Surface runoff and erosion on various sengon (Falcataria moluccana (Miq.) Barneby & J.W.Grimes) – based agroforestry patterns in small scale private forest, Sumber Urip Village, Blitar, East Java

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Abstract. Indonesia is still facing several problems concerning to degraded land. These problems often a result of surface runoff and erosion. The intensity of surface runoff and erosion depended on one of the others is soil cover. Research on surface runoff and erosion on various sengon-based agroforestry pattern has been conducted to address this challenge. Plots of various patterns are as follow A: sengon plantation; B: sengon + coffee + gamal + cassava + cowpea; C: sengon + coffee + gamal + cacao + corn + cowpea; D: sengon + coffee + gamal + ginger + cowpea; E: sengon + coffee + gamal + ginger + corn + cowpea; F: reeds (control). The results show that agroforestry patterns are very effective in reducing soil surface runoff and erosion. The B pattern was considered as the best combination compared to the other combinations in this research. The decrease in the surface runoff and erosion rate was 74.33% and 63.42%, respectively. While the highest surface runoff and erosion occur in the D pattern, which was given the surface runoff and erosion value of 565.6 mm/ha/year and 3.4 ton/ha/year, respectively.

1. Introduction
Indonesia still has extensive degraded land. Based on the latest data, the degraded land in Indonesia has reached 14 million hectares [1]. This problem, among others, occurs due to high surface runoff, high erosion, and the decrease of land cover, especially in sloping areas with high rainfall. Therefore this condition needs to be improved by applying a cropping system that can reduce surface runoff and erosion. One of these cropping systems is the agroforestry system.

Agroforestry is a cropping system by planting a combination of annual plants (timbers) and seasonal crops/livestock. This cropping system is a symbiosis of a tree growing, crop production, and livestock rising where each component is beneficial to each other. It may be traditional and/or introduced [2, 3].

Combined types are sought that could provide benefits both economically and ecologically [4]. In terms of economics, the type which developed should be a type that has high economic value for the surrounding community. Ecologically the combination types which developed must be mutually
beneficial. This is because annual plants in their growth require light to produce optimal crops. However, several shade-resistant plants can live under staple plants. One type of annual plant that can be developed in this cropping pattern is *sengon* (*Falcataria moluccana*).

*Sengon* is a fast-growing plant and can be harvested at the age of 5 - 6 years [5] so that farmers can get their income immediately. Besides that, the leaves of the *sengon* plant are narrow and small so that sunlight can still penetrate to the bottom received by food crops under *sengon*. The development of plant species that are shade resistant and have high economic value, are expected to help farmers to increase their land productivity, especially on densely populated land. Besides, it is expected to reduce the rate of surface runoff and erosion.

According to the background above, this study aimed to determine the appropriate agroforestry system with certain cropping patterns that can reduce surface runoff and erosion. It is expected that this research can be useful in selecting an agroforestry system that can reduce surface runoff and erosion.

2. Material and Methods
This research was carried out in the community forest area around 3.5 ha, located in Krajan Hamlet, Sumber Urip Village, Doko District, Blitar Regency, East Java. The climate type is C3 (according to Oldeman climatic classification system) with an average annual rainfall of 1,478.8 mm with the highest rainfall of 2,618.2 mm per year and the lowest rainfall of 1,024.7 per year. While the highest temperature is 30°Celsius, and the lowest temperature is 18°Celsius [6]. The research location is around 500 m above sea level, and the plots have relatively the same slopes of around 10%.

2.1. Material
The materials used in this study were *sengon* and gliricidia seedlings, cacao and coffee plantation, and corn seeds, cowpea seeds, ginger seeds, Urea fertilizer, and SP 36. While the tools used in this study were: GPS, scales, clinometer, ombrometer, measuring cups, ovens, filter paper and others.

