Sustainability of three modified soil conservation methods in agriculture area

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Abstract. Recent innovations in soil conservation methods do not present any breakthrough. Providing more attractive soil conservation methods from the farmer’s perspective is however still of critical importance. Contributing to this soil research gap we attempt to evaluate the sustainable use of three modified conservation methods, namely JALAPA (Jala Sabut Kelapa - geotextile made of coconut fibres), wood sediment trap, and polybag system compared to traditional tillage without conservation method. This research provides both qualitative and quantitative analysis on the performance of each conservation measures. Therefore, in addition to the total sediment yield value and investment cost – as quantitative analysis, we also evaluate qualitatively the indicator of soil loss, installation, maintenance, and the durability of conservation medium. Those criteria define the sustainability use of each conservation method. The results show that JALAPA is the most effective method for controlling soil loss, but it also requires the most expensive cost for installation. However, our finding confirms that geotextile is sensitive to sun heating by which the coconut fibre can become dry and shrink. Wood sediment trap is the cheapest and easiest to install; however it is easily damaged by termite. Polybag method results in the highest productivity, but requires more time during the first installation. In terms of the farmer’s perspective, soil conservation using polybag system was the most accepted technique due to its high benefits; even if it is less effective at reducing soil loss compared to JALAPA.

1. Introduction
The number of alternative methods for soil conservation is still limited. Soil conservations are commonly conducted in the form of mechanics, vegetative, or chemical methods [9]. In Indonesia, terrace becomes the most accepted mechanic conservations among farmers (Bruijnzeel and Van Eijk, [4] [5], in spite of its ineffectiveness to reduce soil loss [11]. The vegetation-based method is considered to be the most efficient among the others [2]. In some areas, the vegetative method has been recognized to come through local wisdom within the society. Contrastingly, chemical method is less implemented due to high cost investment.

In 2014, the Indonesian government has officially established the Act Number 37 for Soil and Water Conservation. This Act legislated serious fines for anybody who intentionally ignore the implementation of soil conservation on their land. However, soil conservation is still regarded as a non-profitable activity among the farmers. Strict law enforcement of this Act might cause conflicts and difficulties to the society. Moreover, there are numbers of misconception among the farmers related to soil conservation that inhibit the acceptance of soil conservation [5]. Thus, providing methodological
and implementation breakthrough and more attractive soil conservation method from the farmer’s perspective is of critical importance.

Finding new strategy on soil protection should consequently consider the principle of soil conservation and the local resources [7]. This study aims to evaluate the sustainable use of three soil conservation technologies, namely JALAPA (Jala Sabut Kelapa), wood sediment trap, and polybag. The effectiveness of those three methods is compared with the traditional tillage system without any soil conservation method. JALAPA is a geo-textile made of coconut fibres from which the availability of the material is largely found in the study area. Wood sediment trap is simply made from piece of wood placed on certain point that could block the overland flow. Polybag is commonly used by the farmers for seedling phase. Soil erosion responses of those four conditions are monitored using plot erosion situated in Magelang District, Indonesia. We conducted a combination of quantitative and qualitative in evaluating each conservation method.

2. Material and Methods

2.1. Study area

This study was based on experimental study using series of field erosion plots. The plots area is located in Bompon Sub-catchment, Magelang District, and Central Java Province, Indonesia (figure 1). It is in the transition zone between Young - Old Sumbing Volcanoes and Menoreh Mountain. It is situated on 540 amsl. The morphological situation of this area is dominated by hill and valleys complex – with ±60 metres relative height difference. The volcanic ash of Sumbing Volcano has been highly weathered resulting in high content of clay within the soil layer. The volcanic intrusion process during Tertiary period of Menoreh had altered the bedrock into halosite clay mineral. The overlaying weathered volcanic ash on the altered clay mineral generated such a super deep soil (> 2 metres depth). High content of clay created pseudo-sand feature caused by clay oxidation process. The annual rainfall is quite high up to 3000 mm/year.

