

Effect of land management models on soil erosion in wet tropical cacao plantations in Indonesia

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ABSTRACT

Indonesia is one of the world's largest cocoa exporters and is located in a tropical wet region. In tropical regions, surface run off is a major factor behind the occurrence of erosion-driven land degradation. Both land slope and land cover influence the magnitude of surface run off and soil erosion. Cocoa plants are generally cultivated on land that has a steep slope without regard to existing land cover conditions resulting in a susceptibility to soil erosion. The purpose of this research was to measure the influence of land management models used in cocoa plantations on soil erosion caused by surface run off. Soil erosion measurements were performed *in situ* using soil erosion plot models. Soil erosion plots were constructed in six different land conditions based on a combination of land slope (22 – 60%) and land cover or litter distribution (50 – 100%). Results of this researched showed that: 1) erosion was an exponential function of rainfall at all land slopes; 2) the amount of shade influenced the initial soil moisture content; and 3) land cover is the primary factor behind soil erosion in cocoa plantation.

Key words : Erosion, Cocoa land management model, Exponential function

Introduction

Indonesia is one of the world's largest exporters of cocoa ranking below only to the Ivory Coast and Ghana (BP3, 2014; Mattyasovszky, 2015). Cocoa thrives in regions with high humidity and annual rainfall of 1,500 – 2,000 mm and less than three dry months per year (ICCO, 2013). Indonesia is located in a tropical wet zone (BPS, 2013) with annual rainfall greater than 1,500 mm, short dry season, and high air humidity (Michael, 2001). Due to this climatic suitability, cocoa is grown in all parts of Indonesia.

Cocoa plant cultivation is driven by its high economic value in comparison to other agricultural commodities. In addition, almost all regions of Indonesia are suitable for cocoa cultivation as the plant

does not require specific land conditions for its growth. Hence the the cocoa growing area in the country continuously increase. However, the expansion of land used for growing cocoa plants has not resulted in an increase of production; this is caused by a decrease in land productivity of only 0.4 – 0.6ton/ha compared to potential productivity of 1 – 1.5ton/ha (Anonim, 2012). One factor behind this drop in productivity is the degradation of soil quality as a result of erosion (Li *et al.*, 2013). Accordingly, the preservation of land quality is crucial as the productivity of cocoa plant production in South Sulawesi is influenced by soil fertility among other factors.

Surface run off plays a vital role in the degradation of land quality: it is a major factor behind the occurrence of soil erosion in tropical regions. Every

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land management model is unique in the way it influences soil erosion (Arsyad, 2006). Proper soil and vegetation management can reduce soil erosion up to 99% (Labrière, *et al.*, 2015) and land cover is the most crucial element in erosion models (Ekpenyong, 2013). In addition to management models, different types of vegetation have their unique influence on surface run off (Musa *et al.*, 2013).

Generally, cocoa is grown by small, locally-run, community-managed businesses (Rubiyo and Siswanto, 2012). Cocoa is grown on lands that have slopes ranging from very small to over 40% (Liyanda *et al.*, 2013). The over-pruning and excessive weeding of land where cocoa is cultivated lead to soil that is vulnerable to the physical effects of raindrop and surface run off scour.

Soil erosion is generally measured by using a mathematical approach. However, this method is simply an approach and does not provide actual results. Therefore, direct measurements must be performed in situ to accurately determine the influence of land management models and types of vegetation on soil erosion. Measurements were performed using soil erosion plots (Haggard, *et al.*, 2005; Akbarimehr and Naghdi, 2012; Sensoy and Kara, 2014). Results collected were also used to determine erosion coefficients.

This research was performed in situ with direct measurements, thus the data collected can be directly referenced by policy makers as a basis for soil preservation policy in attempts to guarantee continued productivity in agricultural activities. Therefore, this research was aimed to determine the effect of land slope, canopy and land cover by vegetation in cocoa plantations on soil erosion.

Materials and Methods

Field Description

Experiments were conducted during the rainy season 2012 in local cocoa farmers' plantations in the District of Bone, South Sulawesi Province, Indonesia. Six locations with differing levels of land slope and land cover were used in this trial. Measurement plots were constructed at each of these six locations to determine the surface run off and erosion at each location. In addition, supporting data related to land slope and rainfall levels throughout the duration of this research were also collected. Rainfall measuring tools were placed at each research location to

minimalize the bias of measurement results with actual values collected in situ.

Land slope

Land slope was determined by measuring the distance (run) and the difference in height (rise) between two points using waterpass. The measurement data were used to calculate the percentage of slope using the following equation:

$$\text{Slope} = \frac{\text{rise (m)}}{\text{run (m)}} \times 100\%$$

Shadow-covered area

The shadow-covered area was determined by capturing photos of soil surface conditions on clear weather at 12:00 local time. The percentage of shadow-covered area was calculated by comparing the area of land that did not receive sunlight to total land area.

