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Soil erosion and overland flow from Acacia plantation forest in headwater catchment of Vietnam

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Abstract. To assess soil losses and overland flow in Acacia plantations of different ages, five plots (10m² /plot) was set up at different vegetation cover conditions (bare land, 4-month-old Acacia trees, 1-year-old Acacia trees, 2-year-old Acacia trees and 4-year-old Acacia trees) in Truong Son headwater, Hoa Binh, Vietnam. Soil erosion and overland flow was monitored over 75 storm events from September 2017 to October 2018. The main findings included: (1) Overland flow coefficient was highest at bare land (13.3 %), followed by 4month-old acacia (3.0 %), lower in Acacia forest at age 1 (1.5 %) and age 2 (1.4 %) and the lowest at 4-year-old Acacia (0.6 %); (2) The highest amount of soil loss was found in bare land (114.35 ton/ha/year) and decreased over ages of Acacia such as 30.33 ton/ha/year at 4- month-old Acacia, 13.90 ton/ha/year at 1-year-old Acacia, 13.22 ton/ha/year at 2-year-old Acacia and 3.94 ton/ha/6 month at 4-year-old Acacia; (3) Soil erosion and overland flow tended to be decreased due to increasing of Acacia ages with statistic significant difference (p-value < 0.01); (4) Soil erosion and overland flow in this study was higher than once of other previous studies. This suggests that more concern and applying suitable management for reducing the negative impact of Acacia plantation forest in headwater of Vietnam is necessary.

1. Introduction

Soil erosion and surface runoff has long been defined as a main cause of soil and water resource related issues in mountainous areas [1; 2]. Erosion is occurring strongly and seriously, every year, thousand tons of fertilized soil are washed away and then be carried to the low land area by the river or stream [3]. In the developing country, especially Vietnam, where the livelihood of indigenous people mainly depend on the agroforestry activities, the degradation of soil and water poses a big threat [4]. In general, erosion and runoff have the directly impact on all the aspects of ecological, social and economic aspect.

Among many site factors which govern the process of runoff generation and soil erosion as well as protect soil and water resources, vegetation cover is emphasized as a critical important factor [5; 6; 7, 8, 9]. Soil loss induced by runoff composes of detachment and transportation [10], as raindrop impact detach the soil surface and overland flow wash away the eroded sediment [8; 11]. The present of vegetation cover mitigates raindrop impact [12] and reduces the amount of overland flow [13; 14; 15], behind, it also have the ability to trap the sediment transported [16; 17]. Thus, vegetation cover inhibited runoff and erosion. Generally, overland flow and erosion rarely occur on the forested hillslope with high percent of ground cover and litter fall [14; 18]. For a long time, plants have been an effective way to combat erosion as well as being widely disseminated as a means of soil conservation [19].



The previous studies have shared the same view about the roles of vegetation on reducing runoff and erosion, however, the point is the ability to regulate water and reduce erosion are varied depend on the characteristics of plantation at different development stages. Forest with 3 canopy layers can reduce erosion to 3 times compare to forest with just one layer [20]. Behind, at the elder age, due to the large canopy, plants can transpire many times more water and it would lead to the distinctive impact on the infiltration and runoff process. Canopy interception also reduces the amount of precipitation falling on the ground, however it might increase the size of raindrop as a result of raindrop accumulation [21; 22]. The bigger root system have more power to enhance the soil stability and diminish the amount of soil loss [23; 24]. At different ages of forest, the understory vegetation and litter are also dissimilar, while ground cover is expected to be the key factor which retain water and soil by reducing soil detachment, soil crust and increasing infiltration [8; 12; 15].

In the mountainous provinces of Vietnam, the plantation economic model has been widely spread, *Acacia mangium* has become one of the major crop [25]. This fast-growing species is used for various purposes such as timber, firewood, agroforestry, land improvement [26]. Generally, the lifespan of *Acacia* is 7 years and the indigenous people do the different treatment for each development stage. At the end of the lifespan, they do the clear harvesting and after that they burn the left over to remove weeds and make ground preparation before starting new cycle. The roles of *Acacia* planted forest are undeniable, however it should be also taken into account the impact on the hydrological process inside the forest, especially runoff and erosion. Furthermore, the poor and unmanaged planted forest at head water area may lead to many serious consequences as it cannot regulate water and protect soil [9].

Though there have been numerous studies on the ability to protect soil of *Acacia mangium*, but still a lot of information has not been clearly elucidated. Understanding the effect of *Acacia* forest at different stages on runoff generation and erosion is essential for building a sustainable plantation forest model, which can facilitate the rainfall-runoff process as well as protect soil and nutrient in forested watersheds. The ultimate goal of this study was to assess soil losses and overland flow from *Acacia* forest in Luong Son headwater catchment of Vietnam. We measured the amount of runoff and erosion on the bare land and on *Acacia* forest at 4 ages.

