Effect Of Rice Straw Mulch on Surface Runoff and Soil Loss in Agricultural Land Under Simulated Rainfall

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Abstract. Installation of mulch on agricultural land, besides reducing weed growth, can also protect the soil surface from rain and erosion. This study aims to determine the effectiveness of rice straw mulch in reducing surface runoff and soil loss before entering the river. The experimental soil materials were similar to those in Sumber Brantas village, Bumiaji Sub-District, Batu. Runoff modelling utilized the Armfield S12 Rainfall Simulator - Advanced Environmental Hydrology System, with rainfall of 1 and 1.7 l/min. Land with rice straw mulch was compared to land without mulch. The land slope was adjusted to study area conditions, with mild (9%) and steep (15%) slopes. The three-Way ANOVA method was utilized for statistical analysis. In all the experimental runs, it was found that straw mulch effectively reduced the sediment yields that could enter the river area by more than 50%. The results of ANOVA analysis on sediment yield also showed that the significance value of the interactions between slope, rain intensity, and mulch usage was 0 (p<0.05). These results show that the difference in variations in these three factors determines the sediment yield that occurs. In the future, comparing straw mulch with other materials to cover agricultural land should be conducted.

Keywords: Erosion, rainfall simulator, rice straw mulch, soil loss, surface runoff

1. Introduction
Indonesia is known as an agrarian country, in which the majority of the people possess livelihoods as farmers. This condition is supported by the fertility of agricultural lands, as land is the most crucial factor in plants' growth medium. However, the increase in population and socio-economic pressure has caused reductions in agricultural land areas. Many of them are being converted into settlements, which results in agricultural lands being opened in steeply sloped and forested areas. These activities may damage the soil and water.

Damage to soil may occur through the loss of nutrients and organic materials from root areas, collection of salt at root areas (salinizat...
soil saturation by water, and erosion. Rain is the factor that most greatly affects erosion in Indonesia. In this case, the amount, intensity, and distribution of rainfall toward soil and the amount and velocity of surface runoff and erosion damage [1], [2]. The rain that falls to the earth will cause the wearing down of soil that the rainfall flows through, causing erosion on land with certain slopes. Several factors that cause erosion to occur include rainfall intensity, infiltration, surface runoff, soil properties, and soil surface conditions such as soil moisture, soil roughness, slope length, and slope gradient [3], [4].

A portion of the eroded soil will be carried along with the runoff and enter the river flow together with the runoff water, leading to occurrences of sedimentation in rivers. In addition to causing sedimentation, sediments in river erosion can also affect the water quality of rivers [5]. The great amount of land clearing in mountainous and sloped areas puts these areas in greater danger. Sloped areas with a great number of trees are supporting areas that function to absorb rainfall. [6].

One of the sloped areas converted into an agricultural area is Sumber Brantas Village of Bumiaji Sub-District in the City of Batu, East Java. In this area, much of the sloped regions are converted into lands for vegetable cultivation [7], leading to erosion occurrences. Therefore, many studies have been conducted to reduce or control the risk of erosion occurring on agricultural lands in sloped areas, one way of which is with the usage of mulch as covering for the agricultural lands [8]–[11]. Based on the above background, this research aims to determine the effectiveness of rice straw mulch in reducing or controlling the risk of erosion occurring on agricultural lands in sloped areas.

Figure 1. Sumber Brantas village area
2. Methods

2.1. Study Location
The research location for this study is the Hydrology Laboratory of the Department of Water Resources Engineering at the Faculty of Engineering of Universitas Brawijaya, Malang. Meanwhile, soil samples were taken from selected lands of vegetable cultivation at the Sumber Brantas Village of Bumiaji Sub-District, City of Batu (Figure 1). The area of Sumber Brantas Village is 541.1364 ha, is situated at the height of 1400-1700 masl, and receives a high amount of rainfall. The average air temperature is 8 °C to 18 °C. Land use at the Sumber Brantas Village is dominated by agricultural land with 58.82%; this is affected by the fertile condition of the land and the climate that supports agricultural activities. The low regional temperatures encourage the surrounding people to manage their land for the agriculture sector. The land that they manage yields agricultural products, including vegetables such as carrots and potatoes. The population in Sumber Brantas Village is 4,100 people, and most (1,566 people) in Sumber Brantas Village possess livelihoods as farmers due to the contour and fertility level of the land's great potential to be tended as agricultural land [7].

