Infiltration effectiveness of Alfisols under albazia and coconut trees and in barren land in the middle part of Bogowonto Watershed, Central Java – Indonesia

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Abstract. Surface runoff is the source of soil erosion, leading to soil resources degradation in the hilly and the mountainous areas. Albazia is a common revegetation trees at the study area as a source of annual income. Coconut is a traditional plantation tree becoming a source of daily income from its sap and/or monthly income from its fruit. This study was based on field observations during 20 rainfall generated runoff. The collected research data were rainfall intensity, stemflow, throughfall, infiltration, and physico-chemical characteristics of the soil. The results show that the effective infiltration under Albazia trees, under coconut trees, and in barren land respectively 11%, 38% and -39% respectively. Physiological characteristics of Albazia and coconut which include canopies, stems, and roots have controlled the soil capacity of infiltration.The barren land which is only covered by grass and bush vegetation is becoming the main source of runoff in the study area.

Keywords: Albazia, coconut, infiltration, stemflow, throughfall

1. Introduction

Infiltration is a major component that contributes to water reserves in the soil. Surface water can come from direct raindrops that fall on the surface of the earth and can also come from the flow of stems and drops from the leaves if the soil surface is covered by vegetation [1]. The higher percentage of tree canopy cover will make the amount of surface water smaller. However, the ability of soil infiltration will increase along with the increase in tree density [2].

Surface flow is the main source of energy that causes soil erosion, which creates problems of land degradation. The higher the percentage of rainwater infiltration, the smaller the percentage of rainwater that becomes surface runoff [3]. One approach in the effort to control erosion is to keep the infiltration capacity of the land high. In general, infiltration capacity is influenced by the morphological characteristics of the land surface, soil, and vegetation cover [4].

The vegetation that covers the soil surface is very diverse in type, which has an influence on soil infiltration through various forms. Plant morphology starting from leaves, stems, to roots can have a role in determining soil infiltration capacity [5]. Trees with thick leaves will retain a larger amount of rainwater than the trees with less dense leaves. Trees with rough stems will also hold a larger amount of water compared with trees with smooth stem surfaces [6]. Trees with taproots will have a different effect on infiltration compared to trees with fibrous roots.

The study was conducted with the aim of comparing the amount of water produced by coconut and Albazia trees through stem flow and throughfall under the same rain input. The selection of the two tree species was based on the consideration that coconut and Albazia trees are mostly cultivated in the
study area. In the past, many coconut trees were cultivated, but nowadays they are gradually being replaced by Albazia trees, meanwhile there is still limited number of references discussing the soil hydrological response under those two trees [7,8,9]. Information regarding the difference in water yield and changes in the characteristics of water infiltration in coconut and Albazia plantations are substantial for soil and water conservation [10,5].

2. Material and Methods
The research was conducted from December to March 2019. The research location was a mixed plantation located in Kuwaderan Village, Kajoran District, Magelang Regency, Central Java. Geographically, the research location is located at 7.53949° to 7.53938° S and 110.06266° to 110.06270° E. The tools used in the study included a throughfall storage device (a 3-liter basin) and a stemflow storage device (a plastic bag, a manual rainfall gauge, and a 100-ml measuring cup). Infiltration measurements were carried out using a single ring infiltrometer. Soil sampling for laboratory analysis was done using ring permeability and soil drill. Measurement of the circumferences of Albazia and coconut stems was done using meters [11]. Meanwhile, the soil compaction was measured using a pocket penetrometer.

The research was carried out by selecting four Albazia trees and four coconut trees to be installed with stemflow and throughfall collectors. The collectors made simply by sticing the plastic bags allower the stem’s circumferences of the selected trees. The selected Albazia and coconut trees were those with the relative same in circumferences. Stemflow and throughfall measurements were carried out every rainy day as many as 20 times. Measurements were carried out every morning at 7 o'clock. Measurement of infiltration capacity was performed on the soils under the canopy of Albazia and Coconut trees, as well as in the open area (barren land), consisting of 2 measurement points in each. Soil samples in the field were taken to be tested in the laboratory for their physical-chemical characteristics, including organic matter, porosity, macro pore, texture, and initial moisture. There are three soil samples taken from three different locations, namely under Albazia trees, under coconut trees, and in an open area (barren land). All variables measured are estimated to. Soil samples consist of disturbed sampel regarding to measure soil organic matter, particle density, porosity, pore distribution and soil texture, also undisturbed soil sample to measure bulk density. All the samples was taken in 20 cm depth. The effective infiltration was calculated through the percentage between nett rain (the sum of throughfall and stemflow) divided by cumulative infiltration or can be written by equation down below:

\[
\text{Effective infiltration} = \frac{\text{stemflow (mm)} + \text{throughfall (mm)}}{\text{Infiltration capacity (mm)}} \times 100
\]

Data on rainfall were obtained manually by collecting the rain volume in an open area nearest the research location.