2.2. Methods
2.2.1. Research design. The research design used was a Randomized Complete Design [7] with *sengon*-based agroforestry system treatments as follows:

A. *Sengon* (*Falcataria moluccana*) plantation
B. *Sengon* (*F. moluccana*) + coffee (*Coffea sp.*) + gliricidia (*Gliricidia sepium*) + cassava (*Manihot utilissima*) + cowpea (*Vigna unguiculata*)
C. *Sengon* (*F. moluccana*) + coffee (*Coffea sp.*) + gliricidia (*G. sepium*) + cacao (*Theobroma cacao*) + corn (*Zea mays*) + cowpea (*V. unguiculata*)
D. *Sengon* (*F. moluccana*) + coffee (*Coffea sp.*) + gliricidia (*G. sepium*) + cacao (*T. cacao*) + ginger (*Zingiber officinale*) + cowpea (*V. unguiculata*)
E. *Sengon* (*F. moluccana*) + coffee (*Coffea sp.*) + gliricidia (*G. sepium*) + ginger (*Z. officinale*) + corn (*Z. mays*) + cowpea (*V. unguiculata*)
F. *Alang-alang* / reeds (*Imperata cylindrica*) land (as a control plot)

Each treatment combination was carried out with three replications (3 groups), and each group was planted with *sengon* with a spacing of 3 x 3 meters and a mixture of agricultural crops according to the treatment. If the results of the diversity analysis show significant differences, then proceed with the Duncan method different tests.

2.2.2 Research stages. The first stage was making a plot of the cropping patterns, as mentioned above, with a size of 20 x 20 meters. In the lower part of the plots were placed drums to collect surface runoff and erosion sediment. There were 18 drums (6 plots x 3 replications), while the drum dimension was 58 cm diameter, 93 cm high, and 182 cm around. Surface runoff and erosion sediment measurements were carried out in three years old of the *sengon* plantation (medium plant rotation) during one year, on each rainy day in all plots. All runoff and sediments collected in the reservoir were measured and
recorded. The measurement of erosion sediment was carried out by the evaporation method by placing suspension samples into a porcelain dish and oven at a temperature of 105 °C for 24 hours. Erosion was calculated from the remaining sediment in the cup, while the surface runoff was calculated from the water contained in the drum.

The tolerable erosion was calculated with the formula [8]:

\[ T = ((D_e - D_{min}) \times S^{-1}) + F) \times BD \]

Notes:
- \( T \) = Tolerable erosion
- \( D_e \) = Effective soil depth (cm) x soil depth factor
- \( D_{min} \) = Minimum soil depth for plant root (cm)
- \( S \) = Soil sustainability (300 years)
- \( F \) = Soil formation stage (1-1.5 mm/year, depend on soil type)
- \( BD \) = Bulk Density (gr/cm\(^3\))

While the Erosion Hazard Index was calculated with the formula [8]:

\[ EHI = E \times T^{-1} \]

Notes:
- \( EHI \) = Erosion Hazard Index
- \( E \) = Soil Erosion (ton ha\(^{-1}\) year\(^{-1}\))
- \( T \) = Tolerable erosion (ton ha\(^{-1}\) year\(^{-1}\))

The criteria for the Erosion Hazard index is presented in Table 1.

| No. | Value of Erosion Hazard Index | Category   |
|-----|-------------------------------|------------|
| 1.  | < 1                           | Low        |
| 2.  | 1.01-4.00                     | Medium     |
| 3.  | 4.01-10.00                    | High       |
| 4.  | >10.01                        | Very High  |

3. Results and Discussion
The arrangement of cropping patterns between woody plants and seasonal crops in the agroforestry system determine the results greatly to be obtained, as well as their influences on the environment. The selected plants are suitable for farmers' needs but not provide negative impacts on environmental sustainability. The negative impacts on the environment that might occur due to this cropping pattern include increasing the rate of surface runoff and erosion. However, different ground cover vegetation produced different surface runoff and erosion, where better soil cover vegetation will minimize surface runoff fluctuations and erosion [9]. The influence of vegetation on surface runoff can be as intercept rainwater, reduce the speed of surface flow, and the destructive force of rain and surface runoff [8]; [10]. Therefore, increasing land covers could decrease the rate of runoff and erosion [11]. The effect of roots, organic matter of plant debris that falls on the soil surface to biological activities related to vegetative growth, structural stability and soil porosity.