Combination of erodible material from the sensitive clay formation and high rainfall intensity control the erosion rate of this area. The pseudo-sand micro-relief is also eroded and transported during the erosion process, causing high sediment yield along the stream. Those situations are exacerbated by the tillage practice, mainly from the dry land agriculture. Cassava becomes favourite plantation among the farmers in this area (figure 2). During the beginning of growth (first 4 months), there is no significant canopy cover on cassava plant. The soil surface becomes completely bare without any protection against the rainfall and the overland flow energy.

Figure 1. Location of study area.
2.2. Erosion control plot set-up

The main concept behind this research is promoting conservation strategies that consider the ease of implementation, availability of material and resources in surrounding area, and provide the best economic return. In that sense, the local farmers may easily adopt the idea of this research (de Graaff et al., 2008). To fulfil those necessities, four erosion plots were constructed (figure 3).

Plot A implemented the geo-textile technology made of coconut fibre. Coconut becomes one of the valuable vegetation types for community livelihood in the study area. Despite its high availability, coconut fibre has not been utilized for soil conservation by the local farmers. Plot B was designed to apply the principal of sediment trap. A wood branch was placed right on each terrace edge along the plot. Plot C introduced the use of polybag plastic as planting medium. Polybag plastic has been used widely in Indonesia for seedling purpose. However, this planting method may become a solution in initiating the zero tillage concepts. Plot D was prepared for traditional planting method without conservation method, representing the common land management in this area. Each of plots was planted with local Chili (Capsicum annum L) that has good market price during that season.

The plots were situated in the upper slope with 20 degrees of inclination. The original slope had been modified with the construction of a terrace. Each plot had 1 m of wide and 10 m of length. Each plot was separated with 60 cm polymeric-rubber sheet. One third of the sheet was placed on the
ground and supported with bamboo sticks. The plot outlets were directed into a set of drums that could collect up to 400 liters of volume.

2.3. Erosion observation and sediment measurement
The plots had been monitored for 90 days, from October 2016 to January 2017. An automatic weather station was installed nearby these plots to collect rainfall event at 15 minutes intervals. Sediment samples were taken from the drum after daily rainfall event. The bed load and water inside the drums were mixed using a stick; and then immediately sampled by using 300 ml bottles. Those samples were sieved with 42Ø wattman paper. Drying processes were conducted for 8 hours using 105°C in the oven. To get the actual sediment content, each dried sediment sample was weighted and multiplied with the total measured volume in the drum for each sampling period.

3. Results and Discussion
This research provides both qualitative and quantitative analyses on the performance of the tested conservation measure. The total sediment yield is of critical quantitative information in most similar studies [8] [3]. There are only a few studies that thoroughly observe the mechanical process of erosion using similar comparison test setting. Therefore, in addition to the total sediment yield value, we also evaluate the indicator of soil loss, installation and maintenance, investment cost, durability of conservation medium, and productivity. Those six criteria define the sustainable use of each conservation method.

3.1. Soil loss indicator on each soil conservation methods
The complex mechanical processes of soil erosion are imprinted on soil surface. Most of the time, each soil erosion typology can be differentiated during field observation. Specifically, [10] elaborate a method for identifying and measuring indicators of soil erosion. This method is quite common for erosion rapid assessment or for spatial validation of any erosion model simulation. Each of our plots shows different indicator of soil loss.

Figure 4 (a) confirms the evidence of intensive splash erosion on Plot B (wood-sediment trap) and Plot D (traditional tillage). During the splash erosion, the raindrop forces and throws out fine surface material to several millimeters [9]. Those fine materials – mostly silt and clay- is then blocked and sticks on plot borders. Some of the splashes exceed the border’s height (+30 cm). In contrast, both Plot A (JALAPA) and Plot C (plastic polybag) do not result in significance splash feature (Figure 4-b). The groundcover created by JALAPA mats protects 50% of the surface area; thus raindrop does not produce significant splash effect. Raindrop gives effect to geo-textile mainly on the space between the mats; and it causes 40 mm of soil loss during observation period (Figure 5). However, soil beneath the geo-textile remains the same depth.

