Vol. 13, No. 1 (2024): 82 - 91 http://dx.doi.org/10.23960/jtep-l.v13i1.82-91

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Effect of Canopy Cover Level of Cacao and Shade Trees on Splash Erosion of Cacao Land

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Article History:

Received : 07 September 2023
Revised : 26 October 2023
Accepted : 13 November 2023

Keywords:

Cacao plantation,
Canopy cover,
Regression analysis,
Splash erosion

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ABSTRACT

In smallholder cacao plantations, the protective crops used varied, so they have different effects on splash erosion. The management of land cover with a canopy of cacao and shade trees on cacao fields, aims to control of splash erosion. This study was conducted by directly measuring the magnitude of splash erosion under several levels of canopy cover. The magnitude of splash erosion was determined by measuring the depth of the eroded soil using the bottle cap method. The measurements were carried out every rain event (46 rain events with rainfall varied from 0.28 to 97.04 mm). The canopy cover level was determined by analyzing the images taken using a digital camera. The images were processed by Matlab software with closure approach. The data were analyzed by regression analysis to determine the relationship between canopy cover level and the depth of splash erosion that occurred. The results showed that the level of canopy cover influence the depth of splash erosion. In addition, this study indicates that the level of splash erosion not only influenced by the level of closure and rainfall, but also strongly influenced by the size of the leaf cover.

1. INTRODUCTION

Soil erosion is a major problem in agricultural cultivation. Erosion causes a decrease in land productivity due to loss of fertile soil layers for plant growth and reduced soil capability to absorb and retain water. This condition occurs when the rate of erosion is greater than the rate of soil formation (Mandal *et al*., 2006). The phenomenon in Indonesia shows an increase in critical land caused by inappropriate land use, no soil and water conservation measures applied in such areas entailed to severe erosion (MoEF & UNCCD, 2015) and high rainfall intensity causes great soil erosion (Mohamadi & Kavian, 2015; Zhao *et al*., 2019). The amount of soil erosion on farm land depend on the way the land is cultivated (Neswati *et al*., 2023) or managed (Panagos *et al*., 2015) and the erosion rate is more sensitive to changes in land cover than rainfall changes (Paroissien *et al*., 2015). One of the most studied erosions associated with rainfall and vegetation cover is splash erosion (Angulo-Martínez *et al*., 2012; Fernández-Raga *et al*., 2010; Geißler *et al*., 2012; Liu *et al*., 2016; Nanko *et al*., 2008).

Splash erosion is the process of granular release of the aggregate, which is directly related to the erosivity of any rain event (Beguería *et al*., 2015). Rain hit is the main medium that releases soil particles, so the amount and size of the rain falling to the soil surface determines the amount of the erosion (Suripin, 2004) and the relationship is significant (Angulo-Martínez *et al*., 2012). This process is an initial process of surface erosion where the loose soil granules from the aggregate will be transported by the overland flow.

Canopy cover is a barrier of rain blow so it is a factor that affects the erosion of the splash. Canopy cover is an entire plant part that covers an area and is very varied. Canopy cover will affect to rain interception level and be directly proportional (Bahmani *et al*., 2012; Park & Cameron, 2008; Xiao *et al*., 1998). The rate of rain interception will affect the amount of rainwater that falls directly to the soil surface (Park and Cameron, 2008). In addition, the storage capacity of the canopy and water passes is influenced by wind speed, temperature, rain intensity and crop conditions (Véliz-Chávez *et al*., 2014).

Some important agricultural and plantation commodities such as cacao and coffee require shade to obtain optimal production. For cacao plants, heavy shading can decrease yields and cause disease and there is a relationship between production and light intercept in unlimited nutrient conditions. However, high production in unshaded plants requires high inputs in terms of plant protection and nutrition. Annual radiation and rainfall during the dry season is around 70% of annual production (De Almeida & Valle, 2007). Cacao plants aged above 3 months require a shade of 55% (Harun & Ismail, 1983). Shade index was negatively related to yield, higher yield at shade and herb covers <50% (Bisseleua *et al*., 2013). In addition, protective plants are also needed to minimize the impact of the dry season. Protective crops used by farmers consist of several types with different characteristics, especially leaf type. In fact, the leaf type has an impact on the magnitude of splash erosion due to changes in the kinetic energy of rain by interception (Ma *et al*., 2015). Thus, the size of the leaves of the protective tree can also affect the splash erosion because it affects the interception of rain by the canopy so that the rain kinetic energy is also affected. The plant shade widely used by farmers includes wide-leaved trees such as pecan (*Aleurites moluccana* L. Willd.) and small leaf such as gamal (*Gliricidia sepium*).