3. Results and Discussion

3.1. Characteristics of Stemflow and Troughfall
Physiological characteristics of coconut and Albazia trees are different in terms of the canopy area and characteristics of leaves, stems, and roots. Plant physiology, covering the canopy area and characteristics of leaves and stems, influences the characteristics of the stemflow and throughfall produced. Table 1 presents the 18 selected data from 20 measurement data; two measurements were aborted do to error in handling field equipment.
Table 1. Data recapitulation of rainfall, stemflow, and throughfall.

| Date       | Rainfall amount (mm) | Stemflow (mm) | Throughfall (mm) |
|------------|----------------------|---------------|------------------|
|            |                      | Coconut | Albizia | Coconut | Albizia |
| 11/01/2019 | 22.6                 | 17.6    | 19.4    | 26.9    | 27      |
| 19/01/2019 | 5.3                  | 14.1    | 3.7     | 4.9     | 5.4     |
| 20/01/2019 | 15.2                 | 73      | 6.4     | 12.9    | 12.8    |
| 22/01/2019 | 16.2                 | 75.3    | 6.1     | 11.4    | 11.4    |
| 23/01/2019 | 29.2                 | 30.3    | 12.5    | 28.5    | 26.5    |
| 24/01/2019 | 29.2                 | 30.7    | 10.6    | 25.2    | 16.2    |
| 01/02/2019 | 16.2                 | 63.5    | 5.9     | 20.4    | 11.7    |
| 03/02/2019 | 9.8                  | 32      | 3.6     | 8.2     | 7.2     |
| 04/02/2019 | 5.8                  | 39      | 2       | 4.5     | 3.3     |
| 05/02/2019 | 32.5                 | 47.1    | 18.8    | 29.2    | 24.7    |
| 06/02/2019 | 29.2                 | 48.6    | 14.6    | 23.4    | 19.5    |
| 15/02/2019 | 2.5                  | 6       | 1.2     | 1.9     | 2.2     |
| 16/02/2019 | 61.7                 | 86.1    | 36.8    | 51.3    | 45.9    |
| 17/02/2019 | 32.5                 | 39.2    | 22.2    | 24.1    | 30.3    |
| 23/02/2019 | 32.5                 | 66.2    | 13.2    | 21.4    | 21      |
| 01/03/2019 | 34.1                 | 94.6    | 13      | 24.8    | 19.4    |
| 02/03/2019 | 32.5                 | 68.7    | 15      | 30.8    | 22.3    |
| 03/03/2019 | 65                   | 63.4    | 25.7    | 41.1    | 35.3    |
| Average    | 26.2                 | 49.7    | 12.8    | 21.7    | 19.0    |
| Sum        | 472                  | 895.4   | 230.7   | 390.9   | 342.1   |

Table 1 above could be summed up into Table 2 which is shown the statistical analysis of stemflow and throughfall amount under Albizia and Coconut.

Table 2. Statistical analysis of stemflow and throughfall under albizia and coconut.

| Parameters         | Max. Value | Min. Value | Average |
|--------------------|------------|------------|---------|
| Rainfall (mm)      | 65         | 2.5        | 26.2<sup>a</sup> |
| stemflow (mm)      |            |            |         |
| coconut            | 164.1      | 0.7        | 49.7<sup>a</sup> |
| albizia            | 49.6       | 0.5        | 12.8<sup>c</sup> |
| throughfall (mm)   |            |            |         |
| coconut            | 60.1       | 0.5        | 21.7<sup>bc</sup> |
| albizia            | 60.9       | 0.6        | 19.0<sup>bc</sup> |

Note: Same alphabeth shows no significant difference under each conditions using Fihers methods.
The value of stemflow produced by coconut trees is significantly different from the stemflow value produced by Albazia trees. The structure of the coconut leaves that is concentric on a single stem possibly becomes the main cause of the differences in stemflow measurement results [12,13]. The amount of throughfall produced by coconut and albazia trees, in general, are not significantly different and varied, which may be caused by the presence of gusts of wind during the rainfall event [14]. On average, coconut trees produce a higher amount of throughfall than Albazia trees with slight differences [15].

