Research Article

Coconut and Mahogany Plants Based Soil Water Conservation at Volcanic Slopes of Central Java-Indonesia

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Abstract | Vegetative based soil and water conservation is most commonly done by the community to contribute to income improvement at the volcanic slopes in Java Island, Indonesia. Coconut and Mahogany plants have been cultivated as intercrops in most dry-land agricultural fields by many people for different purposes of income generation. The differences in canopy characteristics between the two plants significantly affect the production of runoff. Field evidence is needed to support it as a suitable plant for soil and water conservation efforts. The study was conducted using a field survey method equipped with soil characteristic measurements in the laboratory. The data collection process began with a study of the landscape of the research area which was divided into three zones, namely residual, erosion, and deposition. In each zone, coconut and Mahogany plants were selected with the ideal morphology for measurement of interception, throughfall, and stemflow during rain events. Soil sampling under the plant canopy was used to measure texture, bulk density, particle density, porosity, macro pores, initial soil moisture, and organic matter. Coconut plants are considered better for the purpose of vegetative soil and water conservation than Mahogany. However, Mahogany must be arranged at the upper plot and Coconut at the lower plot to enhance runoff reduction. Coconut can reduce the volume of surface runoff significantly so that the erosion rate becomes smaller. Coconut roots function to stabilize the physical properties of soil which can ensure continuous infiltration and percolation processes during rain events so that the amount of water stored in the soil increases. Those two trees may be planted along the natural drainage canal that is usually located at the edge of dry-land agricultural fields.

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Introduction

Global rainfall patterns in Java-Indonesia is influenced by the presence of a series of west-eastern volcanoes that cross the direction of the monsoon winds. Rainfall events are influenced locally by the body of the volcano so they are orographic. The rainy season generally occurs in October-April when the position of the sun is in the southern hemisphere and the location of Java Island which is south of the equator makes the southern slopes of the volcanic landscape generally have high annual rainfall. The research location is on the southern slope of volcanoes with wavy reliefs and thick deposits of volcanic ash material (Purwaningsih *et al*., 2020). The combination of rainfall conditions, slopes, and thick volcanic ash material makes the threat of erosion a problem for the sustainability of land use, especially for agricultural production activities in general (Rosegrant *et al*., 2009). Water and soil conservation efforts are an absolute necessity for any effort to utilize land resources at the research site and other locations on the slopes of volcanoes in general.

The vegetation cover of the land is one of the determining factors for the amount of rainwater received by the soil. Some of the rain that falls on vegetated does not reach the soil surface directly because it is retained and fills the water storage capacity of plant parts such as plant crowns, stems, and branches (Darmayanti and Fiqa, 2017). Others will pass through the canopy as a throughfall which along with the stemflow reaches the soil surface (Mahasidhi and Prijono, 2021). Stemflow is part of the rain that flows to the soil surface through the stems and twigs of plants. The amount of stemflow is influenced by the type of plant, stem texture, branch density (Ahmed *et al*., 2017) and branching angle (Anand *et al*., 2022). The amount of throughfall is influenced by several factors, including the density of stems and leaves of plants, rainfall, rainfall intensity, and duration of rainfall (Bulcock and Jewit, 2012; Macinnis-Ng *et al*., 2012; Supangat *et al*., 2012). Rainwater retained on plants and does not reach the soil surface is called interception which will evaporate into the air through the evaporation process (Yanez *et al*., 2014; Luna-Robles *et al*., 2019).

The architectural models of trees affect the transformation of rainwater into interception, throughfall, and stemflow. The shape of the plant crown, and the morphology of the surface of stems and leaves affect the ability of plants to retain and redistribute rainwater (Sofiah and Soejono, 2020). Coconut and Mahogany have different architectural models of trees, namely corner and rauh. The corner architectural model has a conical crown so that the stemflow is only concentrated on the main stem. The corner architectural model of tree allows the percentage of stemflow to be greater than the rauh. Rauh is an architectural model of a tree with the characteristics of a monopodial trunk, a rhythmic growth pattern, and forms an orthotropic branching pattern (Ekowati *et al*., 2017). The rauh architectural model produces a small stemflow, because it has many trunk branches.