2. Study site and method

The study was conducted in an *Acacia* forest of approximately 20 ha and a small area of bare land (about 150 m²) nearby, which located in Truong Son commune, Luong Son district, Hoa Binh province (Fig. 1a; 1b; 1c). About topography, Luong Son district is the midland - the transition between the deltas and mountainous, so the terrain is very diverse. The low mountainous terrain ranges from 200-400 m in height, formed by magma, limestone and terrigenous sediments, with a dense network of rivers and streams. Luong Son climate is tropical monsoon, with cold winters - less rainfall and hot summer - heavy rain. The average temperature of the year is 22.9 - 23.30°C. The average rainfall is from 1520.7 to 2255.6 mm/year, but unevenly distributed during the year and even during the season is very erratic (Data provided from Truong Son People committee).

To measure erosion and overland flow, 5 bounded plots were established. One plot was located at the bare land, and 4 other plots were located at 4 different stages of *Acacia* forest which consist of 4 month-old *Acacia*, 1 year-old, 2 year-old and 4 year-old *Acacia* forest. The general site factors of each plot were measured. The average slope and elevation was determined by using GPS, they are 24° and 64.8 m, respectively. Soil samples were taken by using bulk density tube then were analyzed at the lab. The soil is classified as feralit, with a light clay texture, the soil depth ranged from 0.7 to 1.2 m. The porosity of soil at bare land was lower than ones at other forest plots, the value of porosity varied from 25 to 40 %. The under story vegetation cover was measured by applying the Glama software, the result for bare land plot is 0.5 %, at the 4 month-old plot it is significantly higher at 62.9 %, while this value is lower at 1 year-old, 2 year-old and 4 year-old plot at 45.9 %, 36.5 % and 27.8 %, respectively. The percentage of litter fall at the bare land was 0 %, it increase with the increase in the age of tree and reach to the peak at 4 year-old *Acacia* plot at 11%. For *Acacia* plots, the mean canopy cover is 54.9 %, while the mean diameter at breast is 3.8 cm (Table1).

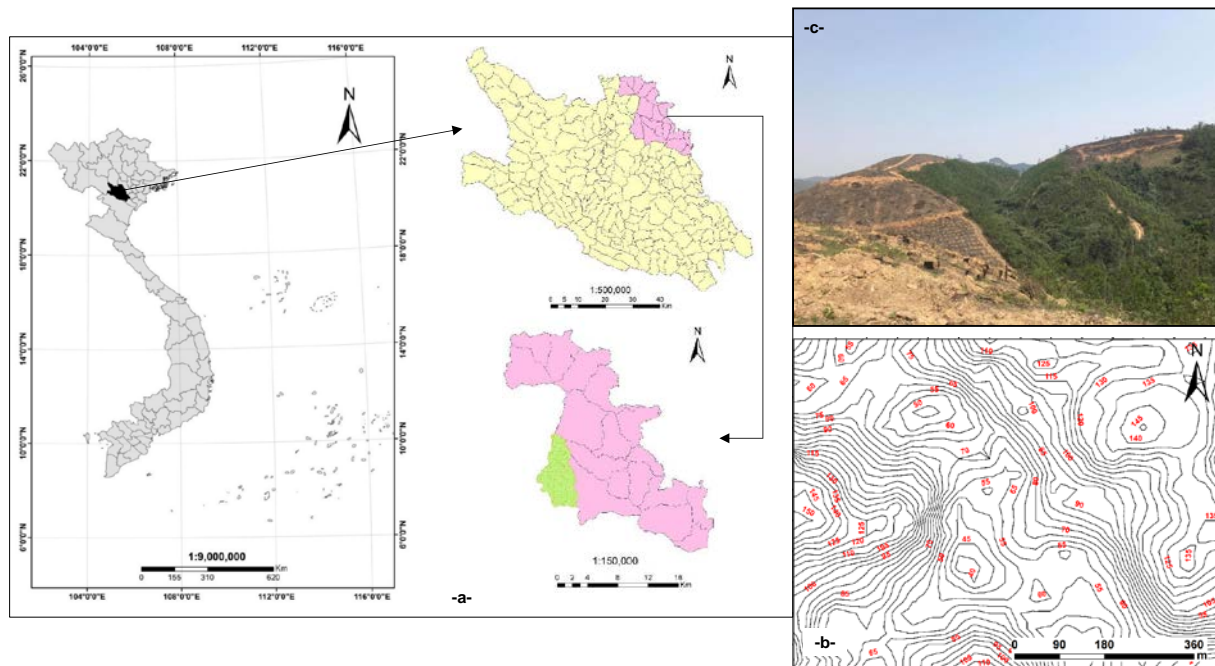


Figure 1. (a) Map of Truong Son Commune, Luong Son District, Hoa Binh Province; (b) Picture of study site; (c) Topography map of Truong Son Commune.