Cacao cultivation systems require shade to improve plant physiology and reduce attacks on pests and diseases (Vanhove *et al*., 2016). Several types of shade plants with different canopy models are often used in cacao cultivation. The use of various shaded plants also affects pest attacks (Bos *et al*., 2007), and there is a good synergy between the environment and cacao production (Bieng *et al*., 2013). Therefore, this study was directed to study the relationship between the diversity of canopy cover on cacao cultivation to the splash erosion that occurs. In addition, assessing the effect of leaf size on splash erosion was also done because the literature search results show that no studies have been conducted that specifically study the effect of leaf size on splash erosion.

2. MATERIALS AND METHODS

2.1. Research locations

The research was conducted on smallholder cacao plantations in one of the important cacao production centers in Sulawesi, Indonesia (Figure 1) from May to July 2021. In general, the climate at the study site includes slightly wet and wet climates, according to Schmidt and Ferguson with average monthly rainfall is 259.5 – 387.6 mm and the dry season only ranging from 1 to 2 months (BPS, 2020; BPS, 2021; BPS, 2022). The topography of the cacao land in the study area was from flat to hilly.

2.2. Rainfall data

Research under natural rainfalls was conducted to measure splash erosion under different ranges of rainfall rates. Splash erosion experiments under field conditions do not allow controlling the factors involved (Fernández-Raga et al., 2017). Rainfall measurements is generally carried out using a bucket type (Fernández-Raga *et al*., 2010) which is a standard type of measurable rainfall (Venkatraman & Ashwath, 2016). The volume of collected rain is measured using a measuring cup. The measuring instrument has been equipped with a rainfall collection equipment (Geißler *et al*., 2012) with a catch can area of 1257.14 cm^2. Rainfall data has been measured directly using a measuring device. Rainfall measurements have been carried out in every rain event. The depth of rainfall was calculated by the equation:

$$R = \frac{V}{A_p x10} \quad (1)$$

where R is depth of rainfall (mm), V is Volume of rain collected (cm^3), and Ap is catch-can area (cm^2)

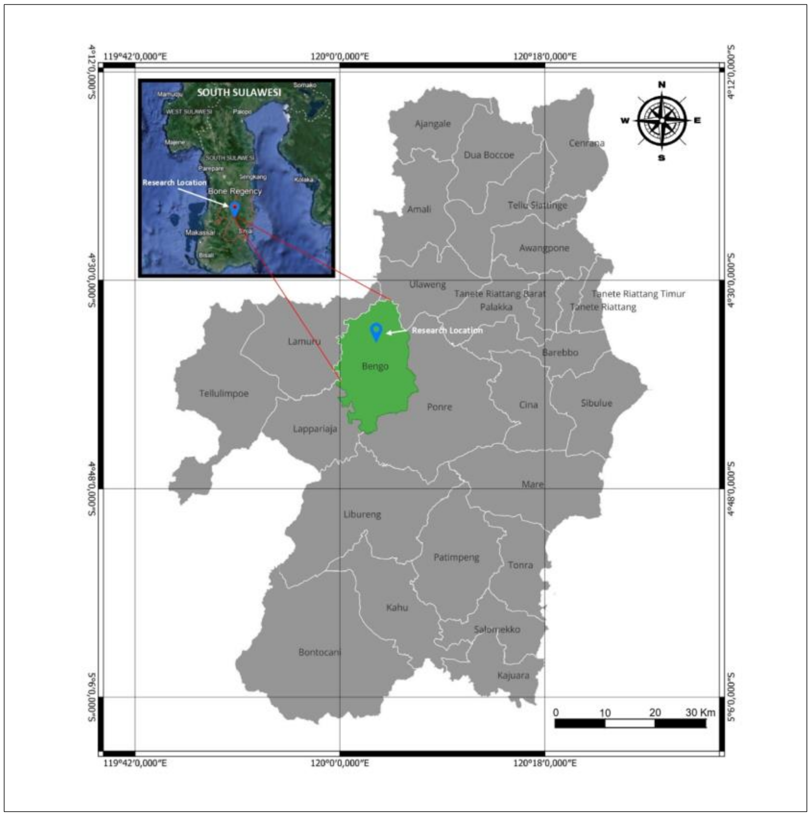

Figure 1. Map of research location

2.3. Canopy cover data

Canopy level data has been determined using image data captured using the camera. Image canopy cover has been taken perpendicularly from the bottom with a canopy distance between 3 to 7 m. The location of the data has been distributed at seven points where the canopy cover is different. The image data has then been processed using MATLAB version 7.6.0 (The MathWorks, Inc). Canopy cover identified by closure approach.

