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SURFACE RUNOFF AND EROSION FROM AGROFORESTRY LAND USE TYPES

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ABSTRACT

Various systems of land use have a different capability in its function as a hydrological parameter and erosion. Surface runoff and erosion depends on the type of land use applied. The objective of this research was to find out the rate of surface runoff and erosion from agroforestry land use types at Miu sub-watershed, Palu watershed, Central Sulawesi, Indonesia, 2016. The method used was the multislot divisor on a plot measured 22 m x 2 m with 3 repetitions in 3 types of land use with a slope of 25-40% (steep). The result showsed that the largest surface runoff amounted from non-agroforestry land use type (10-year-old pure cocoa) by 72.674 liters/ha, followed by teak tree- and cocoa based agroforestry system aged 10 years old amounting to 59.815 liters/ha and the smallest is Candlenut tree-and cocoa-based agroforestry system aged 10 years old by 45.983 liters/ha. The highest erosion was recorded from non-agroforestry land use type (10-year-old pure cocoa) by 4,125 grams/ha, followed by teak tree- and cocoa based agroforestry system aged 10 years old amounting to 2,749 grams/ha and candlenut- and cocoa-based agroforestry system aged 10 years old by 1,280 grams/ha. Candlenut- and cocoa-based agroforestry system aged 10 was more effective to manage surface runoff and erosion rate.

Key words: Surface runoff; erosion; watershed; land use; agroforestry.

INTRODUCTION

The change of land use in the area of watershed, especially at the headstream, do not only produce effect in the area where the activities happens, but also at the downstream in the form of fluctuation of discharge, sediment transport and dissolved material on the system of the other water flow. As a result, land use system applied will affect the aspect of hydrology, among other things, quantity, quality, and continuity of watershed. Forest conversion means reducing the hydrological function of watershed as the result of the increase of erosion and sedimentation which causes water holding capacity decreases (Andreassian, 2004; Masnang *et al*., 2014).

One of the types of land use in the area of Miu Sub-watershed is the land use in the form of a cocoa plantation and other seasonal crops. According to Fadil *et.al.*, (2013), plant's characteristic can increase the rate of surface runoff and erosion caused by the occurrence of cover crop vegetation change. Cocoa productivity decrement is supposed to be related to the plant's age, the decrement of soil fertility level as the result of the nutrient transfer and topsoil loss which is rich of the nutrient element caused by erosion. Nutrient element transported with surface runoff and erosion is the biggest factor of nutrient loss which decreases soil fertility and plant productivity (Fadhil *et al*., 2013).

The result of pre-research in the area of Lore Lindu National Park (Lariang Tengah sub-sub watersheds) also the headstream of Palu watershed, that the conditions of erosion far above the value of etol (tolerable erosion). The lowest level of erosion is 197 ton/ha/year and the highest is 2,210 ton/ha/year, while the Etol value range from 19.6-51.2 ton/ha/year (Naharuddin, 2004).

Land in the area of Miu-sub watersheds has a big potential to be converted as agroforestry. Various systems of land use have different capability in its function as hydrological parameter of surface runoff and erosion, it truly depends on the crown diameter, crown structure and type composition and the existing biodiversity and its management (Geibler *et al.*, 2013; Goebes *et al.*, 2015).

Erosion brings surface soil which is commonly more fertile, full of organic material and trace element so that it causes trace element loss, nutrient relocation and weakening of agricultural productivity (Fuadi *et al.*, 2014). The destruction of soil particles will cause macro soil pore blockage to inhibit soil water infiltration, consequently increase of surface runoff (Van Noordwijk *et al*., 2004).

The rain falling to vegetation is hold up by the plant crown for a particular period of time. Some of water evaporates and rest reaches to the ground because of dripping through fall or flowing down through stem until reach stemflow. Part of precipitation that does not reaches the ground is called interception, it is decided by the characteristic of stand and rain fall (Sadeghi *et al.* 2015, Naharuddin *et al*., 2016). Precipitation reaching the soil is the enumeration of throughfall and stemflow (Germer *et al.*, 2010). That precipitation will infiltrate later on, and the remaining will flow through surface runoff and bring the material of soil particle (erosion). Vegetation can decrease erosion by intercepting rain fall to minimize the kinetic energy of raindrop. Vegetation is also able to increase land infiltration by repairing physicochemical characteristic, to decrease over flow and erosion energy, and to trap loss sediment particle (Dong *et al*., 2015).

