Soil losses and runoff variabilities in varieties of surface coverages

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Abstract. Soil erosion is a natural phenomenon of a landscape system. However, its occurrence has become a threat to the environment and human welfare when populations and human needs increase, especially in agriculture. Erosion can lead to soil deprivation and reduction of soil fertility that resulted in the decline of agricultural productivity and loss of arable land. Complex processes of soil erosion due to detachment, transport, and deposition, strictly depend on climatic, topographic, and biotic factors. Erosion can be worsened by extreme climate, that lately overrides, as the key-geomorphological process of erosion. Therefore, this research is aimed to understand how biotic factors such as different surface coverages can affect erosion within marginal agricultural soil. This study developed a small-scale erosion simulator with erosion pans and rain simulator. Standard small size erosion pan with width x length x depth of 32 x 45 x 20 cm and slope of 10° was used to simulate the erosion processes. Two erosion pans were planted with peanut (\textit{Arachis hypogaea}) and shallot (\textit{Allium cepa var. Aggregatum}). Furthermore, the other two were covered by litter and bare soil. Rain simulator was installed in 3 m of height and produced approximately 160 mm/hr of rain. Runoff water and eroded soil were collected and analyzed to find the amount of soil and water losses. From this experiment, it has shown that our proposed small-scale erosion simulator effectively demonstrates erosion and water runoff. This study found that soil erosion rates among plots were highly variable associated with the type of surface coverage. Variabilities soil coverage decrease the impact of raindrop and soil detachment.

1. Introduction
Soil erosion has been long known as one of the most threatening environmental problem worldwide [1][2]. Soil erosion is a complex process in which the process of detachment, transport and deposition occur [3]. The erosional processes closely depend on landscape morphology [2], rainfall [4] and land surface cover [5][6][7][8]. The attentiveness of sediment production was commonly given to agriculture land (e.g. [9][10][11][12]), where agricultural practices, such as continues ploughing and tillage may increase the risk of surface erosion. The loss of soil surface by erosion can lead to a further environmental degradation [13] such as the depletion of soil nutrients, the reduction of topsoil depth, and the decrement of water infiltration [14].

Erosion is significantly affected by spatial and temporal factors. Universal Soil Loss Equation
(USLE) [15] included at least five spatial and temporal factors: rainfall, soil erodibility, slope length and gradient, land management, and conservation practices. Changes in one factor can lead to the dynamics of sediment erosion. For example, sediment losses over 50 m length plot were 18.9% more (covered by maize) and 30.9% more (bare soil) than those in the 20 m length plot at Wangdongguo catchment, Changwu County, Shaanxi Province, China [16].

Sediment production varies spatially. Complex factors such as distinct vegetation coverage, hillslope gradient, and length have widely mentioned as factors triggering the increment of sediment production. Micro-topography, such as hillslope gradient and length, is undoubtedly influencing the increment of sediment production [2] [17] [18]. However, other than that, micro-climatic and eco-geomorphology of the hillslope can lead to tremendous effects on the variation of sediment production and material composition. During rainfall period, raindrop can be the main trigger of soil erosion [18] and can be worsened by very high rainfall intensity, that lately overrides.

The dynamic of eco-geomorphology processes on the soil surface such as transport and deposition of litter and presence of understory vegetation possibly instigate the variation of ground coverage and provide open sediment transport through hillslope [19]. The absent of understory vegetation has been widely mentioned for causing the increment of sediment production. The effect of understorey vegetation from Tanzawa Mountain, Japan, explained that soil with the minimum ground cover was more susceptible to the exposure of rain splash and sheet wash erosion than with denser ground cover [19]. The erosion rates in different land-use under Mediterranean condition, found that the lowest rates of runoff and sediment loss were found on the soil surface covered by olives grown with semi-natural understory vegetation, in which cover 90% of the ground surface, resulting in the minimization of surface water runoff [20].

Many methods have been carried out to assess the erosion rate in several surface coverages. Plots study was commonly used in evaluating soil erosion (e.g. [21] [22] [23]). However, most of the plot studies were applied in the field that continues monitoring might hardly be conducted, and the input parameters are difficult to be monitored. In this study, we experiment on the sediment production by developing laboratory-scale erosion simulator in different agricultural vegetation coverages. This research is aimed to understand how biotic factors such as different coverages can affect erosion processes within a critical agricultural land.

