Journal of Environment and Earth Science www.iiste.org
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.5, No.8, 2015

Hydrological Performance of Pine Tree, *Melinjo* and Jackfruit for Rehabilitation of Catchment Area of Slope of Mt. Merapi, Indonesia after 2010 Eruption

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The research was financed by the STRANAS scheme research year 2014 of the Ministry of Research, Technology, and Higher Education of Indonesia, and the Japanese Society for the Promotion of Science (JSPS).

Abstract

Estimation of the hydrological performance of individuals and communities trees of pine, *melinjo (Gnetum gnemon* L*)*, and jackfruit very necessary. All the three species have a canopy, roots and stem characters with high potential to enter rainfall into the soil. This study aims to estimate the individual hydrological performance of trees based on through fall, interception, and stem flow and hydrologic performance of community tree based on run-off. The study was conducted on the slopes of Mount Merapi, at Sidorejo village, Klaten. The altitude is more than 500 m above sea level up to the area of Mount Merapi National Forest Sector II. The geographical position between 7 ° 34'15.12" - 7°37'08" S and 110 ° 27'39.6" - 110°29'31.7"E, in the rainy season of 2014. The study is a descriptive, the exploratory approach to the surveys and field measurements. The results showed that the hydrological performance of individual pine tree, jackfruit, and *melinjo* showed that of rainfall that fell most will escape through the canopy (± 62% -81%). The biggest interception percentage is on *melinjo* (19%) > pine (18%) > jackfruit (12%), while the percentage of stem flow from the highest to the lowest is jackfruit (26%) > melinjo (14%) > pine (1%). Community performance of pine trees, jackfruit, and *melinjo* shows that of rainfall that fell in the three communities, approximately 0.01 % to 2.07% will flow as a run-off. Through-fall plays an important role to fill the water catchment area, however, necessary measures to prevent or minimize run-off and increase the rate and infiltration capacity. Necessary to measure the amount of water stored in those third tree stands.

Keywords: Mt. Merapi eruption, hydrological performance, rehabilitation

1. Introduction

The eruption of Mount Merapi, Indonesia in the end of 2010 has caused damage biophysical around the slopes of Merapi to a radius of 13 miles, especially towards the east, south and west of Mt. Merapi. Most of the vegetation and trees in forest protection and forest conservation was burned and dried (Idjudin et al., 2010). Even in the yard and agricultural lands, it is endangered the water catchment area on the slopes of Merapi. The forest on the slopes of Mt. Merapi has an important role as a water catchment area to support the needs of water for farms in the surrounding area, and the whole Daerah Istimewa Yogyakarta (Murtianto, 2005). The loss of trees due to the eruption of Mt. Merapi caused disruption of hydrological functions of the region, thus threatening the sustainability of water supplies and vulnerable to erosion. The rehabilitation of the water catchment area on the slopes of Mt. Merapi is urgent. It is also urgent to choose the trees with the specific characteristic so that the surface of the ground immediately be covered so that preventing erosion and simultaneously restore hydrological functions.

Trees play a strategic role in the rehabilitation and conservation of water catchment area of volcanic sediment after the eruption of Mt. Merapi. The canopy architecture determines the role of trees in the hydrological system performance; stems character, roots character, and litter (Hairiah et al., 2004a; Budiastuti, 2006). Tree canopy density will affect rainfall interception and pass the crown. Roughness rod will determine the amount of water passing through the stem to the ground. Horizontal distribution of tree roots will determine the level of roots bind to the soil while the vertical root distribution will affect the ability to anchor the tree to the ground. They play an important role as the entry of water into the soil. The integration between the characters canopy, trunk, litter and roots of a tree species will affect the performance of the tree in the care of the soil hydrological system. Planting tree species that have the right character to slope conditions will be very useful to accelerate the recovery of water catchment areas while conserving vulnerable volcanic sediment erosion on the slopes of Mt. Merapi after the eruption. Vegetation is a key control for the type and intensity of erosion (Geißler et al., 2012).