3.1. Surface runoff
The agroforestry system produces different surface runoff for each cropping pattern. The average surface runoff in each type-of agroforestry system is presented in Table 2.
Table 2. The average surface runoff in each treatment of the agroforestry system.

| Treatment of agroforestry system | Crop Patterns | Surface runoff (mm ha\(^{-1}\) y\(^{-1}\)) | Surface runoff decrease (%) |
|----------------------------------|--------------|---------------------------------|---------------------------|
| A Sengon                         |              | 162.3\(^a\)                     | 69.71                     |
| B Sengon + coffee + gliricidia + cassava + cowpea | 137.5\(^a\) | 74.33                           |
| C Sengon + coffee + gliricidia + cacao + corn + cowpea | 500.2\(^c\) | 6.63                            |
| D Sengon + coffee + gliricidia + cacao + ginger + cowpea | 565.6\(^c\) | -5 (surface runoff increase)    |
| E Sengon + coffee + gliricidia + ginger + corn + cowpea | 300.0\(^b\) | 44.00                           |
| F Imperata cylindrica land (as a control plot) | 535.7\(^c\) |                                |

Remark: Numbers followed by different letters indicates significantly different at 95%

The occurrence of surface runoff is caused by less infiltration of rainwater into the soil. The measurement results showed that the D treatment agroforestry system might aggregate to 565.6 mm. This showed higher surface runoff and did not differ significantly in the F treatment agroforestry system (control) with a surface runoff value of 535.7 mm. Meanwhile, the C treatment had the lowest infiltration of rainwater into the soil (500.2 mm). The reason is that the land surface of C, D and F treatments have more open canopies than that of A and B treatments. The raindrops in the C, D and F treatments directly on the ground surface with relatively high power. So there was little chance of infiltration. The B treatment agroforestry system had a surface runoff of 137.5 mm, resulting in the lowest surface runoff. These results are not significantly different from A treatment (162.3 mm). However, it is significantly different from the E agroforestry system (300 mm). The results are influenced by the denser canopies of A and B treatments. The dense canopies of A and B treatments have enabled raindrops to intercept, and part of the rainwater flowed through the stem as stem flow with low power so that there was a time of water to infiltrate into the soil profile.

Land surface runoff is the flow of water at the ground level because rainwater that descends to the earth exceeds land infiltration [12, 13]. If the infiltration is high, the water entering the soil will be higher and will produce lower runoff. Whereas if the infiltration is small, the surface runoff will increase.

The amount of surface runoff depends on rainfall, soil type and land use type [14, 15]. Some research indicates that the vegetation very much determines surface runoff on it. It is because vegetation contributes to litter, which can inhibit surface runoff and maintain soil aggregate stability [16, 17], and reduce rain power to be smaller due to canopy plants so that the soil is not easily eroded. Other factors that influence surface runoff in addition to the rainfall intensity and the land cover condition, including the land slope, soil type, and the presence or absence of rain that occurred earlier [18].

The condition of plants that play a role in the value of surface runoff is the closure of the leaf canopy. The higher the closure of the leaf canopy will reduce surface runoff. Besides, the type of plant also affects the value of surface runoff. The denser vegetation land cover is used, the less eroded soil as compared to the vegetation cover of randomly planted land [19].

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Table 2 also indicated that the D treatment of the agroforestry system gave the highest surface runoff value (565.6 mm / year) compared to the other patterns. The sequence of agroforestry system patterns that provide surface runoff from the largest to the smallest was D > C > E > A > B patterns, respectively.

The C treatment has a smaller surface runoff compared to treatment D. This is because, in C treatment, corn and cowpea canopy are denser than that of ginger and cowpea. The B treatment
provided the lowest surface flow rate because cassava has strong roots and can stabilize soil aggregates, and leaves that widen so that rainwater does not directly affect the soil. From the five treatments mentioned above, it turns out the combination of B treatment was a combination that provides the lowest surface runoff (137.5%) and can reduce surface runoff by 74.33%. In contrast, D treatment gave the highest surface runoff (565.6%) and increased surface runoff by 5%.

3.2. Erosion

The agroforestry system produces different erosion values for each crop pattern treatment. The average erosion of each treatment of the agroforestry system is presented in Table 3.

| Treatment of Agroforestry System | Crop Patterns | Erosion Rate (ton ha⁻¹ y⁻¹) | Erosion decrease (%) |
|----------------------------------|---------------|-----------------------------|----------------------|
| A                                | Sengon        | 2.2⁰                      | 46.35               |
| B                                | Sengon + coffee + gliricidia + cassava + cowpea | 1.5⁸                  | 63.42               |
| C                                | Sengon + coffee + gliricidia + cacao + corn + cowpea | 2.9 bc                | 29.27               |
| D                                | Sengon + coffee + gliricidia + cacao + ginger + cowpea | 3.4 c                | 17.08               |
| E                                | Sengon + coffee + gliricidia + ginger + corn + cowpea | 1.9³                  | 53.66               |
| F                                | Imperata cylindrica land (as a control plot) | 4.1 d                |                     |

Remark: Numbers followed by different letters indicates significantly different at 95%

The direct hit of rainwater on the ground will break the soil structure. The higher intensity of raindrops causes a more robust power to collapse soil structure. Furthermore, the soil particles fill and block the soil pores so that the water infiltration decreases. A decrease in water infiltration will increase surface runoff and ultimately increase soil erosion. Different ground cover vegetation will produce different surface runoff and erosion, where better ground cover vegetation will decrease surface runoff and soil erosion.