Table 1. Outline of five plots

Parameter	Bare land	4 month-old	1 year-old	2 year-old	4 year-old
Slope (°)	22	23	23	24	26
Elevation (m)	63	65	64	65	67
Soil depth (m)	0.7	0.9	1.0	1.0	1.2
Porosity (%)	25	28	39	40	38
Understory vegetation (%)	0.5	69.2	45.9	36.5	27.8
Canopy cover (%)	0.0	0.0	60.3	73.9	85.3
Litter fall (%)	0.0	3.5	8.5	9.5	11.0
Density (trees/ 10 m ²)	0	4	4	3	4
Average DBH (cm)	0.0	1.0	2.2	3.6	8.5
Average Height (cm)	0.0	0.6	3.2	4.0	6.2

Each plot was 10.0 m² (2.5 m width x 4.0 m length) and it was bordered by an aluminum plate. The aluminum plate was buried 0.1 m deep into the soil; 0.3 m height above the ground and it was held and reinforced to stand upright by steel wires and bamboo piles, by that way of installing, it could be ensure that aluminum plate can stand firmly and it can prevent the impact of rain splash and the entrance of runoff from out site. To catch overland flow and the sediment carried by overland flow, at the end of each plot an aluminum trough (2.5 m width, 0.3 m length, 0.3 m height) was installed. The trough was covered above with a plastic roof so that rainfall could not fall in [15] (Fig. 2). Using a plastic tube to connect the trough with a plastic reservoir (250 L). Overland flow and sediment were caught by the trough, then flowed through the plastic tube to the reservoir. Plastic rain gauge was installed in an open area near the study plots to measure rainfall over the monitoring periods (Fig. 2a).

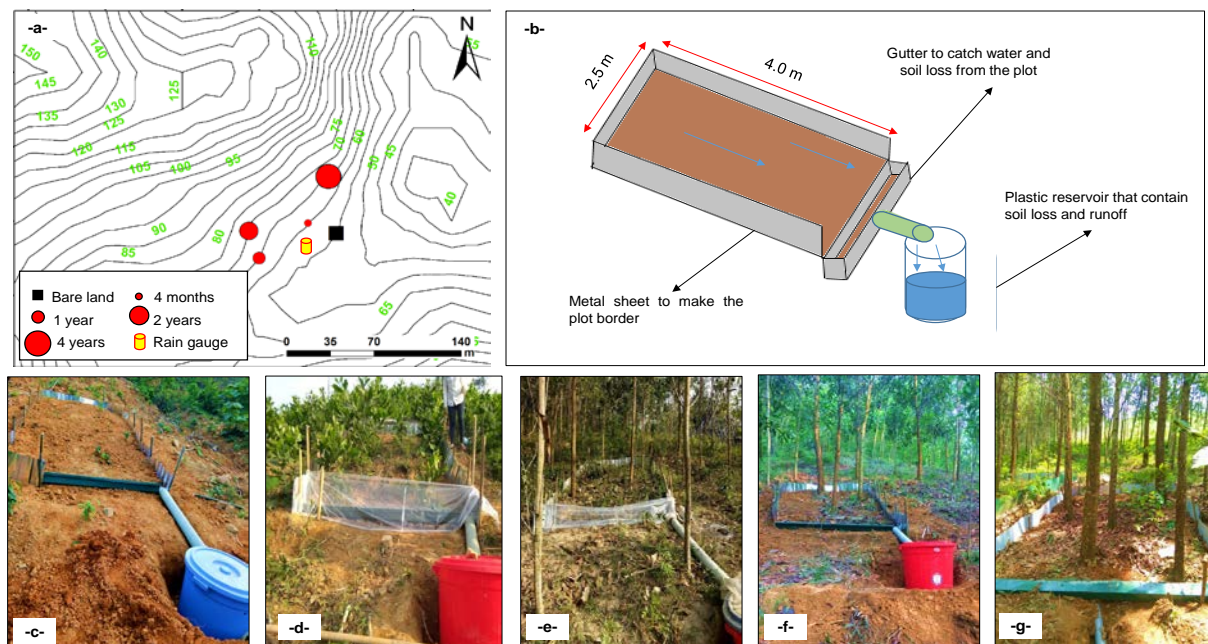


Figure 2. (a) Topography map of the study site; (b) Model of bounded plot; Picture of (c) Bare land plot; (d) 4 month-old plot; (e) 1 year-old plot; (f) 2 year-old plot; (g) 4 year-old plot.

In the first period from September 2017 to December 2017, 4 plots at bare land, 4 month-old Acacia, 1 year-old Acacia and 2 year-old Acacia were monitored. From April 2018 to August 2018, plot at 4 year-old was monitored in additional, totally, over this period all 5 plots were monitored.