![Figure 4](image.png)

**Figure 4.** Indicator of splash erosion on (a) plot 2 and 4 are more evidence rather than on (b) plot 1 and 3.
Continuous splash energy from raindrop can cause soil crusting on any uncovered surface (figure 6 (a)). Moreover, soil in the study area is subject to soil crusting due to domination of clay and silt texture. Consequently, among plot B, C, and D experience soil crusting feature. In contrary, the JALAPA on Plot A effectively protects the soil surface from soil crusting effect. Soil crusting can reduce the soil surface infiltration and thus result in higher overland flow rate. A high overland flow rate can commence sheet erosion and even transport the available detached material from splash erosion. Figure 6 (b) confirms the intensive sheet erosion accumulated at the wood-sediment trap (Plot B).

The development of adverse erosion features during the observation period is dominated by rill erosion. Rill erosion is generated from concentrated overland flow that can cause soil loss 48 times higher rather than that of sheet erosion rate [9]. At our experiment sites, rill erosion occurs on both plot B and D (figure 7). However, the rills development between Plot B and D are moderately different in terms of rill dimension and morphology (table 1). Rill development on Plot B is obstructed by the wood-sediment trap, situated on the edge of terrace riser. Thus, the total length of rill in Plot B is shorter than that of Plot B. Rill development on Plot D continuously extend from the upper slope until the outlet. We do not find any rill initiation on plot A neither plot B. JALAPA on plot A increases in the surface roughness that prevents excessive overland flow rate and infiltrates more water into the
ground. In the same sense, polybag planting system becomes obstacle for overland flow and rill generation, since there are limited open spaces between polybags.

![Figure 7.](image)

Figure 7. (a) Rill erosion feature on Plot B; (b) Rill erosion feature on Plot D.

**Table 1.** Rill development.

| Rill development                     | Plot A | Plot B | Plot C | Plot D |
|--------------------------------------|--------|--------|--------|--------|
| Rill head from upper plot (m)        | -      | 2.3    | -      | 1.2    |
| Average depth (mm)                   | -      | 52     | -      | 56     |
| Average width (mm)                   | -      | 130    | -      | 139    |
| length (m)                           | -      | 5.7    | -      | 7.6    |

3.2. Soil erosion rate

The traditional tillage exacerbates soil erosion, as evidenced by the test-plot D (Fig.8). Soil erosion rate in this plot reaches up to 195.9 Kg - equal to 23.2 mm of soil depth loss. The embedded terrace system is not sufficient to protect the direct impacts of splash, sheet, and rill erosion in Plot D. Consequently, an unprotected terrace riser with steep inclination has promoted severe rill development (figure 7 (b)). This result is in line with the work of [9] explaining that uncovered terrace riser may cause serious soil loss problem. Considering this plot observation is only conducted in a period of one third of the rainy season. In the next 10 years soil loss could reach up to 695.0 mm if the land tillage management remains the same. Such a soil loss will become a serious issue to land productivity that will affect the annual income of the farmers.

One solution of this soil loss is the usage of JALAPA, which could effectively reduce the soil loss up to 43% compared to the traditional method of tillage (Figure 8). As a conservation medium, JALAPA has some advantages. It directly protects the ground surface from raindrop effects and intercepts the splashed material. Additionally, JALAPA considerably improves surface roughness on which runoff development could be limited. Its thick fibre absorbs water and slowly infiltrate to the ground. This result is in accordance with [1] who confirms the effectiveness of geotextile as soil and water conservation medium.
Figure 8. Comparison of sediment yield (in Kg) resulting from each plots erosion.