The results showed that B treatment (sengon + coffee + gliricidia + cassava + cowpea) gave the lowest erosion value (1.5 tons ha⁻¹ year⁻¹) and didn’t significantly different from that of E treatment (sengon + coffee + gliricidia + ginger + corn + cowpea) which was equal to 1.9 tons ha⁻¹ year⁻¹, but significantly different from that of A treatment (sengon plantation) with erosion values of 2.2 tons ha⁻¹ year⁻¹. C treatment (sengon + coffee + gliricidia + cacao + corn + cowpea) with erosion value of 2.9 tons ha⁻¹ year⁻¹, that of D treatment (sengon + coffee + gliricidia + cacao + ginger + cowpea) with erosion values of 3.4 tons ha⁻¹ year⁻¹ and that of F treatment (Imperata cylindrica) with an erosion value of 4.1 tons ha⁻¹ year⁻¹. Whereas A treatment (sengon plantation) was not significantly different from C treatment (sengon + coffee + gliricidia + cacao + corn + cowpea), but C treatment was not significantly different from the D treatment (sengon + coffee + gliricidia + cacao + ginger + cowpea). The highest erosion value occurs in D treatment (sengon + coffee + gliricidia + cacao + ginger + cowpea) which is 3.4 tons ha⁻¹ year⁻¹.

When erosion rate values put in order, the results of the treatment of the agroforestry system, from the highest to the lowest, were D > C > A > E > B treatment, respectively. The D treatment (sengon + coffee + gliricidia + cacao + ginger + cowpea) provides the highest erosion value (3.4 tons ha⁻¹ year⁻¹) compared to other treatments. While the B treatment provided the lowest erosion value (1.5 tons ha⁻¹ year⁻¹).
Three layers of canopies cause low erosion in the B and E treatments, i.e., the first canopy of sengon, second canopies of coffee and gliricidia, and third canopies of foods crops. In contrast, the intercept raindrop occurred gradually, so that runoff power was dropped, and the water mostly infiltrated into the soil profile. Therefore minimal runoff erodes the soil surface.

Higher erosion value of A treatment as compare to the B and E treatments because sengon trees have tall canopies, therefore there were opportunities of rainwater that were intercepted into relatively large grains of water and fell to the ground surface caused splash erosion. Although C and D treatments have three layers of canopies, their erosion values were still relatively high because food crops have a relatively short cycle, so that land was more often cultivated. On the other side, the erosion rate of F (Imperata cylindrica) treatment was the highest than the others, even though Imperata cylindrica covered the land. It was because the Imperata cylindrica leaf has an upright structure, so it was not effective in reducing the power of raindrops.

3.3. Tolerable erosion (T)
Tolerable erosion (T) is allowed erosion rate that does not exceed the rate of soil formation so that topsoil can be found for the place of plant growth. It is challenging to prevent or eliminate erosion until there is no erosion at all. Therefore erosion is allowable at a reasonable level [20]. Determination of T value is significant for agricultural businesses, so that appropriate methods of agricultural practices could be implemented. If erosion has exceeded the tolerable limit, it is necessary to make efforts to reduce erosion less than the T value, so that the agricultural practices could be maintained sustainably [21]. Therefore tolerable erosion is significant primarily related to soil planning [22]. In connection with this matter, the limit of T is the maximum speed of soil loss per year that is allowed, so that the productivity of the land can reach the optimum level for a long time. The limit is used here in terms of agricultural practices [23].