2.4. Splash erosion data

Splash erosion was measured directly in the field (Faisol & Mashudi, 2023) based on the depth of spreading and displacement of the soil due to the blowing of rainwater The amount of splash erosion was obtained based on the thickness measurement of eroded soil layer around the bottle cap installed in reverse (bottle cap method) (Hudson, 1993) at each location in up to five pieces. The method applied in this study has a principle similar to the Splash Cups Method used by several researchers such as (Beguería *et al*., 2015; Fernández-Raga *et al*., 2010, 2019; Geißler *et al*., 2012; Nanko *et al*., 2008). Bottle cap was plugged into the ground until the surface of the bottle cap is level to the ground level. Position of placing the bottle cap was carried out randomly under the canopy will be measured of the splash erosion (Figure 2). Soil surface on the inside of the bottle cap is protected from rain drops so that the bottle surface level does not change. The difference in surface height of the bottle with the soil surface is the eroded soil depth. Eroded soil was measured using a Vernier Caliper and was done after each rain event and then averaged. The average eroded soil thickness is associated with rainfall in any type of canopy cover.

Bulk density measurement was done by taking of three undisturbed soil samples using the ring sample at the study sites. The soil samples analyzed were surface soil to a depth of 5 cm, using the ring sample method (the classical steel cylinder method) (Xu *et al*., 2016). Bulk density data was used to determine the potential of splash erosion in ton/ha.

Figure 2. Measurement of splash erosion in field

3. RESULTS AND DISCUSSION

3.1. Rainfall and Weather

Rainfall measurements were done at the experimental site. It is intended that the rainfall data obtained is the real data that occurred at the location of the experiment. Since there is no rainfall station at the study site, the measurement was done using the self-assembled Rainfall recorders (Figure 3).

Measurements of splash erosion were carried out 46 times with a minimum rainfall of 0.28 mm/day and a maximum of 97.04 mm/day. High rainfall erosiveness affects the great erosion occurring (Angulo-Martínez *et al*., 2012), especially if rare land cover (Ghahramani *et al*., 2011). The average rainfall in the last three years (2019, 2020, 2021) at the research site was 3221 mm/year (BPS, 2020; BPS, 2021; BPS, 2022) or high (Ballabio *et al*., 2017). Thus, the cacao cultivation field at the study site is very susceptible to erosion where crop management, especially protective crops, does not consider erosion control.

Figure 3. Rainfall recorders

3.2. Canopy Cover

In order to know the percentage of canopy cover at the location of observation done data processing (image of canopy cover at observation location) using MATLAB software. The results of image data processing (Figure 4). The percentage of the black area represents the part covered by the plant canopy. The white area represents the throughfall. The percentages of canopy cover obtained from MATLAB tool box are shown in (Table 1).

The data in Table 1 indicate that canopy cover varies between 70.5% - 89.8% and was different at each observation location. There were differences in shade density at different locations. The level of canopy cover has an important role in the hydrological process (Asdak, 2014). Good soil cover vegetation (dense forest) can eliminate the effects of rain and topography on erosion (Satriawan, 2012).