The results of previous studies showed that in the forest, dry fields and yards, on the slopes of Merapi there are 14 dominant tree species, that capable to survive or grow again after the eruption of Merapi (Dewi et al., 2014). They are Kaliandra (*Calliandra calothyrsus*), Kortus (*Acacia decurrens*), Puspa (*Schima noronhae* Reinw), Acacia (*Acacia mangium*), pine (*Pinus merkusii*), Sengon (*Paraserianthes falcataria*), Clove (*Eugenia aromatica*), Mindi (*Melia azedarach* L.), Mahogany (*Swietenia mahogany*), jackfruit (*Artocarpus heterophyllus*), Melinjo (*Gnetum gnemon* L), Minden (*Azadirachta indica*), Alpukad (*Persea americana*), and onions (*Dysoxylum gaudichaudianum*). All of these species have an important value index, canopy density index, roots anchoring index, and roots binding index. These characteristic potential for rehabilitation and conservation of water catchment area deposition of volcanic material after the eruption of Merapi in 2010 (Dewi et al., 2012; 2013).

The hydrological performance of trees can be estimated through the performance measurement approach of individual trees and tree communities (Budiastuti, 2006). The hydrological performance of individual trees can be estimated by measuring the flow of the stem (stem flow), pass the crown gap (through-fall) and interception of rainwater. While the tree community, hydrological performance is measured based on the run-off.

This study aims to estimate the hydrological performance of three potential tree species for rehabilitation of water catchment areas on the slopes of Mt. Merapi, i.e., pine, jackfruit, and melinjo. Furthermore, more types of trees can be found and recommended to recover the slopes of Mt. Merapi.

2. Material and Methods

The study was conducted on the slopes of Mt. Merapi, Sidorejo village, and in the area of Mt. Merapi National Park Sector II, Kemalang, Klaten, and Central Java. Its geographical position is between 7 ° 34'15.12 "- 7 ° 37'08" S and 110 ° 27 '39 .6 "- 110 ° 29'31.7" E, in the rainy season in 2014. The study is a descriptive exploratory survey method and direct measurements in the field. Selected tree species to be estimated hydrological performance is pine (*Pinus merkusii*), jackfruit (*Artocarpus heterophyllus*) , and melinjo (*Gnetum gnemon* L). The tree was chosen because it has the highest cumulative score of index of canopy density (ICD), index of roots anchoring (IRA), and index of roots binding (IRB) (Table 1), so the potential for rehabilitation of the water catchment area of the slopes of Merapi (Dewi et al., 2014).

The estimation of the hydrological performance tree was made in two stages. First, the performance of individual trees: through-fall, interception and the stem flow measurements, and second, the performance of communities trees by run-off measurement. Through-fall is estimated based on the measurements of rain water that passes through the canopy gaps and another canopy components. The measurements of through-fall are shown in Figure 1, left. The volume of water captured in a plastic tub is the amount of through-fall. Measurements were made when raining. The stem flow measurement is an estimation of the amount rainwater flowing through the tree trunk. Rough or smooth surfaces of tree trunks will affect the amount of the volume of rain water that flow through the stem. The measurement of the stem flow is shown in (Figure 1, middle). It is using aluminum foil, small water hose, wax, rubber tires and jerry cans. Aluminum foil cut to fit the circumference of the trunk folded transversely into two parts so that the aluminum foil will be thicker, and then mounted circularly on the tree trunk at a height of about 1.3 m. Before the lower part of aluminum foil was tied with rubber, a small hose was installed to the water reservoir. After the aluminum foil was tied, between the stem and aluminum foil was filled using wax to prevent water leaks. The amount of water being captured in the jerry cans is the number of stem flow. The amount of rainfall interception in the canopy of trees was estimated by the formula: ***Interception, mm = Rainfall - (through-fall + stem flow).*** Performance tree communities estimated by measuring the amount of runoff (run off). How to measure the run off is to create a swath of run-off and apron, as well as installing Chino meters (Figure 1, right).