The objective of this research was to find out the level of surface runoff and erosion in 3 types of agroforestry land use in Miu Sub-watershed, Palu Watershed, Central Sulawesi, Indonesia.

MATERIALS AND METHODS

Location : This study was conducted on 3 types of land use namely; candlenut tree-and cocoa-based agroforestry system aged 10 years old, teak tree- and cocoa based agroforestry system aged 10 years old and non-agroforestry land use type (10-year-old pure cocoa) of the downstream area of Miu sub-watershed, Palu watershed which is located between 1190 49' 31,95" – 1200 03' 18,11" East longitude and 010 11' 20,23" – 010 35' 25,83" South latitude of 300 m above the sea level. It is administratively located at Gumbasa sub district, Sigi district, Central Sulawesi, Indonesia. The study was conducted for eight months, from April 2016-November 2016.

Research Procedure: Surface runoff measurement and erosion were conducted 30 times of rain through Multislot Divisor (Masnang *et al*., 2014) on a plot measured 22 m x 2 m with 3 repetitions in 3 types of land use with a slope of 25-40% (steep). The measurement was done at 7 a.m if the previous day rain fell and caused surface runoff. The amount of eroded erosion soil was determined by the sample of sediment of every plot, the size of the tank with a diameter of 57.5 cm, and placed at the bottom of the plot (in a tank of surface runoff and erosion) when the rain came, and then was dried in an oven (105^{0}C) until its weight became constant, and the last was weighed to know the example weight of sediment. The data of the amount of rain fall during the observation was collected through ombrometer rain gauge. In addition to surface runoff and erosion, physical characteristic was also measured by collecting a sample of soil using ring sample in a systematic sampling in a plot of erosion for each agroforestry system at the depth of 0-10 cm (top soil).

Data Analysis: Surface runoff was calculated by the equation of Schwab *et al.* (1997)

$$Vsr = V1 + 11\ V2$$

Description: Vsr: Volume of surface runoff total (L), V1: surface runoff volume in water bucket I (L), V2: surface runoff volume in water bucket II (L)

The amount of erosion soil was counted by the equation of Schwab *et al.* (1997).

$$W_{e}r = W_{1} + W_{2}$$

Description: Wer: erosion soil weight (g), W1 and W2: soil weight in water bucket I and II (g), W1 and W2= Ve / Vs x (Wfpd - Wfp), Ve : water volume in bucket (L), Vs : filtered-water volume (L), Wfpd : weight of filter paper and the deposit (g), Wfp : weight of filter paper (g)

In order to know the rain fall over the surface runoff and erosion in 3 types of land use, an analysis of simple regression analysis was used. The chosen model was those with the highest and logical determination coefficient (R^2). From the data sheets, it can be found the relationship trend so that can help to choose the model.

RESULTS AND DISCUSSION

Soil Physical Characteristic: The analysis of the soil physical characteristics in 3 types of land use showed s that the type of land use did not influence soil physical characteristics.

Soil texture in 3 types of land use commonly showed s an equality with the value of silty clay loam with the percentage of clay fraction is higher than the sand or dust (Table 2). The ratio of sand and dust content to the clay content as the index of soil erodibility. This is an important criterion to suppose the sensitivity of soil to erosion. Soil with a low ratio (high clay percentage) commonly has low sensitivity to the erosion compared to the other ones with a high ratio (low clay percentage) (Utomo, 1994).

The content of the organic material is seen in the research location with high average criteria in 2 types of land use except for non-agroforestry land use type (10-year-old pure cocoa). The influence of organic material is very important, it is in line with Arsyad, (2010) idea that organic materials can reduce surface runoff mainly in the form of surface runoff and erosion deceleration, infiltration enhancement, and soil aggregate stabilization. In general, the soil quality described by parameter indicator of soil physical characteristics (Table 2), shows that soil quality is not only determined by certain soil quality indicators, but some of those indicators influence each other to determine their quality. The change of land use types from candlenut- and cocoa-based agroforestry system and teak tree-cocoa-based agroforestry system directly change the vegetation composition of plant species but do not simultaneously degrade the quality of soil physical characteristics. It is line with Wardah, (2008) who concluded that the conversion of natural forest into a field which is subsequently converted into plantation or firstly allowed to lie follow into a young secondary forest and then built the plantation land directly change the structure and composition plant species and plant biomass (above, below and at ground level), but not drastically decreasing soil quality (physical, chemical and biological).