Overall, 75 rainfall events were supervised. The interval of at least 6 hours was applied to distinguish rainfall events [15]. Rainfall was measured after each storm even by reading the height of rain water inside the rain gauge. The threshold of rainfall was defined as the smallest amount of rainfall which could induce runoff. The time of each rainfall was also recorded, rainfall intensity (mm hour^{-1}) was calculated by dividing the amount of rainfall by the hour of rain. Antecedent rainfall index for 7 days (ARI7) was defined as the surface soil moisture [15] and it was measured by sum up the time weighted amount of rainfall in 7 previous days.

Using a 3 liter plastic bucket to measure amount of overland flow from plot, which was contained by the reservoir. As sediment settled down, so at first overland flow could be measured directly, but for the lower part, where water was turbid, and then it need to be filtered first. In the field, overland flow was measured in the unit of liter (L), after that it was converted to the unit of millimeter (mm) by diving the amount of overland flow (L) by the area of plot. All the eroded soil from plot which was settled down at the bottom of the reservoir as well as the soil stuck in the trough and the plastic tube, was collected and dried at 150°C for 24 hours. After the soil was dried, it was weighted to define the amount of soil loss in the unit of gram (g).

The correlation between overland flow and both rainfall and API7; between soil loss and rainfall as well as soil loss and runoff were examined by using SPSS software.

3. Results and discussion

3.1. Rainfall and Overland flow response

The number of storm even during the monitored period was 75. The lowest amount of rainfall was 0.5 mm on 29th October 2017. The highest amount of rainfall was 197 mm on 19th July, 2018 (Fig. 3a). The average amount of rainfall was 33.7 mm while the amount of rainfall accumulation was 2528.4 mm (Fig. 4a). Rainfall intensity from 75 storm events ranged from 0.3 mm/hr to 23.9 mm/hr. The maximum intensity was 23.9 mm/hr, which was recorded at intervals of 8.25 hours with total

precipitation 197 mm (19/07/2018). The minimum intensity was 0.3 mm/hr, which was recorded at intervals of 6.2 hour with precipitation 2 mm (Fig. 3a).

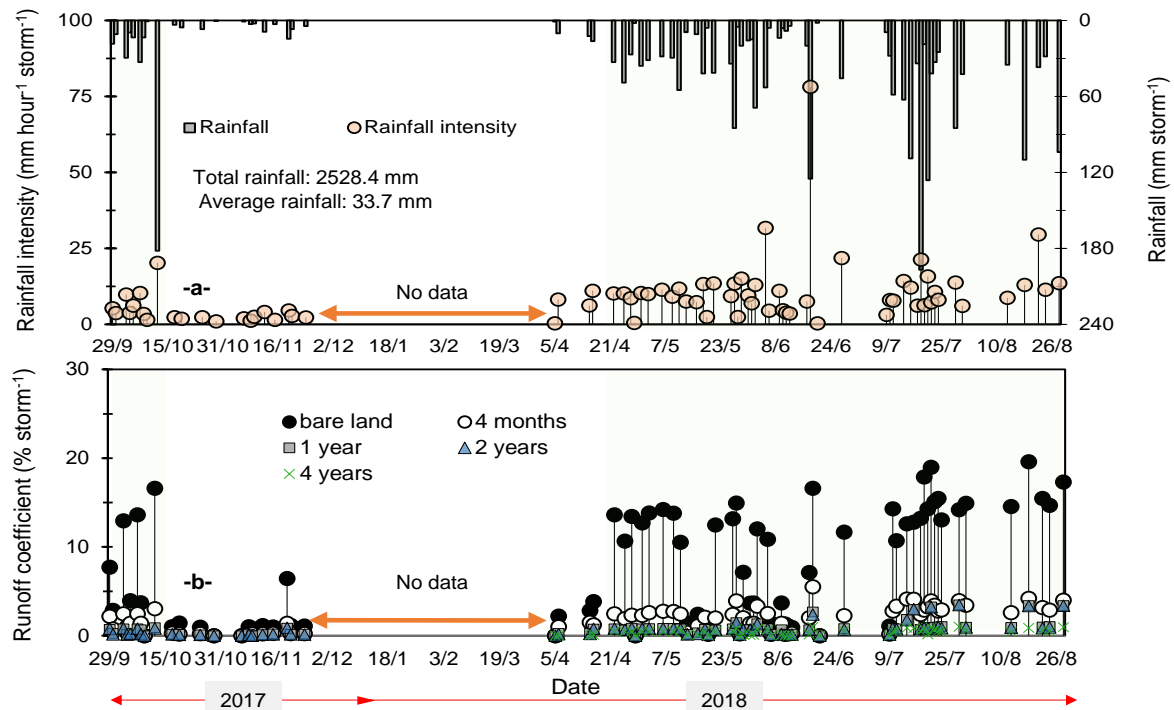


Figure 3. (a) Rainfall and rainfall intensity; (c) Overland flow coefficient from 5 plots over the monitoring plot. The shaded area is refer to the rainy season.