Rainwater that reaches the ground surface through the process of throughfall and stemflow is called net precipitation and will infiltrate into the soil. This process will continue until the infiltration capacity of soil is fully filled. Saturated infiltration capacity will cause surface runoff. The physical properties of the soil become one of the determining factors for the rate and capacity of infiltration. The physical properties of soil that affect the rate and capacity of infiltration include porosity and soil moisture (Yun *et al*., 2018). The dynamics of the physical properties of soil are affected by the tillage and management of the cultivated plants (Pan *et al*., 2018). It is necessary to maintain the physical properties of soil in a relatively stable condition to support the rate and capacity of infiltration.

The influence of plant morphology and physical properties of soil under the canopy has an important role in fulfilling the infiltration capacity that will cause runoff. Coconut and Mahogany plants have distinctly different morphological characteristics. Coconut plants have fibrous roots and flowers in the axial part, while Mahogany plants are taproots with lateral flowers (Ekowati *et al*., 2017). Currently, these two plants are considered more as a source of income but less viewed as conservation crops.

Considering to overcome the problem of soil and water conservation particularly occurs in the study area, the research was purposed to build a conceptual arrangement of *Cocos nucifera* L. and *Swietenia mahagoni* L. in order to minimize runoff. There were several types of steps to achieve the goal of the research, covering to characterize: (1) the runoff production under the canopy (2) the influence of soil characteristics on runoff production.

Materials and Methods

The research was conducted at the southern flank of Sumbing Volcano located in Central Java Province, Indonesia. The slopes of the volcano are a dorman volcano having very thick soil as a common physical feature in the volcanic landscapes of Java Island. The

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research was carried out during the peak of rainy seasons where the runoff production is very intense. The sampling period, therefore, might become representative for measuring the runoff produced from rainfall. The research emphasized on measuring runoff production from coconut and mahogany plants which become common in volcanic slopes in Java Island. The research location is shown in Figure 1.

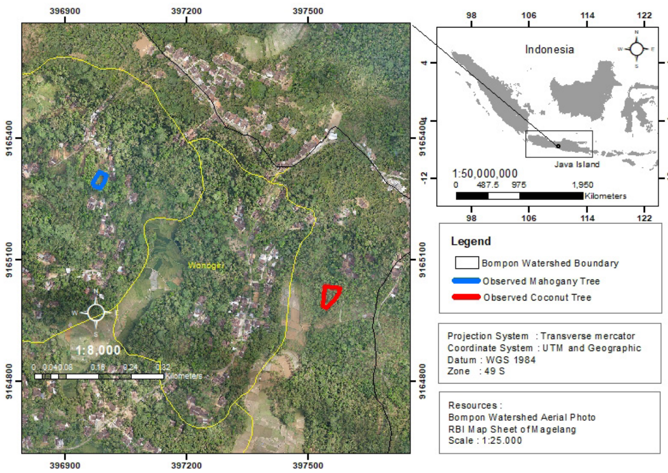

Figure 1: *Research location.*

Rainfall measurements were carried out manually using a 1.5-liters bottle placed in barren land. Rain volume measurement was carried out with a 100 ml measuring cup every day at 07.00 WIB and calculated as the previous rainy day. Rainfall (mm) was obtained by dividing the volume of rain by the cross-sectional area of the rain collector bottle. The highest rainfall during the observation period occurred on January 19, 2022 as much as 133.09 mm. The lowest rainfall occurred on January 12 at 0.88 mm. The total rainfall observed during the observation period was 928.310 mm with an average of 21.589 mm.