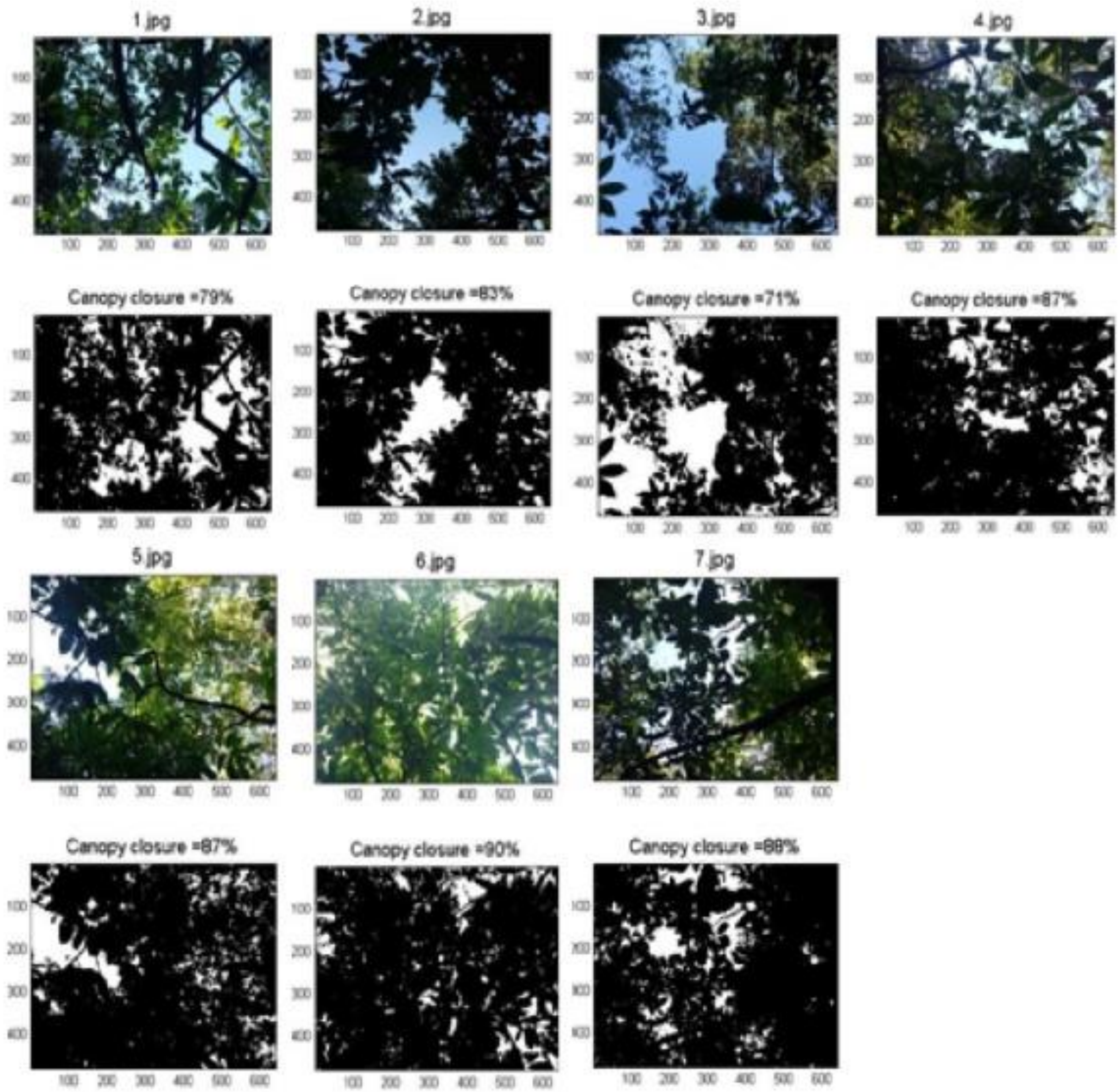

Figure 4. Canopy cover as result of image data processing with MATLAB

Table 1. Percentage of canopy cover obtained through command windows MATLAB

Measurement location	Canopy cover (%)
1	78.88
2	83.26
3	70.50
4	86.81
5	87.21
6	89.80
7	88.42

3.3. The result of splash Erosion Measurement

Data were collected at 7 locations with treatment following farmer system such as litter cleansing. Then the bottle cap was evenly distributed at the site to anticipate non-diversity at some locations. Based on the data obtained in the seven locations with different percentage of canopy cover, it was found that the splash erosion was also different. At locations with canopy cover percentage of 70.51, 78.89, 83.27, 86.81, 87.23, 88.43, and 89.81% were average splash erosion at 2,04, 1.74, 1.72, 1.59, 1.58, 1.37 and 1.29 mm, respectively. The trend of the data is shown in Figure 5, where the relationship between the percentage of canopy cover and splash erosion is non-linear (Ghahramani *et al*., 2011) or the sigmoid function relationship (model Ratkowsky). The greater the canopy cover, the bigger the interception. The rainwater intercepted on the leaves of the plants losses much of its kinetic energy such that its ability to cause splash erosion reduces significantly. In addition, interception of rain by vegetation reduces the amount of water that reaches the soil so that the flow of the surface decreases and reduces the destructive power of rain falling grains upon the soil (Satriawan, 2012).