Field Experiment Design

Surface run off data was obtained from surface run off measurement results collected from each plot. Six plots were constructed each varying in land slope, shadow-covered area, and land cover rate. These plots with their respective land conditions shall heretofore be referred to as cocoa land management models. The following is a list of all land conditions measured at each plot (Table 1).

Model plots were created by constructing plot dividers from plastic (tarpaulin). The purpose of these dividers was to prevent the entrance of water from sources external to the plot. The butt of each divider was buried 10cm into the soil and the exposed 20cm of the divider served as walls to retain run off and total construction was relatively stable. The dividers also worked to prevent seepage of water into or out of the plot. An outlet and pipe were placed at the lower end of each plot to allow the flow of water from the plot to a surface water receptacle. The upper end of the receptacle is covered to prevent rainwater or soil to splash into it.

Manual rainfall monitoring stations were placed beside each of the model plots at a height of 1.5m above ground level. Observation was carried out at the end of every instance of rain. Water collected in the measuring tube was poured into a measuring cup to measure the volume of rain water (V), where the funnel surface area was known. After each mea-

Table 1. Plant shade , land cover, and land slope at each model plot

Plot No.	Outlet Coordinates (LS; BT)	Area (m ²)	Shade area (%)	Land Cover (%)	Land Slope (%)
1	4035'52,4";120002'54,2"	119.05	80	100	22.11
2	4035'53,8";120002'54,3"	123.58	70	80	25.00
3	4035'54,6";120002'56,4"	93.26	75	100	40.10
4	4035'55,7";120002'56,6"	100.22	60	90	53.95
5	4035'54,0";120002'56,6"	100.49	95	100	38.77
6	4035'54,0";120002'58,3"	156.46	95	50	60.56

surement, the receptacle was dried by wiping it with a piece of cloth.

Runnoff water volume and eroded soil mass were determined by using Boix-Fayos's method (Boix-Fayos *et al.*, 2006). Water collected from each surface water receptacle in each model plot was measured to determine the run off water volume. To assess the eroded soil mass, water collected in receptacle was stirred until the sedimentation had dissolved or suspended evenly. Sample of 100 ml of suspension was taken from each receptacle and individually pass through a filter paper. The retained solid in the filter was heated in an oven for 48 h at 105°C before it was weighted.

Data Analysis

Calculating Soil Erosion

Soil erosion is calculated based on the amount of sediment with the following equation:

$$E = \frac{Cap \times Vap \times 10^{-3}}{A}$$

where:

- E = eroded soil (ton/ha)
- Cap = sediment concentration (kg/m³)
- Vap = surface run off volume (m³)
- A = area of land affected by erosion (ha)
- 10⁻³ = conversion value from kg to ton

Calculation of Erosion Coefficient

Surface run off coefficient is calculated by comparing the volume of surface run off to the volume of rainfall (Norbiato *et al.*, 2009)– this is used to calculate the erosion coefficient – or by plotting a graph comparing rainfall and erosion. When using the graph method, the erosion coefficient value can be determined using an equation from data trends. Mathematically, this can be calculated using the surface run off coefficient method (Asdak, 2010; FAO, 2012):

$$K = \frac{\text{surface runoff (mm or cm}^3\text{)}}{\text{rainfall (mm or cm}^3\text{)}}$$

where K = surface run off coefficient

Results

Model Plot Construction

All plots were constructed in the same cocoa plantation, though placed in areas with differing land conditions and vegetation. These variables were intended to discover the influence of vegetation shade and land conditions on surface run off and erosion. Each plot had a different area and shape; the purpose of this was to ensure the physical conditions of each plot were uniform. Thus, the collected data accurately represents the conditions at each plot. The model plot layout and image can be seen in Fig. 1.

Influence of Land Cover on the Quality of Soil moisture and Surface Run off

Changes in soil water content with different levels of land cover and shade during the experiment can be seen in Fig. 2.

Figure 3 expresses the surface run off for several instances of rain at each plot.

Effect of Initial Soil moisture Content on Soil Erosion

At the research locations, initial soil moisture content greatly influenced erosion. The majority of instances of soil erosion occurred as a result of surface run off. In addition, the research locations had relatively good canopy cover and land cover, reducing the erosive effect of kinetic energy from rain fall on the soil surface. This phenomenon is expressed in the following Fig. 4.

Relationship between Rainfall Level and Surface Run off

Surface run off is the primary factor behind erosion.