Landscape analysis was conducted to divide the study area into three zones based on the position and angle of the slopes, namely residual, erosion, and deposition (Purwaningsih *et al*., 2020). In each zone, the selected coconut and Mahogany plants had perpendicular stem morphology so that measurements of interception, stemflow, and throughfall were carried out above the soil surface affected by roots. Measurements of interception, stemflow, and throughfall were carried out when it rained for 43 rainy days. The throughfall (mm) was calculated by dividing the volume of the throughfall with the bottle top cross section area, while the stemflow (mm) was obtained by dividing the volume of the stemflow with the canopy projection area. The interception could not be measured directly in the field. The interception could be estimated by measuring rainfall, stemflow, and throughfall. The difference value between the rainfall and the amount of water flowing through stemflow and throughfall (net precipitation) called interception loss. Referring to the research of Magliano *et al*. (2019), the interception loss is calculated with the following equation:

$$I = CH - (Tfi + Sfi)$$

with: I, Interception loss; CH, rainfall; Tfi, throughfall; Sfi, stemflow.

Observations on the occurrence of runoff created under the tree canopy were made simultaneously with measurements of the rain partition. The measurement of soil infiltration in the field was conducted under all observed trees. Surface soil samples were taken under the observed tree canopy for further physical soil measurements in the laboratory. The data collected through field observations and measurements as well as laboratory measurements are presented in the form of table. The results obtained are discussed descriptively according to the characteristics of the research area and the research results from other parties. Installation of rain partition gauges presented in Figures 2 and 3.

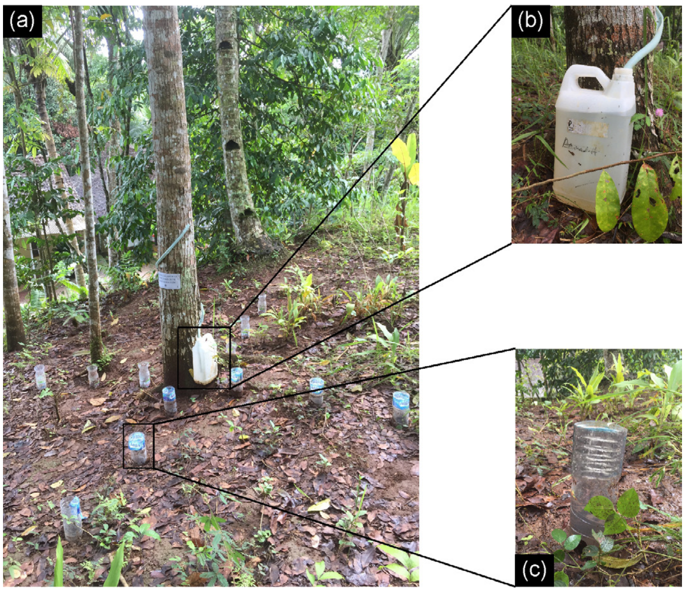

Figure 2: *Mahogany tree sample (a), stemflow measurement (b), throughfall measurement (c).*

Results and Discussion

The coconut plant has a corner architectural model of tree. The coconut plant which was the object of the study had a stem height ranging from 11.7m - 12.2m and a trunk diameter at breast height (DBH) ranging from 14.8-15.3 cm. The projection canopy area of the coconut tree was in the range of 24.4m^2 - 27.6m^2. Coconut has fibrous roots. The base of the coconut trunk is enlarged, which is called the "*bole*". Primary roots will appear in the "*bole*" and then grow horizontally on the top soil layer, while some will grow into the deeper soil layers. In primary roots appear secondary and tertiary roots.

Figure 3: *Coconut tree sample (a), stemflow measurement (b), throughfall measurement (c).*

Mahogany plants have rauh architectural model of tree. The Mahogany plants studied in this study had a height in the range of 10.7m – 13.3m and a trunk diameter at breast height (DBH) ranging from 10.1 cm – 11.6 cm. The canopy projection area of the Mahogany was in the range of 17.6 m^2 - 20.8 m^2. The Mahogany plants have taproots with few long surface roots.