2.2. Design of Rainfall Simulator Setup
Rainfall modeling utilized the S12 – Advanced Environmental Hydrology System Rainfall Simulator instrument [12], [13]. The utilized slope gradients were 9% and 15%. The type of soil utilized in this research was taken from Sumber Brantas Village of Bumiaji Sub-District, City of Batu. The soil of the agricultural land of this location was then utilized as the medium to conduct modeling. To find out the type of soil at the location, analysis of soil type weight, calculation of grain distribution, sieve analysis, and hydrometer analysis [5] were conducted at the Water and Groundwater Laboratory of the Department of Water Resources Engineering at the Faculty of Engineering of Universitas Brawijaya.

This research involves comparing the condition of soil without mulch and rice straw mulch usage [9]. Each of the treatments and variations was repeated three times to obtain better results. Measurement of total dissolved solids (TDS) utilized Horiba U-50 [14]. Results of sediment yield were taken from the amount of soil caught by a filter. After conducting a drying process to determine the dry weight, the sediment yield for each trial was found by weighing [15].

2.3. Statistical Analysis
The effectiveness level of rice straw mulch was analyzed with the method of Three-Way ANOVA [16]. Meanwhile, statistical testing utilized the Statistical Package for Social Sciences (SPSS 26) software as the assisting instrument [17].

3. Results and Discussion

3.1. Calculation of Rain Intensity
Calculation of rainfall intensity magnitude was performed to determine the utilized rainfall intensity when running the rainfall simulator instrument. This calculation was obtained by utilizing data of annual maximum rainfall taken from a daily rainfall measurement station from 2008-2017 at the Junggo Rain Station in Bumiaji Sub-District (Table 1).

The maximum rainfall from 2008-2017 was 105 mm, while the minimum rainfall was 64 mm (Table 1). In the rainfall simulator, the rainfall intensity setting utilized the unit of l/min. Therefore, unit conversion needed to be performed to be relevant to the utilized instrument. The following is the process of unit conversion:
Table 1. Daily Annual Maximum Rainfall Data

| No. | Year | Max rainfall (mm) |
|-----|------|-------------------|
| 1   | 2008 | 87                |
| 2   | 2009 | 89                |
| 3   | 2010 | 64                |
| 4   | 2011 | 100               |
| 5   | 2012 | 76                |
| 6   | 2013 | 98                |
| 7   | 2014 | 96                |
| 8   | 2015 | 105               |
| 9   | 2016 | 68                |
| 10  | 2017 | 87                |

Maximum Rainfall Intensity = 105 mm/hour
Land Area for Modeling = 1.12 m²
Unit Conversion = (105 mm)/(1 hour)
= (0.105 m)/(60 min) x Area (m²)
= (0.105 m)/(60 min) x 1.12 m²
= (0.1176 m³)/(60 min)
= (117.6 dm³)/(60 min)
= 1.96 l/min

Minimum Rainfall Intensity = 64 mm/hour
Land Area for Modeling = 1.12 m²
Unit Conversion = (64 mm)/(1 hour)
= (0.064 m)/(60 min) x Area (m²)
= (0.105 m)/(60 min) x 1.12 m²
= (0.07168 m³)/(60 min)
= (71.68 dm³)/(60 min)
= 1.195 l/min ≈ 1.2 l/min

In this research, there is a limitation of the equipment. As a result, it could only utilize a maximum rainfall intensity of 1.7 l/min or equivalent to 91.10 mm/hour; this high rainfall value still represents the average maximum rainfall intensity at the research location. For comparison, this research also utilized the minimum rainfall intensity of 1 l/minute for the instrument or equivalent to 53.57 mm/hour at the location.

