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Actual Evapotranspiration in Clay Soil on Three Slope Zones in Volcanic Slope of Mt. Sumbing, Central Java-Indonesia

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ABSTRACT

Background: Soil physical properties have not been widely discussed as the main factor of evapotranspiration. This study aimed to see the relationship between land and soil physical factors on the evapotranspiration rate that occured at each slope position.

Methods: Sampling and measurements were carried out on three slope zones in a landscape, *i.e.* the upper slope (erosion zone), the middle slope (transition zone) and the lower slope (deposition zone). The soil sampling was carried out to analyze the soil physical properties. The evapotranspiration rate was measured using a modified chamber in two measurement periods. It was carried out throughout the day since the sun started shining the land until sunset or until the sunlight were blocked by rain clouds.

Result: The average daily evapotranspiration rate was 0.17 mm hr^{-1} with the lowest value was 0.02 mm hr^{-1} and the highest 0.62 mm hr^{-1}. Slope position and slope arrangement were the key factors influencing other controlling factors for the rate of evapotranspiration, including vegetation and soil physical properties.

Key words: Chamber modification, Evapotranspiration, Slope zone, Mt. Sumbing, Volcanic Slope.

INTRODUCTION

Factors that affect the rate of evapotranspiration in general are climatic factors, soil characteristics and tillage. Climatic factors that are quite influential include solar radiation, air temperature, air humidity and wind speed (Krishna, 2019). Soil physical properties such as soil texture and structure affect the soil moisture which also has an impact on the evaporation rate on a land. Soils that contain more sand fractions have higher evapotranspiration rate than soils with high silt and clay fractions (Torres and Calera, 2010). Soil tillage methods also affect the soil physical properties, especially soil structure. The intensive tillage can increase the evaporation rate and water loss from land compared to land with no tillage or minimum tillage (Jambak *et al.*, 2017).

Research related to the effect of land physical properties on water dynamics, especially losses due to evapotranspiration is very interesting to study. The effect of water loss due to land physical factors is interesting because every inch of soil has different properties and characteristics which can also affect the state of other factors on it. The assessment of the dynamics of water loss due to the evapotranspiration process so far generally uses a climate/weather and land cover approach. This approach is widely used because it is relatively easy to collect data on climate and conditions on the land surface (Samani, 2000).

Many methods of measuring evapotranspiration have been developed. Several methods are widely used to measure *i.e.* the Penman-Monteith, Blaney-Cridle method and the measurement method using the energy balance approach (Krishna, 2019). Measurement of evapotranspiration using various existing approach methods, although it is relatively easier and faster, but the climatic conditions above the land surface are not always positively related to the evapotranspiration rate (Sun *et al.*, 2016). Based on these conditions, this research aimed to examine which factors from a land that affect the evapotranspiration rate. By knowing which land factors affect the evapotranspiration rate, it is expected that more accurate and specific measurement data will be obtained at a certain location.

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MATERIALS AND METHODS

The research location is an agricultural land in Wonogiri Village, Kajoran District, Magelang Regency and was part of the Volcanic Slope of Mt. Sumbing, Central Java Province -Indonesia (Fig 1). It is a dry land with corn-peanut intercropping cultivation. The observation location facing east with a slope of 30% - 70% covering an area of 0.68 Ha. Sampling and measurements were carried out on three slope zones based on the appearance of the slope and the position of the slope, namely the upper slope (erosion zone), the middle slope (transition zone) and the lower slope (deposition zone). The area of each slope zone is 0.34 ha, 0.19 ha and 0.15 ha for the upper, middle and lower slopes.

The study was conducted during the rainy season which coincided with the planting season from November 2020 to January 2021. The data collected was soil physical properties, weather conditions and evapotranspiration rate. Measurement of soil physical properties was carried out by taking composite samples at each slope position at a depth of tillage layer (0-20 cm). Measurement of soil properties included analysis of texture, porosity, soil moisture and SOM content. Weather data was collected using an Automatic Weather Station (AWS) with automatic weather recording device (MISOL A3-WH-2310). Observation of evapotranspiration using a modified chamber device. Chamber installation and measurement of data parameters were carried out based on the distribution of slope zones. The chamber was made of 3 mm plexiglass with a size of 60 × 60 × 120 cm. The temperature and humidity recorder was installed inside the chamber. Two of 12 cm fans was also installed inside of the chamber to keep the air mixture in the chamber homogeneous.