2. Material and Method

2.1. Developing erosion simulator

Erosion simulator was developed in particular purpose for simulating sheet erosion within small erosion pans with four different soil surface coverages (Fig. 1). This small-scale erosion simulator consisted of four small erosion pans and a rain simulator with a one-centred nozzle. Erosion pan was explicitly designed to be able to support wet soil inside and discharge the percolated water through small holes under it. The pans were made of a flat iron with a standard size of 32×45×20cm (width×length×depth) and were set with a slope of 10°.
Simulated rain must be applied onto the soil inside the erosion pans. The nozzle was installed right in the centre of the erosion simulator with 3 m of height from the soil surface. As we want to consider soil erosion cause by soil detachment and sheet erosion, the nozzles were chosen considering the size of the drops and its kinetic energy. Therefore, we elected to adopt standard angle full-cone nozzles from Spraying System, models GG-22 with corresponding to flow rate capacities (at 1.5 bar) of 11.5 l/min.

The produced artificial rain should be evenly distributed to the erosion pans with rain intensity approximately 160 mm/hr to simulates extreme rainfall intensity. To ensure that the rain intensity was the same in every part of erosion simulator, we measure the collected water from the rain simulator in five points (random sampling) for 10-minutes with measuring cup. Then, we standardized the water inside the cup to unit depth (mm/hr).

To catch the excess water and eroded soil, we placed measuring buckets in the bottom of erosion pans. The measuring buckets were changed every 3-minutes to know the fluctuation of sediment concentration from time to time. All the collected water and sediment then brought to the laboratory for detail analysis on the amount of runoff water and sediment concentration.

The collected sediment and water were separated using micro-filter paper. Filtered sediment was oven-dried at 105°C for 24 hours. Dried sediment and collected excess water were weighed to determine the amount of sediment and water losses from the experiment.

2.2. Type of soil and cover crops
Three erosion simulators were prepared for three repetitions, namely P1, P2, and P3. Each erosion simulator consisted of four pans for four samples with different coverages. Two erosion pans were planted with two different cover crops. Shallot (*Allium cepa var. aggregatum*) and peanut (*Arachis hypogaea*) were chosen as a productive agricultural commodity that may have the ability to prevent erosion. One pan was covered with litter, and one pan was left as bare soil. All samples got the same treatment. All plot samples were watered with 1 to 1.2 litter every two to three days. Wild weeds were trimmed every 2 to 3 weeks. Shallot was planted in the distance between the seed 15 x 15 cm, on the other hand, the peanut was planted in a distance of 20 x 30 cm between each seed.
Mediterranean soil was used in this study to know the process of erosion in critical agricultural land. The soil was explicitly taken from Selopamioro, Imogiri where the Indonesian government carried out extensive agricultural treatment. Selopamioro is located 15 km from the central Yogyakarta and has become the focus of agroforestry intensification in a dry land. The application of agroforestry-based diversification by the Indonesian government is expected to maintain the balance of nature and maintain this agricultural land to remain productive. Agricultural practice in this location is conducted by intercropping the productive fruit garden with several vegetable crops, corn and beans.

The Mediterranean soil colour tends to reddish-brown and less fertile. The soil mostly consists of clayey soil. From 100cc ring sampler analysis, the textures of the soil are clay with subangular blocky structure. Bulk density ($\rho_b$) and particle density ($\rho_p$) are ranged from 1.26-1.46 gr/cm$^3$ and 2.04-2.10 gr/cm$^3$, respectively. Porosity is ranged from 28 to 40%. The average of infiltration capacity was 265.10 mm/hr that classified as fast categories.

3. Results and Discussion

3.1. Variabilities of soil losses and surface runoff on different cover crops

One hundred and twenty samples were obtained during our experiment. Total sediment collected during the observation period from all twelve erosion pans was 80.74 grams (Tab. 1). Mean sediment production for all type of surface cover was 93.45 ± 95.56 gr/m$^2$/hr. Most significant mean sediment production occurred in bare soil plot with 175.07 gr/m$^2$/hr where 46.8% of the sediment is produced from the erosion pans, followed by 34.7% in the plot with peanut cover, 11.1% in the plot with litter cover, and 3.5% in the plot with shallot cover.