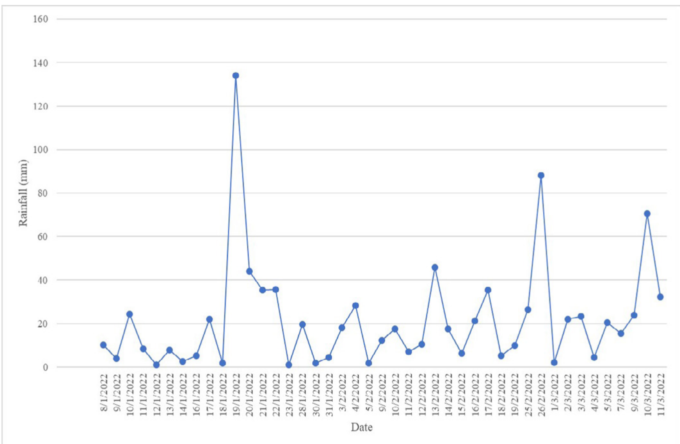

Figure 4: *Rainfall during the research period.*

The Bompon Sub-Watershed has a tropical climate consisting of rainy and dry seasons. The rainy season lasts from September to March, while the dry season lasts from April to August. The research was conducted from January to March 2022. During the research period, 43 daily rainfall data were obtained. Rainfall during the study period was fluctuating and the data are presented in Figure 4.

The value of the rain partition on each plant was different and was influenced by rainfall as the source. Measurement of stemflow, throughfall, and interception in coconut and Mahogany plants obtained 43 data. Coconut has a higher stemflow than Mahogany, which is 0.5% of the rainfall while Mahogany is only 0.2% of the rainfall. The throughfall on Mahogany plants reached 82% of the total rainfall. This value was 11% greater than in coconut plants. Coconut plants had the highest interception. The interception of coconut plants was 11% greater than that of Mahogany plants. The results of the measurement rain partitions are presented in Table 1.

Table 1: *Comparison of average percentage value of rain partition.*

Parameters		Average	Percentage
Rainfall (mm)		21.589	
Stemflow (mm)	Coconut	0.115	0.5%
	Mahogany	0.047	0.2%
Throughfall (mm)	Coconut	15.357	71%
	Mahogany	17.766	82%
Interception (mm)	Coconut	6.117	28%
	Mahogany	3.776	17%

Source: Adilah, 2022

Variations in the value of the rain partition on coconut and Mahogany plants can explain that the value of the rain partition on each of the studied plants has a linear relationship with rainfall. The amount of stemflow, throughfall, and interception increased along with the increasing rainfall. In this case, the dependent variables (y) were interception, throughfall, and stemflow, while the independent variable was rainfall (x). In the equation $y = mx+b$, if the value of y increases with the increase in the value of x, there is a positive correlation. The results of field observation data analysis show that all components of the rain partition have a positive correlation with rainfall.

Infiltration capacity is the maximum ability of the soil to infiltrate water. Infiltration capacity of soil can be expressed in terms of thickness with dimensions of length (mm) or volume (mm^3). This study explains that the infiltration capacity of soil in tree-vegetated land was greater than in barren land with grass vegetation. The result of soil infiltration capacity measurement under the coconut canopy was 281.21 mm, while Mahogany was 201.64 mm, and of barren land was 108.04 mm. Infiltration capacity measurement data under coconut, mahogany, and barren land are presented in Figure 5.

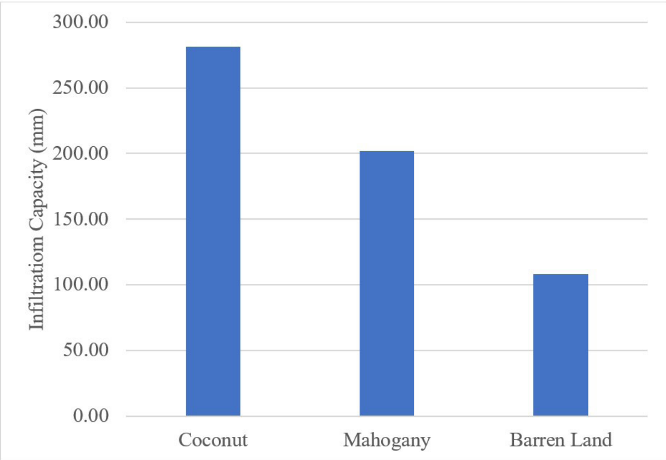

Figure 5: *Infiltration capacity of soil under coconut, mahogany, and barren land.*

The results of the study obtained data regarding clear differences in hydrological characteristics in the environment under coconut and Mahogany plants as a result of differences in plant physiology and soil characteristics. Different root morphology has a significant influence on the physical characteristics of the soil (Metzger *et al*., 2017). Soil characteristic parameters that are the focus of the study are parameters related to infiltration capacity such as initial soil moisture, porosity, organic matter (BO), clay content, and macro pores. The results of the measurement of soil characteristics are presented in Table 2.