3. Result and Discussion

Pine trees (*Pinus merkusii*), jackfruit (*Artocarpus heterophyllus*), and melinjo (*Gnetum gnemon*) are three types of trees that survived after the eruption of Merapi in 2010. They are commonly found around the slopes of Merapi, either in yards, upland, and forests, which is indicated by high of important value index (IVI). The IVI of pine tree, jackfruit, and melinjo are 18.28%, 21.82%, and 17.26%, respectively (Table 1). The greater value of IVI means the more important role of a species in a community (Dewi et al., 2014). The trees have good characters of canopy and roots so that they are potentially to rehabilitate and conserve of water catchment area after the eruption of volcanic sediments (Table 1). Pine has an index of canopy density (ICD) of 0.87, index of root anchoring (IRA) of 0.94, and the index of root binding (IRB) of 0.51 (Table 1). It implies that pine has a dense canopy, has a vertical root system (IRA = 0.94) and has more vertically root rather than its horizontal root (IRB = 0.51). As a result, the pine tree can anchor to the soil strongly and to grip the ground pretty well. Furthermore, it has a great potential to pass the rainwater into the ground, either through the canopy or the root gap. Pine are found in the area near the forest at an altitude more than 1000 m. Some jackfruit tree and melinjo were found in the yard or in upland, on the altitude below 1000 m above sea level. Jackfruit trees have less dense canopy (ICD = 0.51) than melinjo (ICD = 0.90) and pine (ICD = 0.87), but it has a vertical root (IRA = 2.30) more than pine (IRA = 0.94) and melinjo (IRA = 1.38). So that it can anchor stronger and deeper to the soil (Table 1). Melinjo has a highest dense canopy (ICD = 0.90) and has more vertical roots than the horizontal root (Table 1).

The dense canopy has the greater chance to incorporate rainwater into the ground, either through the through-fall, leaf interception or the stem flow. The vertical and the horizontal root has an important role to anchor and to grip the ground, forming the porosity of the soil and passing water into the ground through the gap between the roots and the soil.

3.1 The Hydrological Performance of Individual Tree

The ability of trees to regulate the flow of rainfall led to the water balance in a region (Suprayogo et al., 2002). Hydrological performance tree always starts when the rain is retained in the canopy of trees, whether in branches, twigs, and leaves. When rainfall intensity is high, drops of water will flow through the stem, in the form of droplets dripping from the canopy, or evaporate proportionally to the branching, leaf shape, and size. The rain water that is not retained in the canopy will pass through canopy gaps and reach the ground with a certain force (Hairiah et al., 2004b).

Pine trees, jackfruit, and melinjo showed that they have through-fall higher than the stem flow and interception by leaves. Pine tree canopy has an average through fall performance of 15.2 mm, 14.5 mm jackfruit and melinjo 9.7 mm, during 32 times rain events (Figure 2). The magnitude of this performance is affected by the amount of rainfall. When estimation is calculated based on the percentage of rainfall for about 32 times rain events, the hydrological performance of pine trees is the highest (Figure 3). It has through fall of 81%, whereas melinjo is 67%, and jackfruit is 62%. The biggest percentage of interception is melinjo that is 19%, whereas pine 18%, and jackfruit is 12%. The percentage of stem flow from the highest to the lowest is jackfruit (26%), melinjo (14%) and pine (1%). Through fall has the potential role to fill the water catchment area. However, it is necessary to prevent or to minimize run-off and increase the rate and infiltration capacity.

The magnitude of through fall of those tree species is influenced by the density of the canopy (ICD), crown shape, type of leaf, leaf width and leaf position. Pine trees have needle-shaped leaves, the leaves fall sitting down. Pine also has a lot of branches and leaves, straight trunk, and pyramidal crown, especially on young trees. The pine tree has a canopy density index of 0.87 (Table 1). Index of canopy density of trees on the slopes of Merapi variety ranged between 0.31-0.90 (Dewi et al, 2014). ICD value closer to 1, the better the role of the tree to the hydrological function, allowing rainwater that falls on the canopy intercepted on leaf, and fall down through fraction gap with low of kinetics energy.

Melinjo tree also has a dense canopy (ICD = 0.90), oval-shaped, slender, main trunk straight, and has many branches (35.5 pieces). With an average width of 3.54 m and a high canopy 10.26 m. It is said that melinjo has a closed canopy type. Melinjo leaf shape is oval, tapered at the ends, single type, pointing downward, and the leaf surface is slippery. Its characteristic is causing rainwater pass through the canopy easily. Melinjo has high canopy through fall performance, which is 67% of the rainfall accepted (Figure 3).