| Type of Soil Cover | Name of Plot | Total eroded soil [grams/m$^2$/hr] | Average eroded soil [grams/m$^2$/hr] | Surface runoff [liters/m$^2$/hr] | Average surface runoff [liters/m$^2$/hr] |
|-------------------|--------------|-----------------------------------|-------------------------------------|---------------------------------|-------------------------------------|
| Litter cover      | P1-1         | 65.84                             | 15.12                               |                                 |                                     |
|                   | P2-1         | 51.02                             | 41.21                               | 18.66                           | 14.61                               |
|                   | P3-1         | 6.77                              | 10.06                               |                                 |                                     |
|                   | P1-2         | 340.33                            |                                     |                                 |                                     |
| Bare soil         | P2-2         | 110.59                            | 175.07                              | 39.57                           | 32.80                               |
|                   | P3-2         | 74.28                             |                                     |                                 |                                     |
| Peanut (Arachis hypogaea) | P1-3     | 173.95                            |                                     |                                 |                                     |
|                   | P2-3         | 167.17                            | 129.58                              | 20.25                           | 21.36                               |
| Shallot (Allium cepa var. aggregatum) | P1-4     | 21.31                             |                                     |                                 |                                     |
|                   | P2-4         | 61.32                             | 27.93                               | 18.02                           | 13.24                               |
|                   | P3-3         | 47.61                             |                                     |                                 |                                     |

Table 1. Amount of soil losses and surface runoff.
Figure 2 Timeline of surface runoff

Total produced surface runoff was 17.72 litre, occupying 99.5% of collected sediment and water from the experiment. The mean surface runoff of all plots was 20.50 ± 11.50 l/m²/hr. The smallest surface runoff was found in plot covered with shallot with 13.24 ± 5.24 l/m²/hr, and the greatest was found in bare soil plot 32.8 ± 16.45 l/m²/hr.

The rain intensity in this study is considered to very high intensity with 160 mm/hr. The soil sheet erosion may also be produced on a hillslope with low infiltration capacities [24]. High and intense precipitation also trigger raindrop impacts and splash soil erosion [3]. Thus, the potential of soil erosion can be increased with the occurrence of high rainfall event [25].

Different response of sediment production and surface runoff found among plots, suggesting the variability sediment production associated with hillslope conditions. For instance, a plot with bare soil tends to have less surface coverage than the other plots producing higher sediment and runoff. On the other hand, a plot with litter and shallot with dense cover tends to have a smaller amount of sediment.

Vegetation plays a vital role in decreasing runoff and increases the possibility of sediment deposition [26] Rainfall will immediately become surface runoff or infiltrated into the soil, depending on the spatial conditions above the surface of the land. Incomplete spatial cover (wide intervals and low leaf cover) or long periods without significant cover in the planting system have higher erosion rates [21]. Soil erosion rate in hillslope with sparse cover was five-time greater than that of with cover [27].
Removal of understory vegetation such as S. spinosum from the forest ground increased the amount of runoff and sedimentation by two times greater than a forest with S. spinosum [22]. The results of the study conducted by The monthly soil erosion on land with shrubs is 58.7 g / m², lower than land with high tree plants (eucalyptus plants) which reach 99.5 g / m² [28]. This finding proposed that undergrowth (horticulture or shrubs) has a more significant role in reducing the amount of erosion because it is the last vegetation strata that determine erosion.

3.2. Dynamics of sediment production and surface runoff

The amount of produced sediment and surface runoff rose by time in bare soil and shallot plots, however, it tends to show stable amount for shallot and litter plots (Fig. 2 and 3). The response of sediment production and surface runoff among plots might closely related to hillslope conditions. The erosion rate in the plot without vegetation increased over time with an average erosion rate of 0.52 mm /hour or 4.3 times greater than the rate of erosion in plots with peanut plants. This is consistent with previous research [27] that the magnitude of the rate of soil loss in plots under shading and litter is 5.6 times greater than in plots with dense ferns and thick litter layers.

The amount of surface runoff in the plot with bare soil increases with time. However, the plots covered with vegetation and litter tends to keep a stable amount of surface runoff or rise after the 15 minutes. The average water runoff on the plot without vegetation was 1.2 greater than the runoff on the plot with peanut cover. The increment of surface runoff after some minutes might be related to the vegetation cover and soil condition that affect the erosion process. For instance, saturation of water storage through interception occurs at 10 to 30 minutes depending on litter thickness [29].
Our study shows that average soil losses indeed had a positive relationship with the average surface runoff (Fig. 4). Most of the plots show a significant relationship ($p < 0.05$) between sediment and water runoff production from the plots, except for plot with litter cover ($p = 0.19$). It proposes that the presence of stable litter cover might minimize sediment production by protecting the soil surface from rain, and deliver the rain through litter surface. Surface coverage on slope floor protect the soil surface from raindrop impact [27]; [30] and increase the residence time of surface runoff [31].

4. Conclusion
We evaluated soil losses in different surface coverages with erosion simulator. Sediment production was highly produced in the plot with bare soil than other plots covered with vegetation and litter. The presence of understory surface cover minimizes sediment production on hillslope by protecting the soil surface from disturbances and restrain downslope sediment transport. Litter cover on soil surface might increase the residence time of surface runoff.
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