3.2. Soil Type
Soil sample analysis utilizing the hydrometer method. Hydrometer readings were taken at ½, 1, 2, 15, 30, 60, 120, and 1,440 min after following several prior procedures [5]. Determining the percentages of sand, silt, and clay for the soil sample required data of the soil percentage that settled at the reading time of 1,440 min with a value of 6.421%. Then, referring to SNI 3423-2008 [18], for:

1. Percentage of rough sand (2.0 mm to 0.42 mm)
2. Percentage of fine sand (0.42 mm to 0.074 mm)
3. Percentage of silt (0.074 mm to 0.002 mm)
4. Percentage of clay (smaller than 0.002 mm)
Identifying the soil type in the sample indicated that the sand percentage was 16%, the silt percentage was 77.6%, and the clay percentage was 6.4%. Next, using the soil texture triangle, it was found that the soil type utilized in this research is silt loam soil (Figure 2). Thus, overall, the evaluation for comparing the usage of mulch in this research is only relevant for silt loam soil.

3.3. Rainfall Simulator Simulation

The magnitude of runoff that occurs indicates a volume of rainwater that is no longer infiltrated into the soil and flows freely on the soil surface. A greater value indicates a greater volume of water that flows to lower regions [9]. Based on the overall results for runoff, it was found that the largest runoff of 1.667 l/min occurred for land with rice straw mulch, rainfall intensity of 1.7 l/min, and slope gradient of 15%. Meanwhile, the smallest overflow value of 0.633 l/min occurred for land with rice straw mulch, rainfall intensity of 1 l/min, and slope gradient of 9% (Figure 3). The usage of mulch did not affect the magnitude of the runoff that occurred [10].

The amount of sediment yield indicates soil particles of other materials that are carried by the runoff flow. A greater value indicates a greater amount of carried materials. The largest sediment yield value of 3.698 grams occurred for land without straw mulch with rainfall intensity of 1.7 l/min and a slope gradient of 15%. Meanwhile, the smallest sediment yield value of 0.485 grams occurred for land without mulch with rainfall intensity of 1 l/min and a slope gradient of 9% (Figure 4). Thus, the effectiveness of straw mulch to hold back sediments was 53%.

The largest TDS value occurred for land with rice straw mulch, rainfall intensity of 1.7 l/min, and slope gradient of 15% with a value of 278.000 mg/l. Meanwhile, the smallest TDS value occurred for land without mulch with rainfall intensity of 1 l/min and slope gradient of 9% with a value of 185.667 mg/l (Figure 5). The usage of straw mulch also causes adverse impacts because it increases the TDS value of runoff water that enters the river. In addition, TDS value increases may occur because of the characteristic of rice straw that contains high contents of chemicals such as phosphates, surfactants, ammonia, and nitrogen [19].
**Figure 3.** Results of running the runoff

**Figure 4.** Results of running sediment yield

**Figure 5.** Results of running TDS
3.4 Statistical Analysis

A. Data Normality Testing
Normality testing is one of the prerequisites in performing three-way ANOVA. This research utilized the Shapiro-Wilk method. This method used is because the data for each tested variable was less than 50 [20]. In an analysis by normality testing, the data is said to possess normal distribution if the data has a significance value greater than 5%. The highest significance value was the significance value of runoff for land without mulch, which was 0.816. Meanwhile, the significance of sediment yield for rainfall intensity was the lowest significance value, which was 0.67. The average significance value for runoff, sediment yield, and TDS was 0.364, which means that the variables utilized for the runoff data have a normal distribution because the value is more significant than 0.05 (Figure 6).

B. Data Homogeneity Testing
Data homogeneity testing is another prerequisite in performing ANOVA [21]. To achieve verification of homogenous data, the statistical significance must be greater than the significance value of the test, with the utilized level of significance for the test being 0.05. The analysis results found that the significance value of data for runoff was 0.06, sediment yield was 0.095, and TDS was 0.691. It is meant that all the data are homogenous and may be utilized for further analysis calculations.

C. Three-Way ANOVA Testing
Accordingly, with the initial hypothesis on ANOVA testing on runoff data, the analysis results were expected to fulfill H1 with p < 0.05, meaning that usage of treatment variations for each variable affected the amount of the runoff volume that occurred.

Results of ANOVA analysis on runoff indicated that the significance of the slope was 0.001 (Table 2). This condition means that the usage of slope gradient variations (9% and 15%) influenced differences in the amounts of runoff volume that occurred. The significance of rainfall intensity was 0, indicating that rainfall intensity variations affected the runoff volume. The significance of mulch usage was 0.728 (Table 2), indicating no differences in the runoff volume that resulted from mulch usage. The same was true for interactions between slope, rainfall intensity, and mulch usage, which had the same significance value.