Pine leaf that shape like needles and supported by many branches form a dense and closed canopy, allowing rainwater remain intercepted by leaves, at 18% of the precipitation that falls. Jackfruit tree has a single leaf type, stiff, smooth and more upward than pine or melinjo. However, rainwater interception capability is lower (12% of the precipitation that falls), than the leaves of melinjo (19% of the rainfall). It is likely that the jackfruit tree canopy gap is wider than in the two other trees (ICD = 0.51) so that more rainwater drips through the canopy gaps.

The young pine trees have the gray bark but become dark and rough surface when they are older. So that the flow of water through the stem is slow, with a percentage of 1% of rainfall. On the other hand, the jackfruit tree and melinjo have smooth bark so that more rainwater flows through the rod on jackfruit and melinjo, these are 26% and 14% (Figure 3).

3.2 The Hydrological Performance of Tree Community

The estimation of the hydrological performance of pine trees community on the slopes of Mt. Merapi shows that the average rainfall during 32 times rainfall events is 21.67 mm, and the average run-off is 0.45 mm. In other words, the rain fall on pine trees is about 2.07% will flow as run-off (Figure 4). On the other hand, the run-off on melinjo and jackfruit are almost the same at around 0.01-0.02% of the rainfall that fell on both the tree community. Run-off on a pine tree community (±2.07% of rainfall) is greater than under the melinjo tree community (±0.01% of rainfall) or under a jackfruit tree communities (± 0.02% of rainfall). It is likely due to the land slope where pine grows, which is about 10 ° while for the jackfruit and melinjo is only about ± 2-3^{o}. Besides slope, the low value of run-off is also related to the soil texture. The texture under the third trees community is sandy to sandy loam that easy to absorb rain fall. All trees community showed a similar pattern of relationship between rainfall and run-off. When the rainfall increase so does the run-off. It is urgent to control the run-off and to increase the infiltration of rainfall so that the water absorbed by that soil is increased. In addition, it also require organic matter management to improve soil water holding capacity after the eruption of Merapi. Vegetation cover plays an important role in reducing surface runoff and prevent erosion (Department of Forestry, 1997; Agus et al., 2002; Asdak, 2002). The more diverse species composition and vegetation structure, the better impact on the environment, soil, and water. Pine trees, jackfruit, and melinjo, can be planted together in the same area so that their complementary hydrological performance will increase infiltration and reduce runoff and erosion.

4. Conclusion

Based on the characteristics of the canopy, roots, and stems of pine trees, jackfruit, and melinjo, they are potentially for rehabilitation and conservation of water catchment areas on the slopes of Mt. Merapi. The performance of individual hydrological pine trees, jackfruit, and melinjo showed that rainfall that fall to the trees approximately 62% -81% will pass through the canopy gap. Hence, it needs to control the water flow so that more water infiltrate into the soil. The response of tree communities to the precipitation that falls on the canopy showed a similar pattern (Figure 5). Run-off will increase when rainfall increased. The community performance of pine trees, jackfruit, and melinjo showed that rainfall that fell through the trees, about 0.01% to 2.07% will flow as a run-off. Hence, it is necessary to prevent the run-off and increase infiltration. It is useful to measure or estimate the amount of water stored in the three communities of pine trees, jackfruit, and melinjo for a complete understanding of the hydrological performance of the third tree.

Acknowledgment

Thank to the Ministry of Research, Technology, and Higher Education of Indonesia, for funding this research through research scheme STRANAS 2014. The authors also appreciate to the Japanese Society for the Promotion of Science (JSPS) for supporting this manuscript writing.

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Figure 1. The measurement of throughfall (left), stem flow (center), and run-off (right)

Table 1. Trees character based on Important Value Index (IVI), Index of Canopy Density (ICD), Index of Root Anchoring (IRA), and Index of Root Binding (IRB) (Modified from Dewi et al., 2014)

No.	Tree Name	Local Name	IVI	ICD	IRA	IRB
1	*Pinus merkusii*	Pinus	18.28	0.87	0.94	0.51
2	*Artocarpus heterophyllus*	Nangka	21.82	0.51	2.30	0.47
3	*Gnetum gnemon* L	Melinjo	17.26	0.90	1.38	0.31