Table 1. Physical Soil Characteristics.

Land Use Type	Parameter	Value	Criteria
Candlenut tree-and cocoa-based agroforestry system aged 10 years old	Texture	Silty clay loam	-
	% sand: 7.2		
	% dust: 39.5		
	% clay : 53.3		
	Infiltration ml/cm^2/minute	0.32	Slow
	Unit Weight (UW) (g/cm^3)	1.6	
	Organic materials (% BO)	82%	High
Teak tree-and cocoa based agroforestry system aged 10 years old	Texture	Silty clay loam	-
	% sand: 6.7		
	% dust: 37.8		
	% clay : 55.5		
	Infiltration ml/cm^2/minute	0.25	Slow
	Unit Weight (UW) (g/cm^3)	1.9	
	Organic materials (% BO)	75%	High
Non agroforestry (10-year-old pure cocoa)	Texture	Silty clay loam	-
	% sand: 6.2		
	% dust: 35.4		
	% clay: 52.8		
	Infiltration ml/cm^2/minute	0.21	Slow
	Unit Weight (UW) (g/cm^3)	1.3	
	Organic materials (% BO)	22%	Low

Infiltration velocity analysis showed s that 3 types of land use have poor soil ability to pass water since the area was dominated by the fraction of silty clay loam having smaller soil particle.

Surface Runoff: The amount of surface runoff occurred is determined by the amount of water that is stored in the container in the erosion plot during the rain.

Table 2. Surface Runoff on Various Types of Agroforestry Land Use.

Land Use Type	Surface Runoff liters/ha	Rain Fall (mm)
Candlenut- and cocoa-based agroforestry system aged 10 years old	45.983	528
Teak tree- and cocoa based agroforestry system aged 10 years old	59.815	528
Non-agroforestry (10-year-old pure cocoa)	72.674	528

Surface runoff of non-agroforestry land use type (10-year-old pure cocoa) was 72.674 liters/ha, followed by teak tree- and cocoa-based agroforestry system aged 10 years old by 59.815 liters/ha and the lowest is candlenut tree- and cocoa-based agroforestry system aged 10 years old by 45.983 liters/ha (Table 3). The high surface runoff of non-agroforestry land use type (10-year-old pure cocoa) was probably caused by the low organic material. It is in line with the study conducted by Darmayanti and Solikin, (2013) that one of the determining factors of surface runoff and infiltration velocity is the existence of organic material on the ground. In addition to organic material, vegetation constituent as the raw material of also influences the high of surface runoff.

Relationship Between Rain Fall and Surface Runoff: Surface runoff in 3 types of land use observed during the research period is the water flowing above ground which truly depends on the amount of rain fall of per time unit.