![Figure 6. Results of significance testing with the Shapiro-Wilk method](image-url)
Therefore, the factors that affect the occurring runoff are slope and rainfall intensity, while the usage of rice straw mulch on land without soil did not affect the volume of the occurring runoff.

Results of ANOVA analysis on sediment yield indicated that usage of slope variations, rainfall intensity variations, and mulch usage affected differences in the amount of sediment yield that occurred. The significance values of each variation were 0.153, 0, and 0 (Table 2). The significance of interactions between slope, rainfall intensity, and mulch usage was 0 (Table 2). This means that differences in variation usage in these three factors determined the amount of sediment yield that occurred.

For TDS analysis, the significance of the slope was 0.153 (Table 2). This indicates that the usage of slope variations did not influence differences in the TDS amount that occurred. The significance of rainfall intensity and mulch usage was 0 (Table 2), meaning that the two influenced the TDS value. The significance of interactions between slope, rainfall intensity, and mulch usage was 0.391 (Table 2). This means that there were no differences from each treatment toward the TDS value that occurred. Therefore, the three factors did not affect the resulting amount of TDS.

### Table 2. Significance of ANOVA Analysis Results

| Source                        | Runoff Sig. | Sediment Yield Sig. | TDS Sig. |
|-------------------------------|-------------|---------------------|----------|
| Corrected Model               | 0.000       | 0.000               | 0.000    |
| Intercept                     | 0.000       | 0.000               | 0.000    |
| Slope                         | 0.001       | 0.000               | 0.153    |
| Rainfall intensity            | 0.000       | 0.000               | 0.000    |
| Treatment (with or without mulch) | 0.728   | 0.000               | 0.000    |
| Slope * Rainfall Intensity    | 0.728       | 0.002               | 0.001    |
| Slope * Treatment             | 0.490       | 0.000               | 0.042    |
| Rainfall Intensity * Treatment| 0.025       | 0.000               | 0.010    |
| Slope * Rainfall Intensity * Treatment | 0.176 | 0.000 | 0.391 |

### Table 3. Estimation of the Influence of Variation Usage for Each Variable

| Dependent Variable | Runoff Mean | Sediment Yield Mean | TDS Mean |
|--------------------|-------------|---------------------|----------|
| 1.7 l/min          | 1.517       | 1.079               | 0.249    |
| 1 l/min            | 0.817       | 2.281               | 0.217    |
| 9%                 | 1.075       | 2.130               | 0.231    |
| 15%                | 1.258       | 1.230               | 0.236    |
| Without Mulch      | 1.158       | 2.474               | 0.201    |
| Straw mulch        | 1.175       | 0.886               | 0.266    |

The enormous mean value was sought for each treatment using the Bonferroni test [22]. Meanwhile, because rainfall intensity and slope are natural properties, they cannot become considerations in establishing the determining factor. For example, the greatest runoff volume occurred for the treatment with rainfall intensity of 1.7 l/min, slope gradient of 15%, and land with rice straw mulch. Because rainfall intensity and slope are natural properties, then the option of land with straw mulch cannot be considered to reduce the potential of erosion occurring on land with consideration of the runoff volume amount. The same was true for TDS; because the largest value occurred for land with rice straw mulch, the option of land with straw mulch thus cannot be considered as an option for reducing the potential of erosion occurring on land. Meanwhile, the largest sediment yield occurred for the treatment of land without mulch (Table 3). Therefore,
the option of land with straw mulch is effective to be considered an option for reducing the potential of erosion occurring on land with consideration of the factor of the amount of sediment yield that occurred.

4. Conclusion
From the simulation results by the rainfall simulator, it was found that straw mulch effectively reduces sediment yield that can enter the river area by greater than 50%. Results of ANOVA analysis for sediment yield also showed that the significance value for interactions between slope, rainfall intensity, and mulch usage was 0 (p < 0.05). This means that differences in variations in these three factors also determine the amount of sediment yield that occurs. However, because rainfall intensity and slope are natural factors, mulch usage may be considered an option to reduce erosion. A suggestion for further research related to this topic is to compare several alternatives of land cover to straw mulch.

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