Data collection was carried out in two periods, *i.e.* (1) when the plant was in the middle of the vegetative phase and (2) when the plant entered the generative phase. Observations for the first period were carried out 38 days after planting (DAP) to 40 DAP and the second period observations were carried out at 69 DAP to 71 DAP. Each measurement period was carried out for three days as a repetition. Measurements were carried out starting at 08.00 in the morning or since the sun started shining the land until 17.00 in the afternoon or until the clouds were thick before the rain occurred. Observations were stopped when thick clouds covered the sunlight because when there was no sunlight, the plant stomata were closed and the photosynthesis and transpiration processes stopped (Wang *et al*., 2018). Data recorded from the chamber in which were temperature data and RH data were downloaded at each end of the measurement.

The evapotranspiration calculation using this chamber method went through several stages as described by Mcleod *et al*., (2004). The evapotranspiration value was then analyzed using a modified equation from Stannard (1988) and Hewitt *et al*. (2018):

The value of the evapotranspiration rate is then calculated to obtain the average value of the land weighted evapotranspiration rate (mm day^{-1}) using the equation:

$$ET \text{ land weighted average} = \frac{\Sigma\ (\overline{ET} \times Al)}{A}$$

Where

$\overline{ET}$= Average evapotranspiration rate the average rate of evapotranspiration in each slope zone (mm day^{-1}).

Al= Zone area of each slope (ha) dan A is the total area of research (ha).

RESULTS AND DISCUSSION

Soil properties and land management

Size and percentage of soil fraction affect the status of soil porosity. Soil texture has an inverse relationship with the amount of soil pore space where the finer/smaller the soil texture, the greater the soil porosity (Utomo, 2016). This soil porosity affects the amount of moisture that can be stored in the soil pore space (Rabot *et al*., 2018). Table 1 shows the soil at the observation location is dominated by clay texture which has a more dominant fine fraction so that it has a high porosity between 37.79% (middle slope) to 56.09% (upper slope).

Soil organic matter (SOM) content at each slope position had varying values. It is influenced by the position and degree of slope (Wiwaha and Kurniawan, 2021). Higher SOM content in the upper slope position was caused by the construction of a terrace at the observation site. Making terraces on sloping land is a soil conservation effort that aims to inhibit the rate of soil and SOM loss due to erosion (Jambak *et al*., 2017).

SOM content of the soil was in the low. Although, the SOM content in the soil, especially on the upper and lower slope, was well associated with soil particles in forming the soil structure on the surface layer that was subangular blocky. As explained by Neto *et al*., (2016) that the shape of the soil structure will also tend to be rounded when it has sufficient SOM content. Ahmad *et al*., (2019) also explained that the addition of organic matter into the soil layer can improve soil physical properties and plant growth.

Surface vegetation

Rate of plant growth was influenced by the position of the slope. Fig 2 shows a difference in the physical condition of the vegetation at each slope position in each observation period. The physical condition of the surface vegetation was only observed visually and descriptively. Plants on the upper slope tended to grow better than plants on the middle and lower slope. Possibly this was due to the amount of solar radiation and heat received on the upper slope was more and sufficient for better plant growth. As observed by Li *et al*., (2021) which showed that beside the nature of the soil, conditions of sunlight and higher air temperature can support better plant growth.

Vegetation condition on land surface determines the evapotranspiration rate that occurs. The wider canopy of plants can increase the rate of evapotranspiration due to physiological activities, *i.e*. respiration and plant photosynthesis. The condition of the plants on the upper slope at the first observation was better than the plants on the lower slope. With a more developed canopy, the evapotranspiration rate on the upper slope in the first observation was higher than the others (Fig 2). Besides that, the condition of the plants in the second observation was relatively the same which caused the evapotranspiration rate on the land to be relatively the same and even tended to be

Table 1: The value of physical properties and SOM at the depth of tillage layer (0-20 cm).