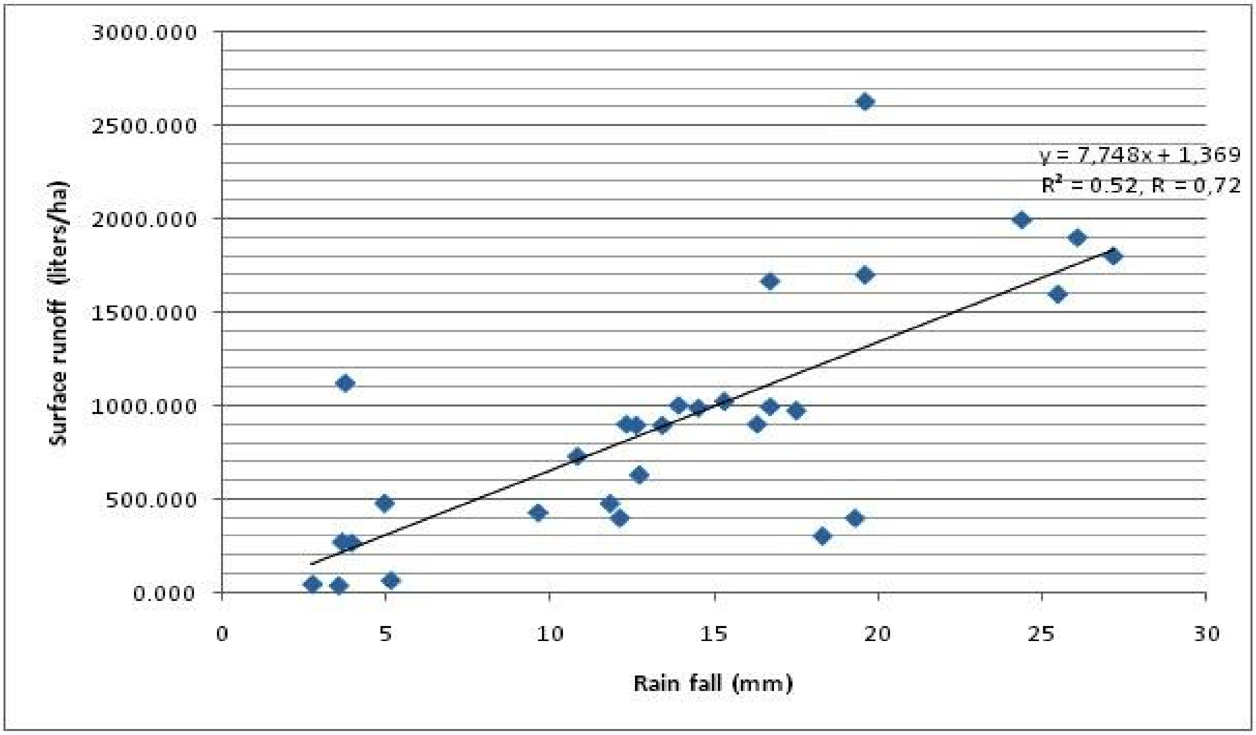

Fig. 1. Relationship between rain fall and surface runoff in candlenut tree-and cocoa-based agroforestry system aged 10 years old

Fig. 1 indicates that 52% of surface runoff of candlenut- and cocoa-based-agroforestry system aged 10 years old was influenced by rain fall while 48% by other environmental factors with the value of R= 0.72 (strong).