The existence of trees has an impact on the physical condition of the soil related to the root system. The initial soil moisture in the coconut and Mahogany vegetated soil was significantly different from the barren land. Water coming from the stemflow will be transported into the soil layer to increase soil moisture (Levia and Germer, 2015; Jian *et al*., 2018; Carlyle-Moses *et al*., 2018). The clay content in all soil samples taken was also not significantly different because the soil type and texture class were the same at the research location where the samples were taken. Variation plants in soils with the same texture class have an impact on different soil porosity, so the porosity measurement was not significantly different between coconut and Mahogany plants, but it was significantly different with barren land. Coconut and Mahogany have macro roots that contribute to increasing soil porosity, while in barren land no macro roots are found because the dominant vegetation is grass.

Soil pores can be divided into micro pores, meso pores, and macro pores. In this study, macro pore measurement was carried out which is the place for air and water to move freely. The presence of macro pores acts as a way for water to enter the inner soil layer so that it is related to the infiltration capacity. Macro pore and infiltration capacity have a positive correlation. Macro pores in coconut, Mahogany, and barren land vegetated soils were not significantly different. Barren land showed the highest porosity value but a low infiltration capacity. This deviation occurred because macro pores in barren land were unstable and easily dispersed by water.

Organic matter functions as a binding agent for soil particles (cementing agent) to form a soil aggregate. Increasing the size and stability of aggregates has a positive effect on other physical properties such as increasing water retention capacity, macro pores, total porosity, aeration, and infiltration capacity. The presence of organic matter in the soil is influenced by the conditions of the plants that grow on it. The more cover crops, the higher the organic matter content (Jarvis *et al*., 2013).

Infiltration capacity of soil differs in one area of land depending on the vegetation on it. Table 2 shows that the organic matter content in coconut and Mahogany

Table 2: *Soil characteristics under coconut plants, mahogany, and barren land.*

Sample	Initial soil moisture (%)	Porosity (%)	BO (%)	Clay (%)	Pores (%)	Infiltration capacity (mm)
Coconut	49.89^{ab}	47.74^{ab}	4.11^{a}	60.76^{a}	57.19^{a}	281.21^{a}
Mahogany	53.12^{a}	49.85^{a}	3.71^{a}	61.80^{a}	53.65^{a}	187.78^{a}
Barren Land	46.26^{b}	38.02^{b}	2.39^{b}	66.93^{a}	61.75^{a}	108.04^{b}

Notes: Means followed by different letters are significantly different (least significant difference (LSD) $p \leq 0.05$) (Source: Adilah, 2022).

fields was significantly different from barren land. Coconut and Mahogany plants produce litter which is decomposed into organic matter. Ermadani *et al.* (2018) stated that various kinds of vegetation such as *Tithonia diversifolia*, *Chromolaena odorata*, and *Gliricidia sepium* that grow well in tropical soils can be a source of organic matter to increase soil organic matter levels. Another study conducted by Yulnafarmawita *et al.* (2013) proved that planting *C. odorata*, *G. Sepium*, and *T. diversifolia* on ultisol soil Limau Manis Padang was able to increase organic matter from 1.23% to 2.9%, 2.88%, and 3.06%.

Tree architecture affects the amount of stemflow. Stems with concave branches upwards will increase the amount of stemflow (Levia and Germer, 2015). Coconut plants with a corner architectural model and a funnel-shaped crown are one of the factors they have a higher amount of stemflow than Mahogany. Coconut stems have a surface that tends to be smooth so that water flows quickly to the ground. Sampurno *et al.* (2019) conducted a similar study on coconut and Albazia plants. The results of research conducted by Sampurno *et al.* (2019) showed that coconuts transferred rainwater to the soil surface through stemflow which was 33% greater than that of Albazia plants.