Both wood sediment trap and polybag medium also could control the soil loss rate up to 22% and 26% less than traditional method, respectively. Wood sediment trap has a maximal capacity to store the sediment depending on the wood height. When the sediment load already reaches the maximum capacity, sheet erosion will overtop the wood height and transport the material downward to the outlet. It implies that there should be extra maintenance for clearing the sediment trap periodically. In the case of polybag, it is less effective rather than JALAPA, but it is still slightly more effective than the method of sediment trap. The effectiveness can be increased by placing more polybag within the plot, since it will completely protect the soil material. However, we should consider the planting space to maintain an optimal growth of the crop.

3.3. Sustainability of conservation methods

In terms of soil loss protection, the three proposed conservation methods are already proven to reduce the soil loss rate (Figure 4-a). Nevertheless, the sustainability of a soil conservation method is not merely based on how much soil can be protected. Thus, we summarize the qualitative and quantitative performances of each plot that can imply their sustainability use.

Table 2 shows that none of the methods can completely fully the criteria of sustainability. Geo-textile are the best performer for soil loss control, but this method also requires the highest installation cost. Although coconut fibre is barely eaten by termite, our finding shows that geo-textile is sensitive to sun heat by which the coconut fibre can become dry and shrink (figure 4 (a) (b)). Wood sediment trap is the cheapest and easiest in installation process; however it is easily damaged by termite. Polybag method results in the highest productivity, but requires more time and money for first installation. Polybag is not only moderately effective in reducing the soil loss, but it also protects against the pest, i.e. mole cricket (*Gryllotalpa gryllotalpa*). A kilogram of chilli was valued up to 25,000 IDR, thus the farmers received 55,000 IDR from plot C with polybag. In terms of farmer’s perspective, soil conservation using polybag system can be more accepted due to its high beneficiary, even less effective in reducing the soil loss compared to JALAPA.
Figure 9. (a) Broken geo-textile due to continuous sun heating; (b) habitat of termite beneath JALAPA.

Table 2. Performance of soil conservation method.

| Conservation methods       | Soil Loss Indicator                                      | Soil loss depth (mm) | Investment Cost | Installation and maintenance                                      | Durability                        | Productivity                   |
|----------------------------|----------------------------------------------------------|----------------------|-----------------|------------------------------------------------------------------|-----------------------------------|--------------------------------|
| Geo-textile                | Low splash erosion, low sheet erosion                    | 13.2                 | 100.000 IDR     | • Quick installation (less than 1 hour)                           | • Moderate durability             | Low productivity (0.1 Kg of Chillies) |
| Wood sediment traps        | High splash erosion, moderate sheet erosion, moderate rill erosion | 17.9                 | Free of charge  | • Quick installation (less than 1 hour)                           | • Low durability                  | Low productivity (0.05 Kg of Chillies) |
| Polybags                   | Moderate splash erosion, moderate sheet erosion          | 17.1                 | Rp.1000/pc (65.000 IDR) | • Requiring more time (2 days)                                   | • High durability                 | High productivity (2.25 Kg of Chillies) |
| Traditional                | High splash erosion, High Sheet erosion, High rill erosion | 23.2                 | -               | -                                                               | -                                | High productivity (0.08 Kg of Chillies) |

4. Conclusions
We have evaluated the sustainable use of three soil conservation methods, namely JALAPA, wood sediment trap and polybag system. Comprehensive empirical analyses on the effectiveness and the efficiency of each method have been carried out to define the sustainability of each proposed conservation methods. Results show that JALAPA geotextile is the most effective method for soil conservation, but it is the most expensive one and it requires detailed maintenance for effective implementation. A negative aspect however is its sensitivity to sun heat and hot climate, making JALAPA a suitable method for areas with cool temperature regime and higher economic farming system (e.g, potato, cabbage, carrot, etc). Meanwhile, despite the easiness and readily available resources, the method based on wood sediment trap has proven to be insufficient to control sheet and rill erosion. Consequently, from the farmer’s perspective, soil conservation using polybag conservation method is the best acceptable practice due to its high beneficiary; even it is less effective than JALAPA in reducing soil loss.
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