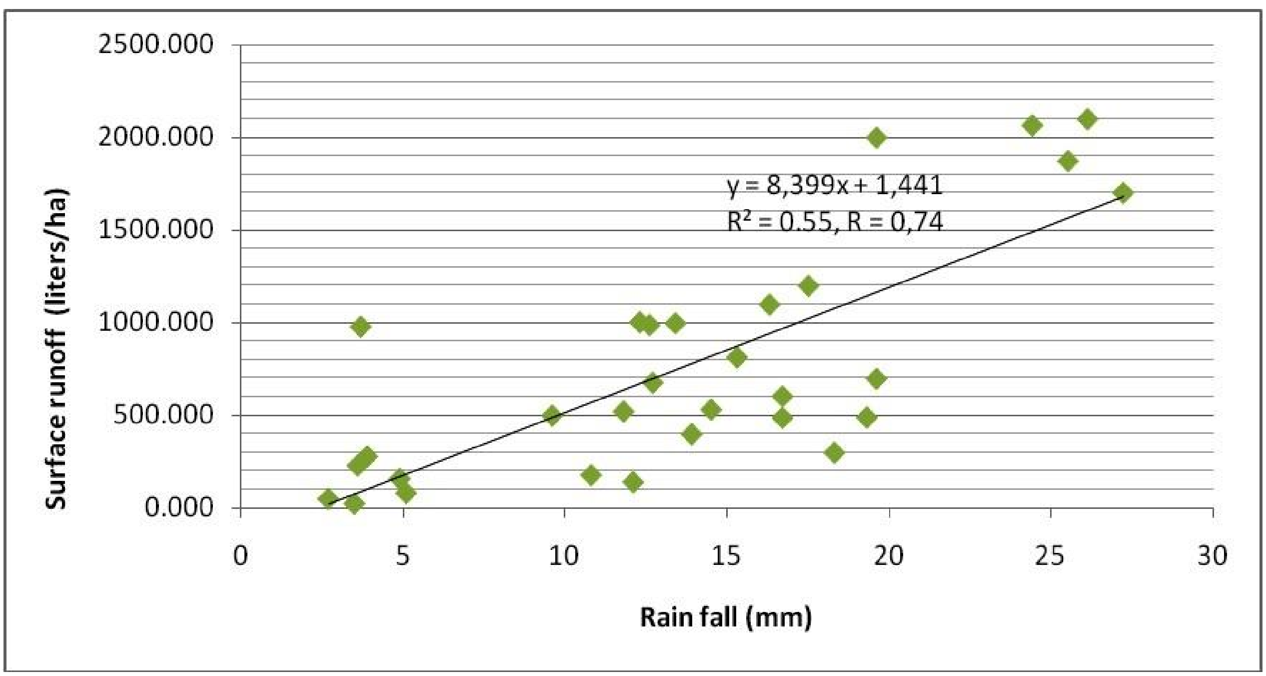

Fig. 2. Relationship between rain fall and surface runoff in teak tree- and cocoa-based-agroforestry system aged 10 years old

Fig. 2 Indicates that 55% of the surface runoff occurred at the teak tree- and cocoa-based-agroforestry system aged 10 years old was affected by rainfall while 45% was influenced by other environmental factors with a value of R = 0.74 (strong).

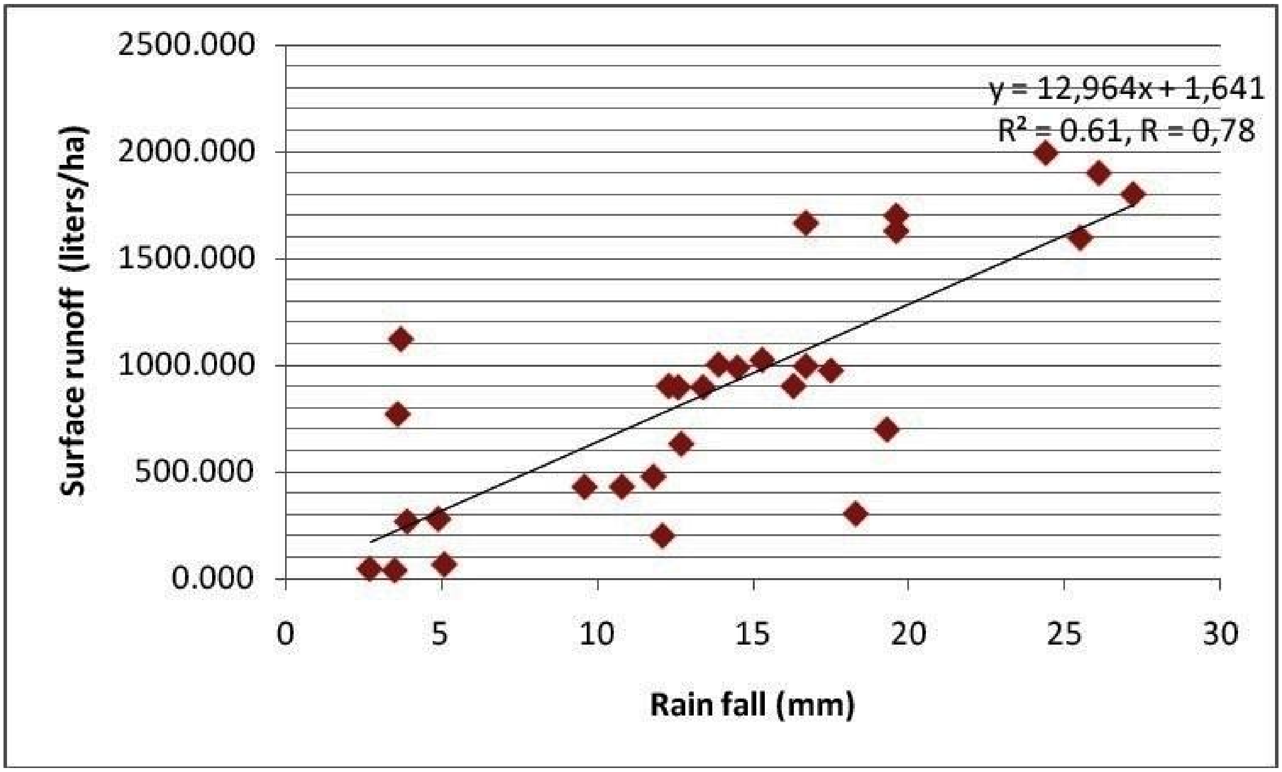

Fig. 3. Relationship between rain fall and surface runoff in non agroforestry land use type (10-year-old-pure cocoa)

Fig. 3 Indicates 61% of the surface runoff occurring at non-agroforestry land use type (10-year-old pure cocoa) was affected by rainfall and 39% influenced by other environmental factors with R = 0.78 (strong).