The rainfall threshold which caused the surface flow in five plots also had different levels, in more detail: plot 1 was 2.5 mm; plot 2 was 5.5 mm; plot 3 and plot 4.0 was 7.0 mm, and plot 5 was 8.4 mm (Fig. 3). Overland flow in the five plots heeded the changes with a relatively uniform trend. The overland flow coefficient was varied between each plot, the runoff coefficient after 75 storm events at bare land was 13.3 %, at 4 month-old Acacia was 3.0 %, at 1 year-old and 2 year-old Acacia runoff coefficient in turn was 1.5 % and 1.4 %, at 4 year-old Acacia it dropped to 0.6 % (Fig. 3b). Overall, after the monitored period, the amount of runoff accumulation was the highest at bare land plot, intermediate at 4-month-old Acacia plot, the second-lowest at 1-year-old Acacia plot, third-lowest at 2-year-old Acacia plot and the lowest at 4-year-old Acacia plot with the average runoff accumulation equal to 334.99mm, 76.24 mm, 36.92mm, 35.76mm and 14.33 mm, respectively (Fig. 4a).

The result of the T-test indicated that there was the significant different in the amount of overland flow response among plots (p value < 0.00), except for plot 1 year-old and plot 2 year-old (p value > 0.05) (Fig. 4b). Overland flow had strong relationship with precipitation (p value < 0.00) whereas, it was not correlated with API7 (p value > 0.05) (Table 2).

The highest overland flow at bare land might be explained by two factors, which are vegetation cover and leaf litter. Previous researches have proven that plant play an irreplaceable role in penetrating runoff and protecting soil. Especially, floor coverage is vital for diminishing soil erosion [8]. Behind, the root systems were capable of penetrating the soil layers to improve the soil infiltration capacity, reducing the volume of surface runoff as a result of the high infiltration rate afforded by the addition of organic matter to the soil [27]. Bare land plot induced highest amount of overland flow, it is attributable to the fact that this plot had very low percentage of vegetation cover at just 0.5 %, it also had no litter fall, canopy cover as well as had no root systems (Table 1). At the 4 year-old Acacia plot, the figure for overland flow coefficient drop to 0.6 %, and it was the lowest compared to other plots. Other studies also shared the same result that in the forested hill-slope, overland flow rarely occurs [8;

14; 18]. This study also consented with Miyata. et al [8], who reported that the annual overland flow yields in without-floor coverage plot was 1.7 - 3.6 times greater than in floor coverage plot, proving that coverage was responsible for the decreased surface runoff.

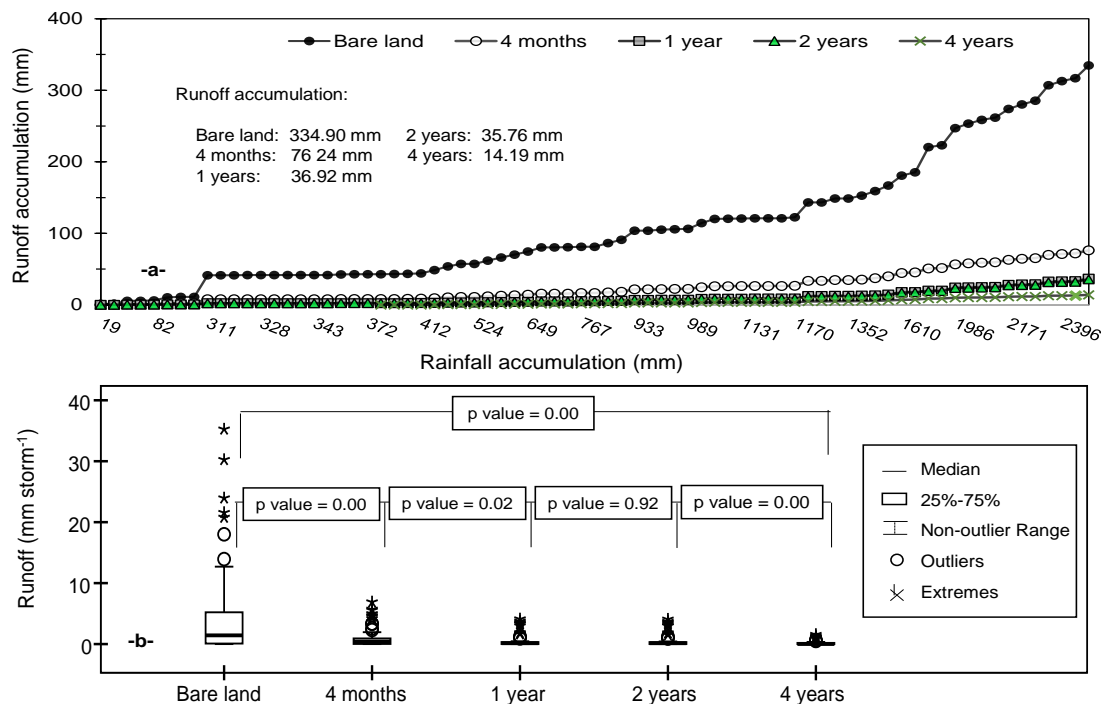


Figure 4. (a) Runoff accumulation from 5 plots over the monitoring plot; (b) Overland flow from 5 plots over the monitoring period. P value > 0.05 indicated that there was no statistically different between the figures for two plots.

