consecutively, were 11.0 cm h^{-1}, 18.5 cm h^{-1}, and 19.0 cm h^{-1} at hydraulic head of 10 cm, 15 cm and 20 cm. The high hydraulic head means higher driving force that cause higher infiltration rate. This in line with Zhang *et al*. (2019) who indicated that infiltration rate tends to be higher at higher water pressure which was created by a hydraulic head inside the ring.

The data distribution slightly deviated from the model with R^2 value of 0.70, 0.67, and 0.73, respectively at 10 cm, 15 cm, and 20 cm initial hydraulic head (Figure 5). The soil aggregate of the study area which was categorized as very stable (Table 1) according to Kurnia *et al*. (2006) and De Boodt (1667) was responsible for maintaining the infiltration process so that it can withstand certain hydraulic pressures created in the infiltrometer as mentioned by Niewczas and Walczak (2003), and Zhang *et al*. (2019).

The overall test result showed that the minimum infiltration rate which based on BWI indicated a better performance than other methods (Table 4). The data distribution has strong relation with the model with more than 70% data contribution. However, the minimum infiltration rate value was higher than the soil permeability value. The closest minimum infiltration rate to the saturated soil permeability of the study area was the value which was resulted by the measurement based on FTI. However, the value was lower than the saturated soil permeability and the data contribution to the model was the lowest, with R^2 0.27, 0.47, and 0.63, respectively for 10 cm, 15 cm, and 20 cm initial hydraulic head.

The lowest bias value found on FTI but the R^2 value was also the lowest. The bias values were 3.1 cm h^{-1}, 3.5 cm h^{-1} and 1.8 cm h^{-1} at hydraulic head of 10 cm, 15 cm, and 20 cm. The small bias seems to relate to the smaller increment interval used during measurement. However, this method captured a relatively small variation in the field which contribute to the small R^2.

From the three methods tested it was known that only COD showed a tendency of increasing value, either the minimum infiltration rate value, value of bias or the MAE. This indicated that there was the effect of standing water level in the infiltrometer to the parameter being measured. However, this needs further detailed observation.

The initial and constant infiltration rates measured by constant method are faster with the higher of hydraulic head. The improvement of method is expected to eliminate the influence of hydrostatic pressure caused by inundation.

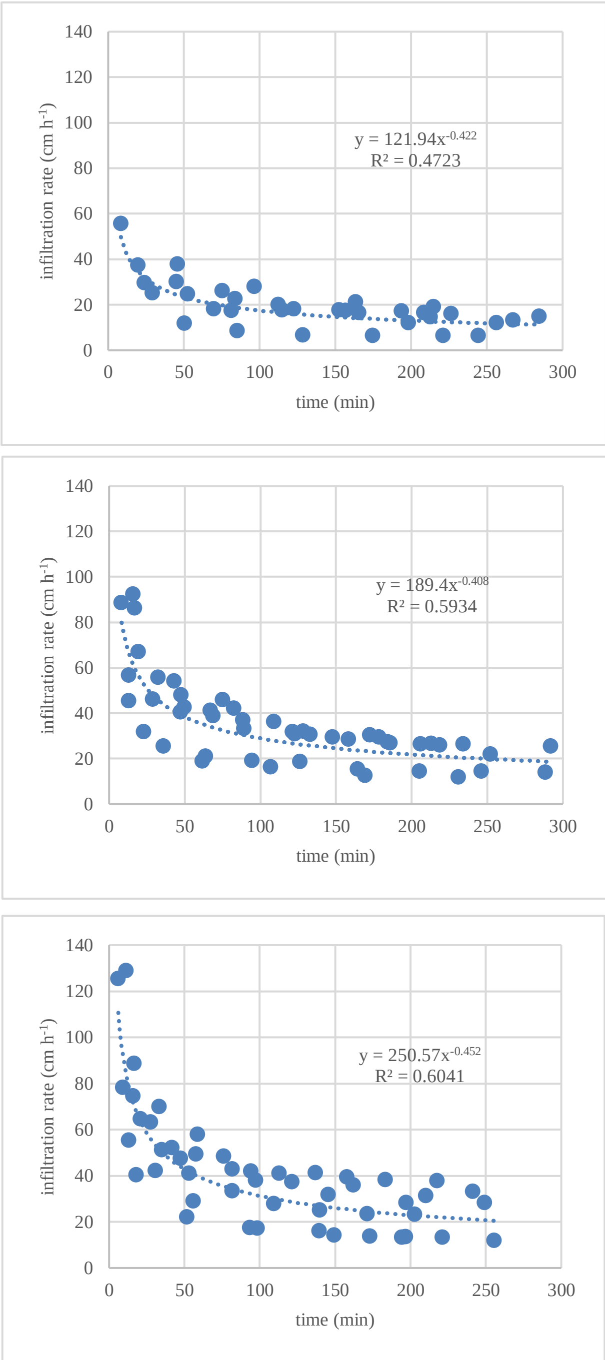

Figure 5. Infiltration rate based of COD at 10 cm (upper), 15 cm (middle), and 20 cm (lower) initial hydraulic head

CONCLUSION

There were no indication that initial hydraulic head affect the minimum infiltration rate on the falling head method. The initial hydraulic head of 10 cm, 15 cm and 20 cm generated minimum infiltration value respectively of 4.8 cm h^{-1}, 5.5 cm h^{-1}, and 4.8 cm h^{-1} based on fixed time interval and respectively of of 13.2 cm h^{-1}, 12.8 cm h^{-1}, and 18.8 cm h^{-1} based on bulk water level interval.

The falling head and constant head method, clearly, generated different minimum infiltration rate values. The constant head method at 10 cm, 15 cm, and 20 cm hydraulic head generated minimum infiltration rate values respectively of 11.0 cm h^{-1}, 18.5 cm h^{-1}, and 19.0 cm h^{-1}. The values were higher than of the fixed time interval based falling head method.

Infiltration field measurement using the falling head method either based on time interval or water level interval did not show an increasing trend of minimum infiltration rate values due to the increase of hydraulic head. However, the infiltration field measurement using constant head showed an increasing trend of the minimum infiltration rate values due to the increase of hydraulic head.

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