Determination coefficient value of the influence of rainfall over other surface runoff thought to have an effect on the increase of infiltration velocity. The tight cover can lead to the increase of ground-based biological activity due to the availability of organic materials and environmental improvements (micro climate and moisture), soil biological activity has a positive influence over the soil porosity and infiltration velocity enhancement.

Haridjaja *et al.*, (1991) stated that rain falling above ground will be infiltrated into the soil after being retained by the crown's plant. This infiltration process will occur until the field capacity is fulfilled. If the field capacity has been fulfilled and the rain is still going on, then the excess rain water remains infiltrated into percolation water and the other water will fill the basin or depression deposit. Furthermore, after depression deposits are fulfilled, the excess water will become a pool of water or surface mooring and before it becomes a surface stream, the excess water will evaporate even though the amount is very small.

Erosion: Erosion is the event of moving or transporting parts of the soil due to the interaction of work between climate factors, topography, vegetation, and human to the soil.

Table 4. Erosion on Various Types of Agroforestry Land Use Type.

Land Use Type	Erosion grams/ha	Rain Fall (mm)
Candlenut-and cocoa-based agroforestry system aged 10 years old	1,280	528
Teak tree- and cocoa based agroforestry system aged 10 years old	2,749	528
Non-agroforestry (10-year-old pure cocoa)	4,125	528

Table 4 indicated that at the same rainfall i.e 528 mm, the largest erosion was in non-agroforestry land use type (10-year-old pure cocoa) by 4,125 grams/ha followed by teak tree-and cocoa based agroforestry system aged 10 years old by 2,749 grams/ha and candlenut tree-and cocoa-based agroforestry system aged 10 years old by 1,280 grams/ha. The tendency for the extent of erosion occurred is consistent with what proposed by (Messing *et al*., (2003); Vahabi and Nikkami, (2008); Zuazo and Pleguezuelo, (2008) that factors affecting soil erosion include precipitation, vegetation, and slope. Rainfall energy is identified as the main cause of erosion, which tends to occur when the soil lacks a vegetative protective layer (Zuazo and Pleguezuelo, 2008).

The present results are supportive to findings of Asdak, (2006) he concluded that surface flow and surface erosion increased with the reduction of plants. This research showed s that the effect of land use on the agroforestry system to non-agroforestry was an important factor affecting the extent of erosion. This was also supported by the results of the research of Suratman, (2005) that the greatest erosion hazard level was in hilly and mountainous areas that have been utilized as dryland farming. Rainwater ability as the erosion causal is sourced from the rate and distribution of raindrops, where those two indicators affect the magnitude of the rainwater kinetic energy.

Relationship between Rainfall and Erosion: The result shows that the relationship between rainfall and erosion has a strong (positive) relationship in 3 types of land use namely; candlenut tree-and cocoa-based agroforestry system aged 10 years old, teak tree-and cocoa based agroforestry system aged 10 years old and non-agroforestry land use type (10-year-old pure cocoa). It is explained further in , (Fig. 4, 5 and 6).