Table 2. Summary of correlation analysis between overland flow, soil erosion and both rainfall and soil moisture characteristics.

Plot	Overland flow & Rainfall		Overland flow & ARI7		Soil erosion & Rainfall		Soil erosion & Overland flow	
	R ²	p-value	R ²	p-value	R ²	p-value	R ²	p-value
Bare land	0.96	< 0.00	0.04	> 0.05	0.90	< 0.00	0.83	< 0.00
4 month-old	0.92	< 0.00	0.03	> 0.05	0.89	< 0.00	0.90	< 0.00
1 year-old	0.71	< 0.00	0.03	> 0.05	0.71	< 0.00	0.89	< 0.00
2 year-old	0.70	< 0.00	0.02	> 0.05	0.70	< 0.00	0.84	< 0.00
4 year-old	0.96	< 0.00	0.05	> 0.05	0.87	< 0.00	0.75	< 0.00

The amount of overland flow at Acacia forest plots were lower than that at bare land plot, especially, it decreased as the age of forest increased. 4 month-old plot had highest understory vegetation cover at 69.2 %, however it had low percentage of litter fall at 3.5 % and it also had the

lowest porosity of soil (Table 1). Behind, the very small Acacia tree had the undeveloped root system and canopy cover. It should be noted that at this very young stage, the soil is not stable, as it was disturbed by the previous harvesting activities. Normally, the lifespan of Acacia tree is 7 years, when tree is mature, the indigenous people will do clear-cut, after that, they will burn all the residual to remove weeds before they start to plant the new forest. The impact of clear-cutting and burning together with the soil compaction caused by machine and vehicle, which were used to support for the cultivation activities - resulted in the serious soil disturbance. For the short period, soil under new planted Acacia forest could not rehabilitate. Thus, human disturbed activities would be the factor behind the fact that amount of overland flow from 4 month-old plot was higher than other plots, which were covered by Acacia forest at the higher stages. Another study, which focused on the infiltration characteristics at different ages of Acacia forest and was conducted in the same study site, at the same period has showed that there was the positive relationship between the infiltration rate and the age of tree [28]. Soil with high infiltration rate will reduce the rate of infiltration excess overland flow [29].

Comparing with previous research on runoff from other land use type in the world [30], it could be seen that the overland flow coefficient of Acacia in this case was much greater (Fig. 5). This result was related to the Acacia plantation location, this was the headwater area with the height of 60 - 400 m and the steep slope. Steeper slope is a key factor which enforce the ability to generate overland flow and soil erosion. Besides, the porosity of soil in this study was lower than ones from other studies, it just ranged from 25 % to 48 %. Infiltration rate at the study site was also not as high as ones at other locations [28]. Furthermore, the cultivation activities of indigenous people in the mountainous area of Vietnam has not been sustainable, it might be the reason for the high overland flow coefficient.

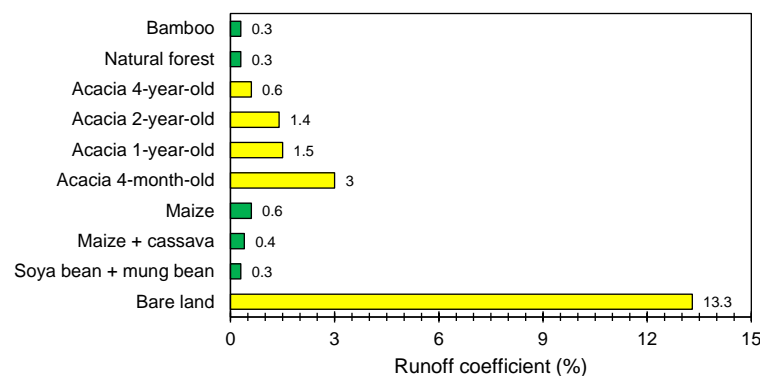


Figure 5. Comparing overland flow coefficient from this study with other previous study in the world. The compared results adopted from the study of Aru and Barrocu [30].