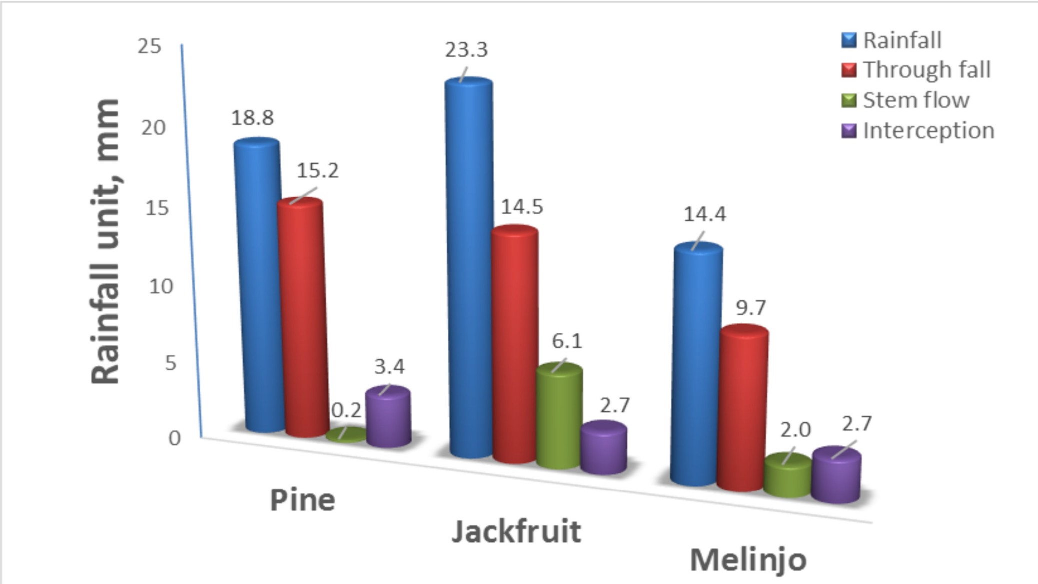

Figure 2. The hydrological performance of individual trees (pine tree, jackfruit, and melinjo), consist of through fall, stem flow, and interception (The average of 32 times rainfall events)

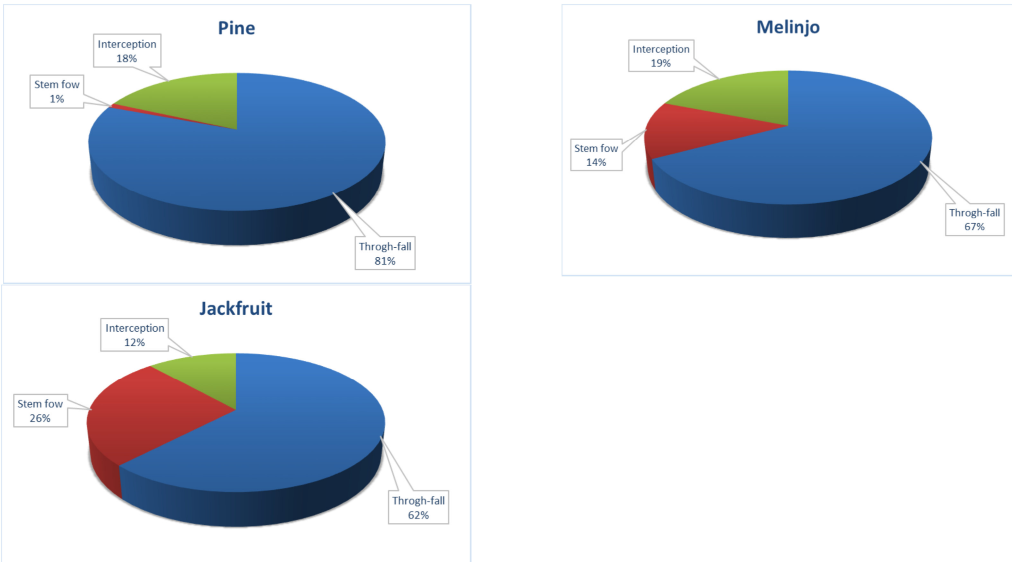

Figure 3. The hydrological performance of individual pine tree, jackfruit, and melinjo, based on percentage of rainfall distributions. In all three species, most rainfall (± 62% -81%) fall down through the canopy gaps (through fall)