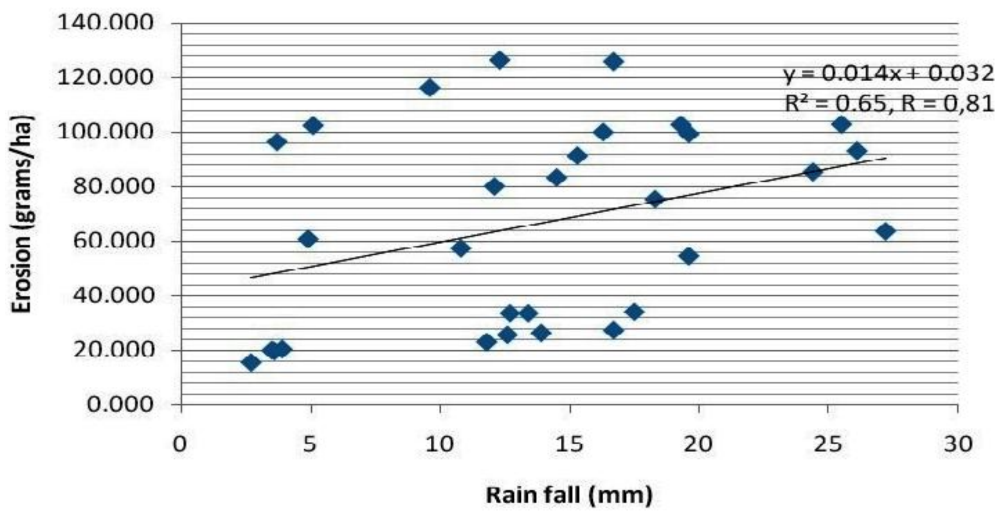

Fig. 4. Relationship between rainfall and erosion in candlenut tree-and cocoa-based agroforestry system aged 10 years old

The analysis result of Fig. 4 indicates that the magnitude of surface erosion was 65% determined by the rainfall conditions in candlenut tree-and cocoa-based agroforestry system aged 10 years old.

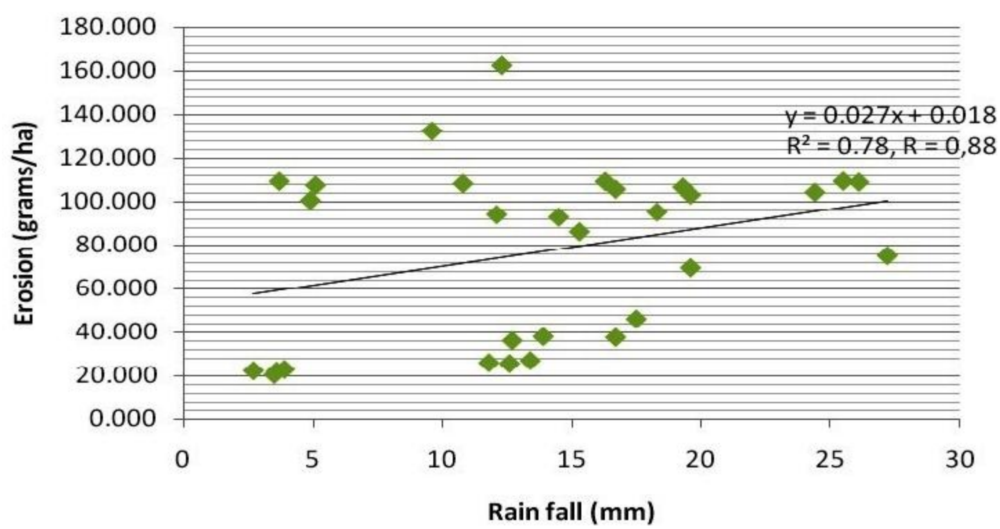

Fig. 5. Relationship between rainfall and erosion in Teak tree- and cocoa based agroforestry system aged 10 years old

The coefficient value of teak tree- and cocoa based agroforestry system aged 10 years old is 0.88 and the value of determination coefficient is 0.78. This means that the magnitude of surface erosion is 78% determined by rainfall conditions (Fig. 5).