3.2. Soil erosion

The amount of soil loss was relatively quick responded to rainfall. Over 75 storm events, the amount of soil loss accumulation at bare land plot was 103.75 kg, it was 3.8 times higher than that at 4 month-old plot (27.52 kg), was 8.3 times higher than that at 1 year-old plot (12.60 kg), was 9.1 times and 29.1 times higher than that at 2 year-old plot (11.99 kg) and 4 year-old plot (3.57 kg), respectively (Fig. 6a).

With the same result as overland flow, the amount of soil loss exported from 1 year-old and 2 year-old Acacia plot was not substantial different (p value > 0.05), in contrast, there was the statistically significant different these two plots and other plots as well as the different among other plots (p value < 0.00) (Fig. 6b). This result showed that the elder stage of forest diminished the amount of soil loss, however, at the age of 1 year and 2 years, the amount of soil loss was nearly equal. The sediment yield at bare land plot, 4 month-old plot, 1 year-old plot, 2 year-old plot and 4 year-old plot was 144.36 ($\text{ton ha}^{-1} \text{ year}^{-1}$), 30.33 ($\text{ton ha}^{-1} \text{ year}^{-1}$), 13.90 ($\text{ton ha}^{-1} \text{ year}^{-1}$), 13.22 ($\text{ton ha}^{-1} \text{ year}^{-1}$) and 3.94 ($\text{ton ha}^{-1} \text{ 6 month}^{-1}$) (Fig. 7).

Soil loss was sharply determined by both the amount of rainfall and overland flow (p value < 0.00) (Table 2). It mean that the higher amount of rainfall and higher amount of runoff resulted in higher amount of soil loss exported.

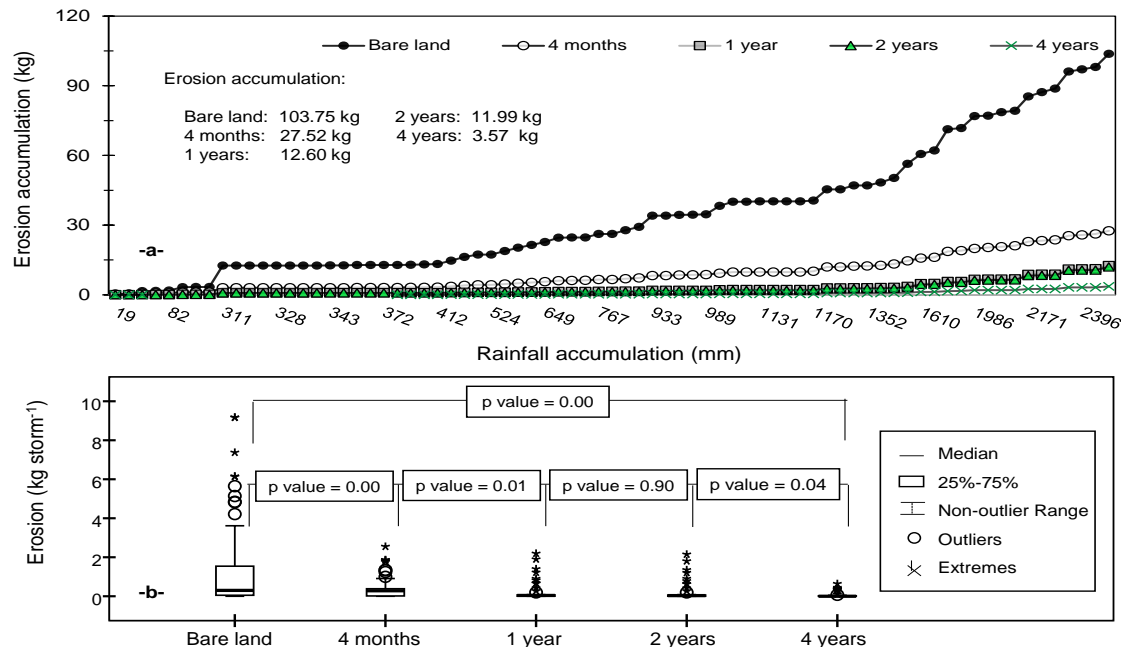


Figure 6. (a) Erosion accumulation from 5 plots over the monitoring plot; (b) Erosion from 5 plots over the monitoring period. P value > 0.05 indicated that there was no statistically different between the figures for two plots.

Over the 75 storm events, the amount of soil erosion accumulation reached to the peak at bare land plot while it was significantly lower at the Acacia plantation plots. There are several scientific based reasons to explain for this result. Normally, in the process of erosion induced by runoff, soil is detached by the raindrop and transported by overland flow [10; 24]. Splash erosion is emphasized as the main erosion component [24] and it negative impacts can be mitigated by ground cover [12]. Bare land had the negligible percentage of understory vegetation and had no litter fall, so the rain splash erosion was likely to occur here. Besides, the amount of overland flow from bare land plot was much higher than that from the rest plots, as a result, the amount of soil loss in response to overland flow from bare land was also the greatest. Miyata et al [8] also found that erosion rate at bare land area was 3.7 times higher than well vegetated plot, whereas, Miura et al [31] stated that sediment transported from vegetation removal plots were 10 times larger than plots which were covered by Japanese cypress forest.