The factors considered in determining the value of T are the sufficient depth of soil, physical characteristics, and other soil properties that affect root development. A deep, medium-textured with moderate permeability has a lower layer that is good for plant growth, has a T value higher than shallow soil. Some of the lands have T values more significant than 11.21 tons per hectare [8]. The maximum T value for land in Indonesia is 2.5 mm per year, namely for deep soils with reasonable thickness of subsoil. Soils with less depth or lower impermeable properties, T values must be less than 2.5 mm per year [24]. The T values of the studied area are presented in Table 4.

| Treatment of Agroforestry System | T (ton ha⁻¹ year⁻¹) | Measured Erosion Values (ton ha⁻¹ year⁻¹) |
|----------------------------------|--------------------|------------------------------------------|
| A                                | 2.43               | 2.2                                      |
| B                                | 2.38               | 1.5                                      |
| C                                | 2.45               | 2.9                                      |
| D                                | 2.11               | 3.4                                      |
| E                                | 2.32               | 1.9                                      |

From Table 4, it can be seen that the C treatment (sengon + coffee + gliricidia + cacao + corn + cowpea) and the D treatment (sengon + coffee + gliricidia + cacao + ginger + cowpea) have measured erosion exceed their tolerable erosion (T) values. This table also indicates that the T value of D treatment is the lowest compared to other treatments.

Although the plots are located in the same area, the plots have various T values. However, T values are close to each other. The variation of the T values occurred because of the local variation of soil characteristics, such as soil depth, texture, even soil materials. This showed that every inch of soil has
different characteristics. The lowest T value of D treatment may be due to the position of the plot in the upper slope so that the weathering rate of the soil in this plot relatively lower as compared to other plots. The erosion rate of D treatment exceeding its T value because erosion values were relatively high due to food crops that have a relatively short cycle. Therefore, the land was more often cultivated, and its T value was the lowest as compared with the other treatments.

3.4. Erosion Hazard Index

The erosion hazard index value of the land is an index to know the danger level of erosion condition that indicates a threat of land degradation. The erosion hazard index is defined as a ratio value between potential erosion as indicated by measured erosion value and tolerable erosion (T) of a land.

Calculation results of erosion hazard index at the study area can be seen in Table 5.

| Treatment of Agroforestry System | Measured Erosion Values (ton ha\(^{-1}\) y\(^{-1}\)) | T (ton ha\(^{-1}\) y\(^{-1}\)) | Erosion Hazard Index | Grade |
|----------------------------------|---------------------------------|------------------|---------------------|-------|
| A                                | 2.2                             | 2.43             | 0.91                | Low   |
| B                                | 1.5                             | 2.38             | 0.63                | Low   |
| C                                | 2.9                             | 2.45             | 1.18                | Medium|
| D                                | 3.4                             | 2.11             | 1.61                | Medium|
| E                                | 1.9                             | 2.32             | 0.82                | Low   |

Table 5 shows that all treatments have low to moderate grades of the erosion hazard index. The A, B, and E treatments have low values of erosion hazard index, while the C and D treatments have moderate values of erosion hazard index. Low to moderate erosion hazard indexes of the studied area indicate that the agroforestry system reduced erosion at certain levels close or even lower than tolerable erosion values. The erosion values of all treatments were lower than that of the untreated with the agroforestry system (Table 3).

4. Conclusion

The *Imperata cylindrica* land has the highest erosion rate and relatively high runoff as compare to all agroforestry systems. Agroforestry systems might quite useful in suppressing runoff and erosion in community forest land. Low to moderate erosion hazard indexes of the studied area indicate that the agroforestry system reduced erosion at certain levels close or even lower than tolerable erosion values. The combination of plants in agroforestry systems can affect the amount of surface runoff and erosion. The more closure and stratified plant canopies in this system result in the lower intensity of surface runoff and erosion. The sengon (*F. moluccana*) based agroforestry system with a combination of sengon (*F. moluccana*)+ coffee (*Coffea sp.*)+ gamal (*G. septium*) + cassava (*M. utilissima*) + cowpea (*V. unguiculata*) was considered as the best combination compared to the other combination in this research.

Higher erosion value of A treatment as compare to the B and E treatments because the sengon trees have tall canopies, therefore there were opportunities of rainwater, which was intercepted into relatively large grains of water and fall to the ground surface causing splash erosion. Although C and D treatments have three layers of canopies, their erosion values are still relatively high because food crops have a relatively short cycle, so that land was more often cultivated. Although the land of F (control) covered by *Imperata cylindrica*, the erosion rate was the highest than the others. It because the leaf of *Imperata cylindrica* has an upright structure, so it was not effective in reducing the power of raindrop.
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