Slope zone	Texture	structure	Consistency	Porosity (%)	SOM (%)
Upper	Clay	Subangular blocky	Slightly sticky	56.09	2.8
Middle	Clay	Granular	Slightly sticky	37.79	1.5
Lower	Clay	Subangular blocky	sticky	53.68	1.9

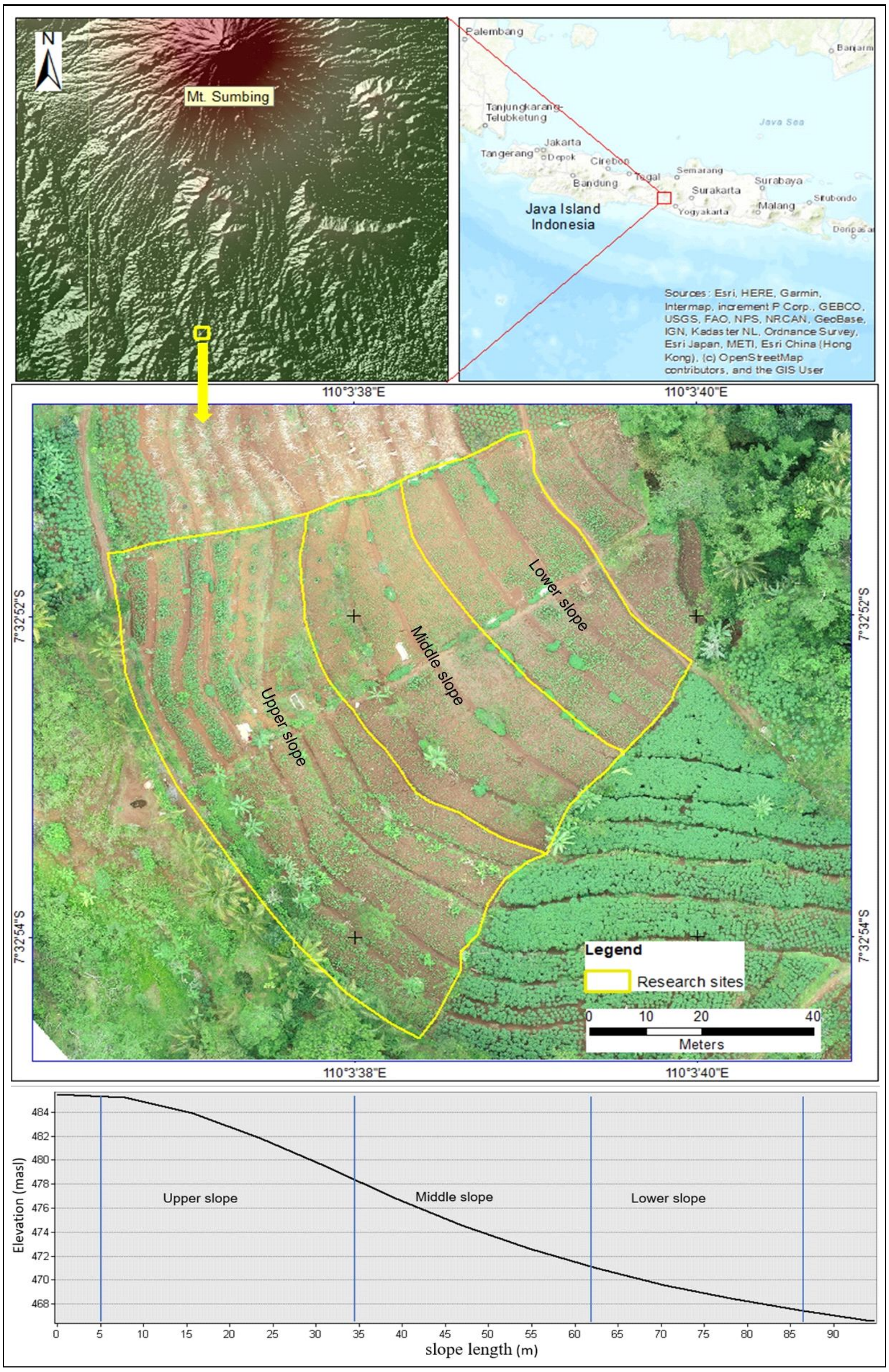

Fig 1: Research site.

higher on the lower slopes because the soil moisture reserve was larger than the upper slopes.