The effect of rainfall on splash erosion can be seen in Figure 6. We can see the relationship between canopy cover and splash erosion on three different rainfall that is 2.38, 4.87, and 13.14 mm/day, respectively. There is a positive correlation between the amount of rainfall and the splash erosion. As (Arsyad, 2010) indicated, the greater the rainfall, the bigger the grain size of rainfall. This author also indicated that rain grain size is positively correlate to the mass and speed of rain grains, so that it also correlate positively to the kinetic energy of the rain grain which is the main cause of splash erosion (Zambon *et al*., 2021). Further Ma *et al*. (2015) stated that the high intensity of rainfall will reflect the amount of kinetic energy produced that can determine the size of the erosion to be generated. In addition to the kinetic energy of rain, the covering of the ground surface by the canopy is also covered by splash erosion (Wang *et al*., 2020). Differences in rain intensity under the canopy are the main cause of different spark erosion. Ghahramani *et al*. (2011) was also states that the erosion that occurs was greater in rare canopy closures or canopy cover by vegetation reduces erosion (Harliando *et al*., 2023). Beer *et al*. (1998) suggests that canopy cover plays a major role in soil protection against erosion.

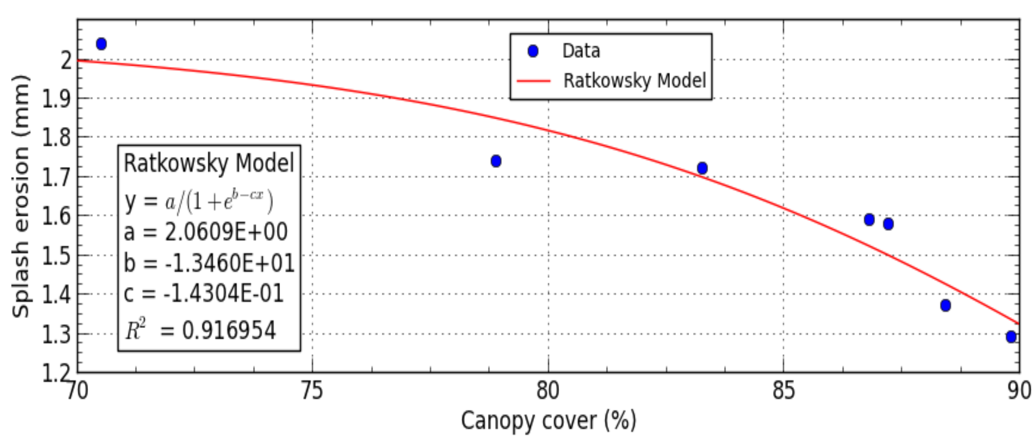

Figure 5. The relationship of canopy cover with splash erosion

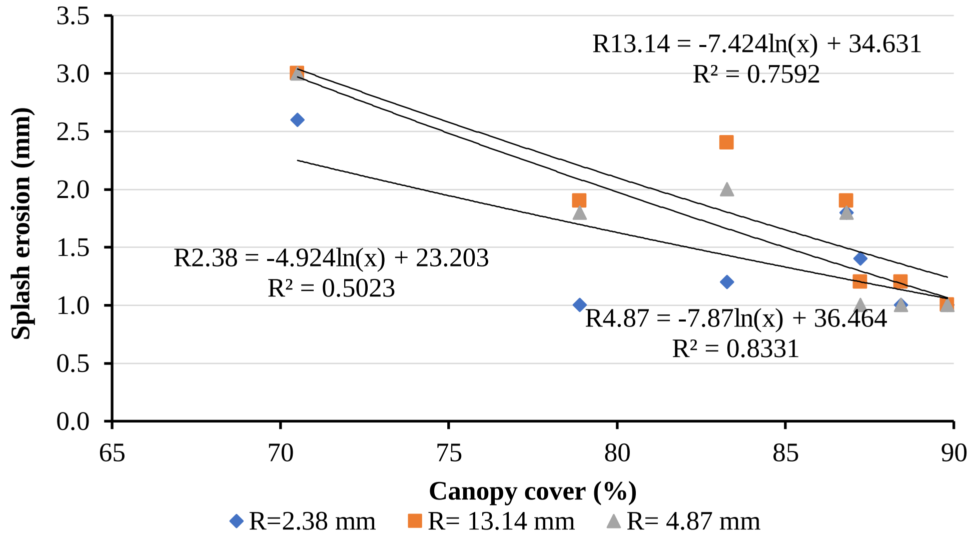

Figure 6. Relationship between canopy cover to erosion at some rainfall level

Figure 7. Conditions of canopy cover at locations with a closure of 78.88%

However, in the canopy area of 78.88% (Figure 7) there was a decrease in erosion thickness at all levels of rainfall (high, medium or low). The protective plants have a narrow leaf so that breaks raindrops that cause the mass of rain drops. Reduction of rain grain mass causes the kinetic energy of rain to fall. The reduction of kinetic energy due to interception by plant canopy contributes to the decrease of splash erosion (Ma *et al*., 2015).