Mahogany plants have rauh architectural model with monopodial branches and stems that grow rhythmically upwards (Halle *et al*., 1978). This architectural model allows high proportion of stemflow. However, the rough and grooved surface of the Mahogany stem causes a lot of rainwater to be absorbed into the stem and reduces the stemflow. Research by Fadhilah *et al.* (2021) studied the rain partition on Mahogany plants and produced data that the throughfall on Mahogany plants reached 81.799% of the total rainfall. Stemflow in the two plants studied had the lowest percentage compared to throughfall and interception but had a significant effect on groundwater input (Guswa, 2012), increased soil moisture (Jian *et al*., 2018), and had the potential to cause runoff (Guswa *et al*., 2014). Wang *et al.* (2011) conducted a study of stemflow on *C. korshinskii* and found that stemflow can reach a depth of 90 cm in soil in Tengger desert. This is very beneficial for the distribution of water through infiltration in the deep soil layer.

The throughfall did not change much of the rain drops so that the amount of throughfall did not significantly different from the rainfall. The difference in the value of throughfall is generally influenced by the canopy conditions of each plant (Carlyle-Moses *et al*.,2014; Zimmermann and Zimmermann, 2014). One of the factors that affect throughfall is the water storage capacity of each plant canopy. If the water storage capacity in the plant canopy is greater than the rainfall, the rain water will be retained in the plant canopy. On the other hand, if the rainfall is greater than the water storage capacity, there will be saturation in the canopy and throughfall will occur. The value of throughfall in plants is also influenced by the density of the canopy (Geissler *et al*., 2012). Mahogany plants have high throughfall, because the canopy density is lower than coconut.

Interception of coconut plants is higher than Mahogany. The interception is affected by biotic and abiotic factors such as rainfall, rainfall intensity, canopy projection area, and hydrophobic nature of each plant part (Ahmed *et al*., 2017). Coconut leaves have folded shape and wider area so they can hold more water. Coconut midrib which is large and has space also causes the amount of water to be retained more. Coconut also has a dense crown so as to increase the interception. This is in line with the statement of Magliano *et al.* (2019) that greater interception occurs in plants with large and dense crowns. Differences in vegetation structure have a strong relation with the amount of rainwater interception (Francis *et al*., 2022). Previous research by Bulcock and Jewitt (2012) obtained interception value of 14.9%, 27.7%, and 21.4% in *Eucalyptus grandiis*, *Acacia marnsii*, and *Pinus patual* under the same rainfall.

Rainwater that reaches the ground surface after going through the interception mechanism (net precipitation) will fill the infiltration capacity of the soil. The infiltration capacity of soil in the same area can have different values. This indicates that the growing vegetation also affects the infiltration capacity of soil. Research conducted by Yu *et al.* (2018) proved that there is a relationship between root mass and soil porosity characteristics which will further increase soil infiltration. Yu *et al.* (2018) studied the value of total porosity under *C. camphora*, *M. grandiflora*, *E. decipiens*, *L. lucidum*, *O. fragrans*, *Z. serrata*, *K. paniculata*, *P. orientalis*, *C. deodara*, and *M. glytostroboides* and obtained a porosity value of 52.72%, 46.29%, 43. 65%, 47.42%, 49.18%, 46.26%, 46.24%, 46.18%, 46.14%, and 46.31%, respectively.

Liu *et al*. (2019) in their research explained that vegetation roots are the important factor affecting soil infiltration. Data on the infiltration capacity of coconut plants has the highest value compared to Mahogany and barren land. The large and wide coconut roots can increase the porosity and aeration of the soil leading to high infiltration capacity of the soil under coconut plants. Mahogany plants have taproots that grow lengthwise into the ground. These root characteristics affect the ability of Mahogany roots to form macro pores in the soil vertically. Taproots form soil pores with a narrower reach. The high infiltration capacity allows the soil to absorb more rainwater. Increasing the infiltration capacity of soil can be conducted in water and soil conservation related to increasing groundwater input (groundwater) and suppressing runoff. Soil infiltration under coconut plantations is more effective in controlling runoff. This condition needs to be supported by the morphology of the coconut trunk which is perpendicular to the soil surface, so that rainwater falls at the area under the canopy of coconut.