3.2. Characteristics of Soil and Infiltration under Coconut and Albasia Plantations

Soil physical properties have an influence on the availability of macro pores and aggregate stability, thus determining infiltration capacity. The results of measurements of soil characteristics are presented in Table 3.

Table 3. Characteristics of soil used in barren land, under coconut trees and under Albasia trees.

| Variables            | Coconut | Albasia | Barren Land |
|----------------------|---------|---------|-------------|
| Organic matter (%)   | 3.5a    | 3.3a    | 2.4b        |
| Sand (%)             | 14a     | 12a     | 10a         |
| Silt (%)             | 14a     | 18a     | 14a         |
| Clay (%)             | 72a     | 69a     | 76a         |
| Porosity (%)         | 57a     | 56a     | 50b         |
| Macro pore (%)       | 36a     | 34a     | 40a         |
| Soil moisture (%)    | 51a     | 52a     | 53a         |
| Soil compaction (Kg/cm²) | 1.3b   | 1.4b     | 2.5a        |
| Infiltration capacity (mm) | 186.9ab | 287.5a   | 18.9b       |

Note: Same alphabet shows no significant difference under each conditions using Fihers methods.

In general, the physical properties of the soil under coconut trees, under Albasia trees and in an open area (barren land) are not significantly different. The availability of macro and micro pores is one factor that determines infiltration capacity. The micro pore illustrated in the measurement of soil texture shows a value that is not different between the three soil samples. The macro pore of the soils in an open area (barren land) is relatively the highest compared to the other soil samples. The low organic content in the open area (barren land) causes the availability of micro pore to be temporary. When the soil is in wet condition, the macro pore of the soil in the barren land will be closed as a consequence of the breakdown of the soil structure [16].

Another factors that determining infiltration capacity is root structure. The presence of the deep macro roots spreading under coconut and Albasia trees leads to the availability of macro pores, which are evenly distributed throughout the entire soil profiles. The availability of macro pores in the entire soil profiles makes the infiltration capacity significantly different from the infiltration capacity of the soils in the barren land which is only covered by grass. Grass roots only reach the surface soil layer, while the lower soil will tend to be compressed [17].

The calculation of the effectiveness of infiltration is presented in percentages which is a ratio of nett.rain and infiltration capacity, presented in Table 4. Calculation of infiltration effectiveness of the soil in the barren land results in a value that is more than 100%, which illustrates that the nett rain are partially flown away as run off, so that it is given negative value. This could happened because infiltration capacity at barren land is lower than the nett rain that falls on its surface. Meanwhile, coconut and albasia are having a larger amount of infiltration capacity compared to its nett rain that falls under each trees. The value of infiltration effectiveness of the soil under coconut and Albasia
trees are always below 100%, which illustrates that the entire rainfall are infiltrated and can retain the runoff of water from the surrounding fields.

Table 4. Effectiveness of infiltration as affected by various vegetations.

| Variable                  | Barren land | Coconut | Albazia |
|---------------------------|-------------|---------|---------|
| Rainfall (mm)             | 26.2        | 26.2    | 26.2    |
| Stemflow (mm)             | -           | 49.2    | 12.8    |
| Throughfall (mm)          | -           | 21.7    | 19.0    |
| Nett. rain (mm)           | 26.2        | 70.9    | 31.8    |
| Infiltration capacity (mm)| 18.9        | 186.9   | 287.5   |
| Effectiveness (%)         | -39         | 38      | 11      |

From the Table 4 above we could note that the most effective condition to infiltrate rainfall is under the coconut tree with the infiltration effectiveness 38% followed by albazia with 11% and the uneffective condition at the barren land with negative number of infiltration effectiveness and becoming run off source. But this undesirable conditions could be minimized by the presence of albazia and coconut trees that could help to infiltrate the excess water from the barren land.

4. Conclusion
All water that falls both through the stemflow and throughfall of the coconut and Albazia trees will be infiltrated, while some of the rainwater that falls on barren land will become overland flow. The conclusion of this study is supported by the results of the research as follows:

a. The average stemflow of coconut and Albazia trees during the observation is 49.2 mm and 12.8 mm, meanwhile the average throughfall of Albazia and coconut trees is 19 mm and 21.7 mm, respectively.

b. The average value of soil infiltration capacity under coconut trees, under Albazia trees, and in barren land is 186.9 mm, 287.5 mm, and 18.9 mm, respectively.

c. The effectiveness of infiltration of the soil under Abazia trees, under coconut trees and in barren land is 11%, 38%, and -39%, respectively. Thus, the soil in the barren land has the potential to produce overland flow.

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