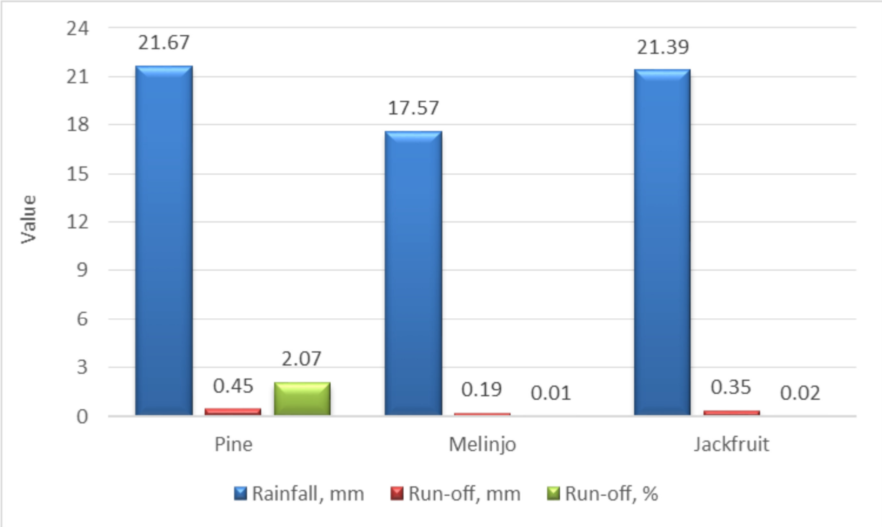

Figure 4. The hydrological performance of trees community (pine tree, jackfruit, and melinjo) based on run off measurement.

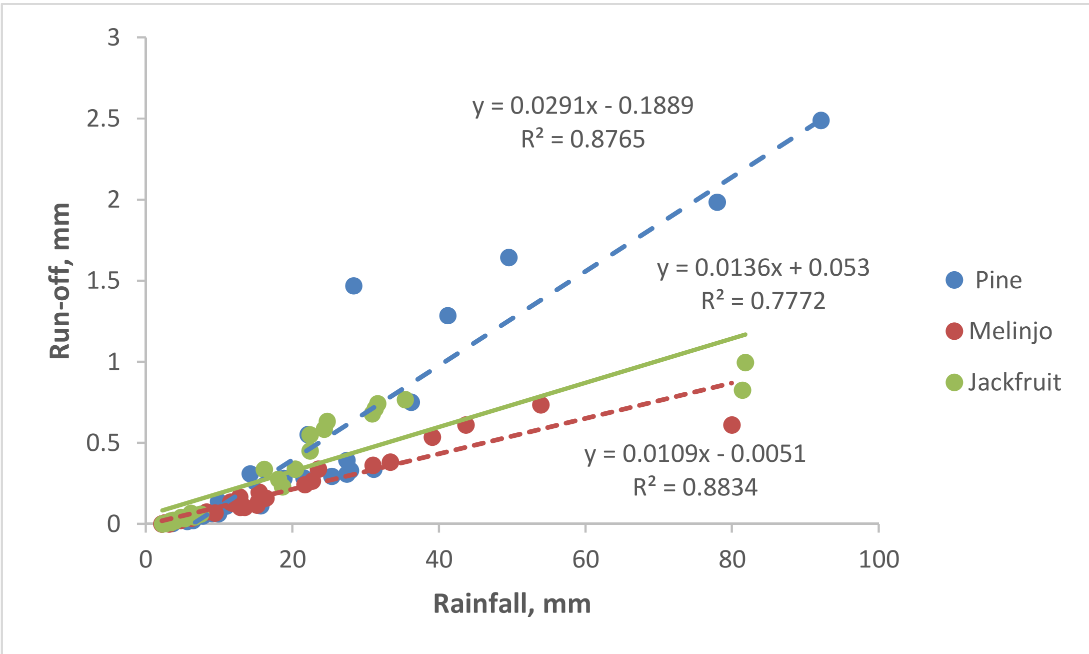

Figure 5. The relationship between rainfall and run-off for each trees community