Sharing the same result as overland flow, the amount of soil loss was different among Acacia forest plots, and it was lower as the forest getting elder. As we have mentioned above, overland flow was one of the factors causing the high erosion rate. The different in the amount of overland flow caused the varied in the amount of soil loss response as they have strong relationship. Besides, differences in soil erosion at different vegetation types can also be explained by different porosity [32]. The porosity of these 4 plots increase with the increase in the age of forest. 4 year-old forest had the highest porosity so it had less infiltration excess overland flow and the soil loss exported from this plot was the smallest among other Acacia forest plots. Moreover, the canopy and the root system also played an important role in reduced erosion. Large canopy interception might cause the lower net precipitation and high root density might help keeping the soil particle and strengthening soil [24]. At the elder stages of forest, both canopy and root system were more developed, it resulted in the decreased

amount of soil erosion. Although some previous study have found that in term of erosion eliminating, understory vegetation cover was more important than canopy cover as raindrops accumulated on the canopy and when it fell down it would become bigger with higher kinetic energy [21; 33], but for this case, the height of tree at 4 year-old was not high (6.2 m) and the ground was covered with both understory vegetation and litter so the erosion rate was still small. Another reason for the lower soil loss at 4 year-old forest might be attributable to the human activities. As people made the severely soil disturbance before they grow the new forest so at the 4 month-old forest the soil structure was still weak and erodible, but by the time the soil quality would recover and become more stable, so at the later stages of Acacia forest the amount of erosion was smaller.

The amount of soil erosion in the study at different ages in Acacia was greater than in some other studies [34; 35] (Fig. 7). Most of the increases in soil erosion was attributed to vegetation cover change. As mentioned above, it can be explained by factors such as soil type, plot scale, vegetation cover type, density, etc. The soil type in this study area is feralit. Characteristics of this type is thick weathered crust, airy soil, drainage, poorly polluted substances, many iron oxides, aluminum, easily degenerated. Besides, the overland flow of Acacia forest in this study was also the higher compare to other studies. Furthermore, difference in distribution of headwater plantation and growth cycles of Acacia is also one of the causes of severe erosion in the study site. Clear cutting and burning after harvesting 7-year-old Acacia to prepare the ground and deforestation for the new cycle contains the potential risk of severe soil erosion.

The result of the T-test indicated that there was the significant different in the amount of overland flow response among plots (p value < 0.00), except for plot 1 year-old and plot 2 year-old (p value > 0.05) (Fig. 4b). Overland flow had strong relationship with precipitation (p value < 0.00) whereas, it was not correlated with API7 (p value > 0.05) (Table 2).

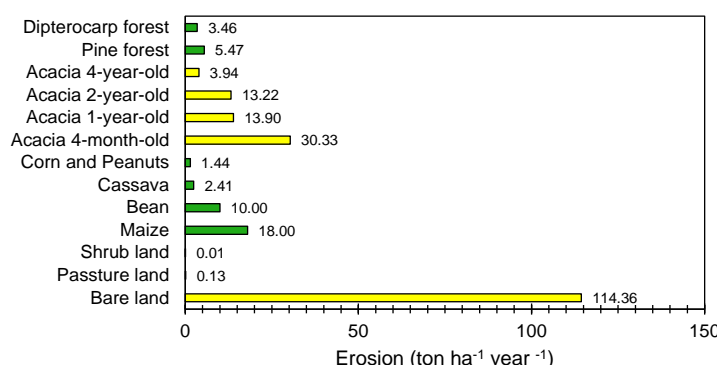


Figure 7. Comparing soil erosion from this study with other previous study in the world. The compared results adopted from the study of Mohammad and Adam [34], and Craswell et al [35].

4. Conclusion

Overland flow coefficient was highest at bare land (13.3%), lower in ages 1-2 of Acacia and the lowest at 4-year-old Acacia (0.6%); The highest amount of soil loss was found in bare land (114.35 ton/ha/year) and decreased over ages of Acacia such as 30.33 ton/ha/year at 4-month-old Acacia, 13.90 ton/ha/year at 1-year-old Acacia, 13.22 ton/ha/year at 2-year-old Acacia and 3.94 ton/ha/6 month at 4-year-old Acacia; Soil erosion and overland flow tended to be decreased due to increasing of Acacia ages with statistical significant difference (p -value < 0.01); Soil erosion and overland flow in this study was higher than ones of other previous studies. This suggests that more concern and applying suitable management for reducing the negative impact of Acacia plantation forest in headwater of Vietnam is necessary, especially for the case of Acacia plantation forest at the young age.

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