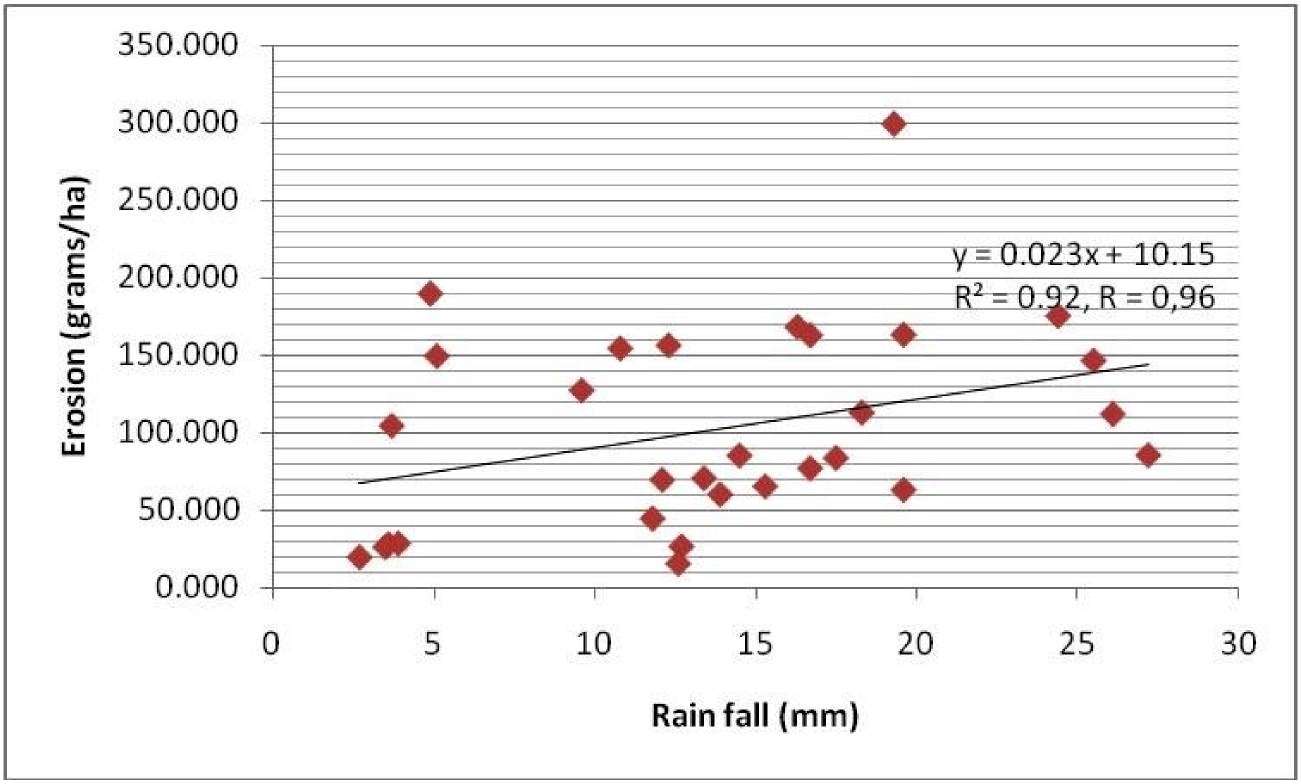

Fig. 6. Relationship between rainfall and erosion in Non-agroforestry (10-year-old pure cocoa)

The correlation coefficient of non-agroforestry land use type (10-year-old pure cocoa) is 0.95 and determination coefficient is 0.92. This means that the magnitude of surface erosion is 92% determined by rainfall conditions (Fig. 6).

Based on (Fig.4, 5 and 6) correlation coefficient (very strong) relationship between rainfall and erosion on all types of land use, was supported by Arsyad (2010), he concluded climatic conditions determine the tendency of erosion to reflect the state of rainfall patterns. In addition to rainfall patterns, types, and vegetation growth, as well as soil types, also affect erosion in the tropics. Rainfall is the most influential factor for erosion in Indonesia, in this case rainfall, intensity, and rain distribution determine the strength of rain dispersion to a soil, the amount, and speed of surface runoff and erosion.

The agroforestry land use system compared to non-agroforestry (pure cocoa) is more effective in controlling surface runoff and erosion, in line with research conducted by Udawatta *et al.* (2002) the treatment of agroforestry land use can suppress 10% surface runoff and erosion 19%.

Conclusion: Candlenut tree-and cocoa-based agroforestry system aged 10 years old was more effective in controlling surface runoff and erosion than the teak tree- and cocoa based agroforestry system aged 10 years old and non-agroforestry land use type (10-year old pure cocoa). Land use, agroforestry systems need to be done in the farm system in order to minimize the occurrence of surface runoff and erosion. The increase in surface runoff in line with the amount of erosion that occurs in 3 types of land use ie; candlenut tree-and cocoa-based agroforestry system aged 10 years old, teak tree- and cocoa based agroforestry system aged 10 years old and non-agroforestry land use type (10-year-old pure cocoa)

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