3.4. The relationship between rainfall and canopy cover to splash erosion

Splash erosion was measured under stands of cacao and protective crops with similar topography and soil type. The ground was cleared of grass and other ground cover. The level of canopy cover and rainfall varied as factors affecting splash erosion. Rainfall characteristics are one of the major factors affecting splash erosion (Comino *et al*., 2016). In this case, the depth of rainfall does not have a strong influence, but is more affected by maximum rain for a short time up to 1 hour (Nanko *et al*., 2008) and the splash detachment will decrease with increasing rainfall (Ekwue & Seepersad, 2015). When the intensity of rain increases, interception of the forest canopy decreases (Bahmani *et al*., 2012) so that erosion increases (Fernández-Raga *et al*., 2019). The heterogeneous spatial effects on individual plants increase with increasing rainfall (Park & Cameron, 2008). The largest rainfall interception occurs in small rainfall and decreases in large rainfall (Xiao *et al*., 1998).

The relationship between rainfall and the depth of splash erosion tends to be directly proportional and non-linear function at high intensity (Mohamadi & Kavian, 2015). Large rainfall causes a small interception so that throughfall is greater. However, the relationship between shade conditions to erosion does not occur clearly because the effects on rainfall interception are determined by several factors (Figure 8) such as single or mixed vegetation (Hall & Calder, 1993), vegetation types (Geißler *et al*., 2012; Venkatraman & Ashwath, 2016) and rainfall and rainy season conditions (Ghahramani *et al*., 2011). Even in certain conditions, the splash erosion in the forest is greater than the open environment (Liu *et al*., 2016).

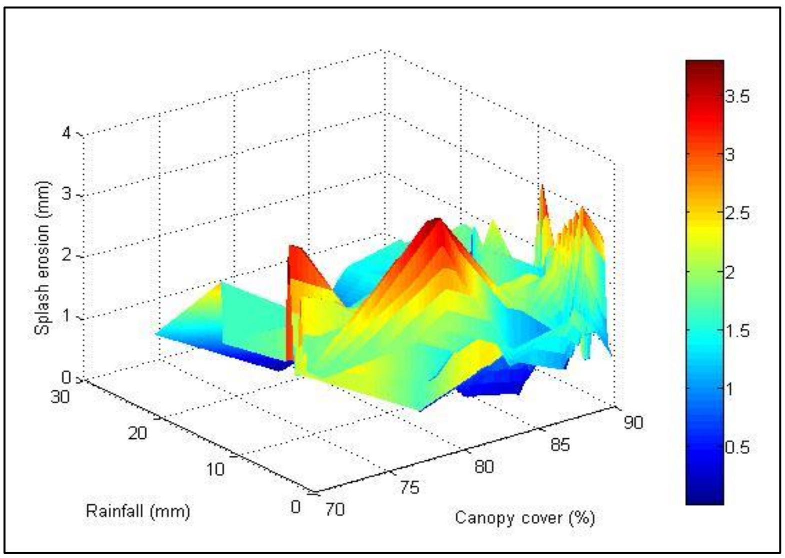

Figure 8. Relationship between the canopy cover, depth of rainfall and depth of splash erosion

4. CONCLUSIONS

The percentage of plant canopy cover on cacao field has non-linear relationship or sigmoid function to splash erosion and the magnitude is inversely proportional. In addition to the percentage of canopy cover, splash erosion on cacao fields was also affected by the depth of the rainfall and the area of the leaves of the protective plants. The size of narrow protective leaves can reduce the splash erosion because it decreases the size of the rainfall to soil, so that the mass of rain grains is reduced. The reduction in rain grain mass causes the kinetic energy of rain to decrease as a cause of splash erosion. In addition, the decrease in kinetic energy of rain is also caused by the interception of rain on the plant canopy.

Acknowledgements

Our gratitude to the Directorate of Research and Community Services, Ministry of Research, Technology and Higher Education, for research funds provided to the research team through Hasanuddin University.

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