Climatic conditions

In addition to the physical properties of land and surface vegetation, the rate of evapotranspiration is influenced by climatic factors. Fig 3 show the climate component that is the main energy source that affects the evapotranspiration rate on site. The average net radiation value (R_{net}) was 1411.43 W m^{-2} to 1524.86 W m^{-2} in the first observation period and 1196.19 W m^{-2} to 1550.51 W m^{-2} in the second observation period. The highest Rnet value in the first

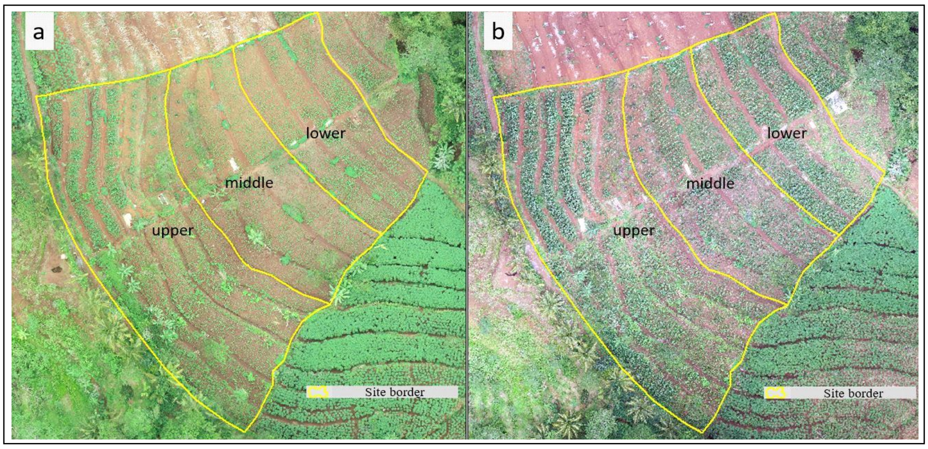

Fig 2: Aerial photo of the condition of the research land plants during (a) the first period of observation and (b) the second period of observation

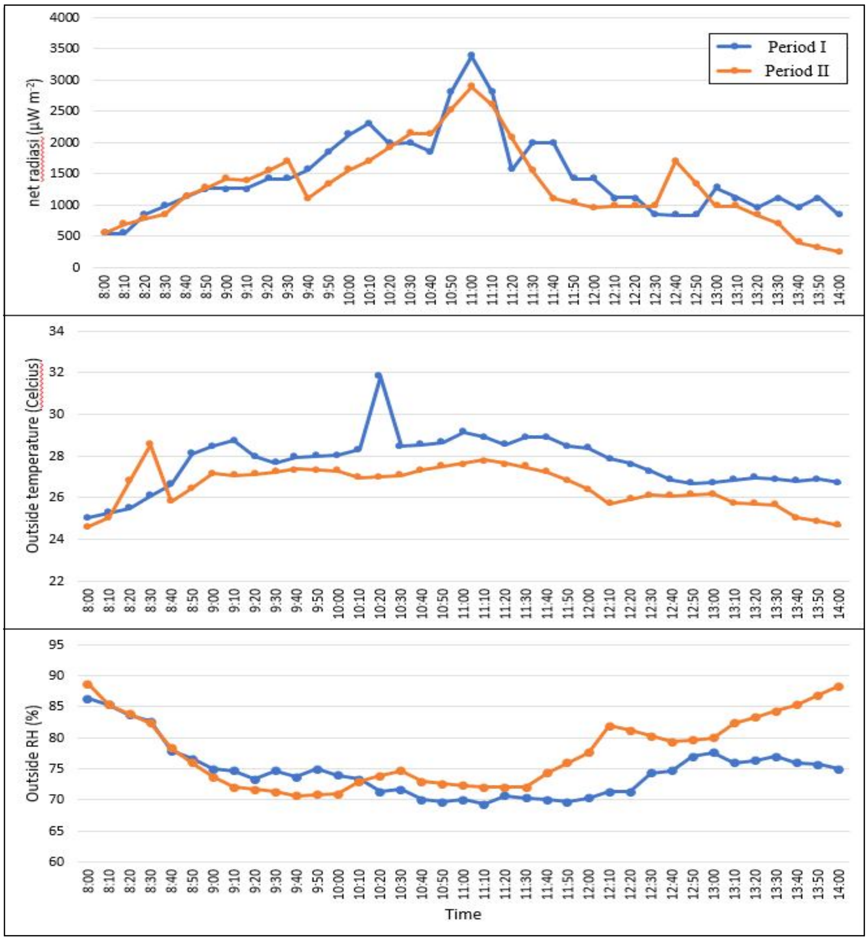

Fig 3: Average net radiation (R_{net}), outside air temperature and RH (RH) of outside air in the first and second observations.

observation period was 4707 W m^{-2} which occurred in the second repetition (39 DAP) and the highest R_{net} value in the second observation period was 3648 W m^{-2} which also occurred on the second day of observation (70 DAP). The highest air temperature in the first observation period was 31.8°C and the lowest was 25°C, while the highest temperature in the second observation period was 28.5°C and the lowest was 24.6°C. The RH in the first observation period was 63% to 90% with an average value of 73.25% to 75%. In the second observation period, the RH value was 61% to 98% with an average of 73.37% to 79.87%.