Morphological observations of coconut and Mahogany stems in the research area were mostly carried out in a state not perpendicular to the ground surface. Various effects of processes in the surrounding environment potentially caused the coconut stems to become inclined, ranging from slopes, wind blows, radiation, the presence of growth-disturbing organisms, to soil movements that often occur in the research area (Samodra, 2022). Based on the field observations, the morphology of the stems that were not perpendicular caused the stemflow to not fall on the ground which was affected by the roots, thus creating surface runoff.

The most inclined tree trunks are found in the erosion zone which has the largest relative slope angle compared to the residual and depositional zones. Coconuts and Mahogany are widely planted along erosion ditches where there is a lot of land crawling and cliff landslides, causing the trees to grow with slanted trunks (Todingan *et al*., 2016). The cultivation of annual crops such as coconut and Mahogany was originally intended to control the development of the rills and gullies, but in fact it triggers the creation of surface runoff which increases the rate of erosion.

Coconut and mahogany plants purposed at reducing runoff should be cultivated to have perpendicular stems to ground surface. Coconut and mahogany planted on locations with sloping slopes will naturally grow with stems not perpendicular to the soil surface, so they must be managed to grow upright. Plant management in the growing period is very important to ensure plants in the productive period remain in an upright growing condition. Environmental changes related to soil removement must always be considered and corrected through regular soil management (Ngô, 2014).

The coconut and mahogany have a significance economic value for the local community at the study area as a source of income. Those two plants also have a function to preserve favorable soil environment to store water. Based on the observation of the community's daily life, the coconut trees can be functioned as daily income through the brown sugar production from the sap. The productive age of coconuts in the research area is quite long, ranging from 10 years to more than 50 years. Coconut produces sap which can be harvested daily; fruit is harvested every 35 days; and the trunk is used if it is at least 30 years old. Coconut plants will be cut down and the trunks are used as building materials. There are some other potential economic generation through coconut plantation as discussed by Reddy and Sang-Arun (2011) Meanwhile, Mahogany trees can only be harvested once every ten years.

Coconut and Mahogany plants may be applied as conservation plants to perform productive conservation practices. Assessment of the success of conservation activities is seen from the economic aspect, in this case the continuous improvement of community welfare. The combination of planting coconut and Mahogany is a form of soil and water conservation occur in the community. The runoff from Mahogany plants can be minimized by coconut plants which have a large infiltration capacity. Mahogany plants play a role in supplying water into the soil because of their small interception. The two plants symbiosed to minimize soil erosion and run off by planting Mahogany at the higher ground than coconut. The excess run off from area under canopy of Mahogany will infiltrate into the soil under the canopy of coconut. Trees and crops arrangement on slopes had been discussed by Purwaningsih *et al*. (2020) in order to control landslide induced by gully erosion.

Conclusions and Recommendations

This research proves that coconut has the potential to become a conservation plant, in terms of its ability to control runoff and stabilize the physical properties of soil. The effectiveness of plants for reducing runoff is also influenced by stem morphology which can guarantee stemflow, especially in soil, whose physical properties are influenced by the presence of roots. The plant arrangement should be mahogany at the upper place of the coconut to ensure the runoff production become minimum. Furthermore, plants must also have economic value. Coconut plants can function as a source of daily income continuously through harvesting and processing coconut sap. The combination of planting coconut and Mahogany can contribute to community income and become a conservation of the physical environment in the context of reducing runoff.

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Novelty Statement

Coconut and mahogany have two essential functions, i.e., as soil-water conservation plants and income improvement for farmers.

Author's Contribution

Afifatul Husna Al Adilah: Conducted the research, prepared and drafted the initial manuscript.
Junun Sartohadi: Support the initial ideas of research problems, develop the field techniques of measurement, provide fieldwork accommodation, and writing improvement.
Suci Handayani: Supervised the field and laboratory measurement.

Conflict of interest
The authors have declared no conflict of interest.

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