The evapotranspiration rate on land occurs due to differences in the amount of moisture content in the soil and in the air. Soil moisture content is a key variable that determines the potential energy in water movement and gas and carbon exchange at the soil surface and atmosphere (Seneviratne *et al*., 2010). The lower of air humidity compared to the soil moisture, the faster the evapotranspiration rate (Ruairuen *et al*., 2015). The amount of energy required to change soil moisture from liquid to gas also varies in each situation where the higher the soil moisture, the greater the energy required to evaporate it (Seneviratne *et al*., 2010). The energy to change the liquid form to gaseous form mainly comes from solar radiation (Rnet), where this R_{net} affects changes in air temperature (Abtew and Melesse, 2013). The results of the observations showed that the amount of R_{net} was positively correlated (r^2 = 0.6-0.8) to the increase in air temperature where the higher the temperature, the easier it was to evaporate water into the air. In the first observation, it rained every day, causing the soil on the lower slope to be saturated. This saturated soil caused the evapotranspiration rate to be low because the energy required for evaporation was not sufficient. In the second observation, it did not rain often so that the soil moisture on each slope was relatively the same and the energy required for evaporation did not vary much on each slope so that the evapotranspiration rate that occured tended to be the same.

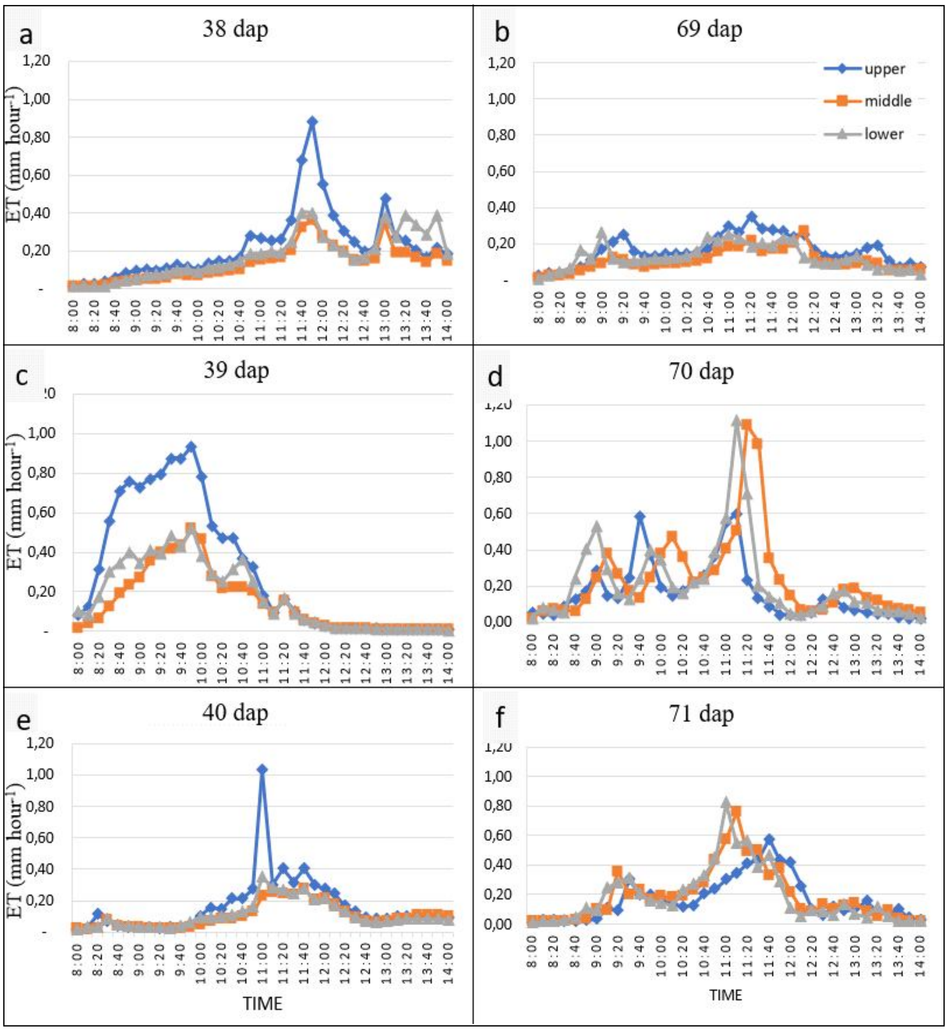

Fig 4: Fluctuations in the value of evapotranspiration (mm $hour^{-1}$) throughout the day in the first observation period (a, c, e) and the second observation period (b, d, f).

Table 2: The results of measuring the evapotranspiration rate using the Penman-Monteith method and chamber measurements. The evapotranspiration values in the table are presented in mm day $^{-1}$.

	Observation Period	Penman-monteith	ET chamber			
			Upper slope	Middle slope	Lower slope	weighted average
I	38 dap*	4.09	8.27	5.01	6.51	6,87
	39 dap	3.61	11.40	5.53	6.70	
	40 dap	4.29	6.00	3.70	4.01	
	Average	4.00	8.56	4.75	5.74	
II	69 dap	4.51	6.10	3.96	4.81	6,37
	70 dap	3.99	6.14	8.84	8.12	
	71 dap	4.07	6.16	6.96	6.97	
	Average	4.19	6.14	6.59	6.64	

Evapotranspiration rate

The evapotranspiration rate at both times of observation showed the difference between the upper, middle and lower slope (Fig 4). The evaporation or transpiration rate that occurs and which process is more dominant is influenced by the state of the land (Kaur *et al,* 2017). In the first observation, where the physical condition of the vegetation on the upper slopes was better than other, the evapotranspiration rate was higher. In the second observation where the physical conditions of the plants on each slope were almost even, the rate of evapotranspiration that occured also tended not to differ much. As Zhongmin *et al*. (2009) that the physical condition of the plant greatly affects the rate of evapotranspiration that occurs on the land.

Value of the evapotranspiration rate from the measurement results with chamber showed a more varied value at each slope position compared to calculations using the Penman-Monteith model. The Penman-Monteoth evapotranspiration value as a comparison was calculated using the CROPWAT application. Comparison of the results of the calculation of evapotranspiration on the research area of the chamber method with the Penman-Monteith method can be seen in Table 2.

The weighted average value of the chamber method evapotranspiration rate was 41.7% and 34.2% greater than the value of the Penman-Monteith evapotranspiration rate in the first and second period measurements. The smaller value for the Penman-Monteith method was due to the fact that this method only used global climate data and did not consider the position of land slopes in its measurement (Yadav *et al*, 2017). Results of research conducted by Manik *et al*., (2012); Prastowo *et al*., (2016); and Taolin *et al*. (2017) at various locations showed that the average value of evapotranspiration rate calculated using Penman-Monteith method was 3 mm day^{-1} to 4.8 mm day^{-1}. Ruairuen *et al*., (2015) explained that the microclimate that occured on each slope affected the evapotranspiration rate. The largest evapotranspiration rate generally occurs at higher slope positions because the solar energy obtained on the upper slope is greater than the area at the lower slope position. The difference in the value of the evapotranspiration rate at each slope position with the chamber method showed that the slope factor affected the microclimate that was formed. As explained by Luo *et al*., (2018) that measuring fluctuations in the value of evapotranspiration in a small and limited area based on land characteristics is more effective using the chamber method.

CONCLUSIONS

The fluctuation of the evapotranspiration rate was influenced by land, plant and soil factors. The parameters of land, plants and soil respectively were: (1) position and slope angle, (2) plant growth rate, (3) soil fraction and moisture content. The land factor was the main controller that influenced other factors. The difference in altitude was relatively small so that the intensity of solar radiation was not significantly different in influencing the rate of evapotranspiration. The results of the direct calculation of the evapotranspiration rate in the study area provided evidence that the calculation based on the slope position and slope angle was more detailed than the calculation based on the Penman-Monteith model.

Conflict of interest: None.

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