



Original Article

## Runoff Generation and Soil Erosion at Different Ages of Acacia Plantation in Hoa Binh Province, Vietnam

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Received 20 December 2018

Revised 22 March 2019; Accepted 31 August 2019

**Abstract:** To determine the characteristics of runoff generation and soil erosion at the different ages of Acacia plantation in Luong Son headwater of Vietnam, four plots ( $15\text{m}^2 \text{plot}^{-1}$ ) were set up. Of those, two plots were at up-hill and down-hill in 1-year-old and two plots in 5-years-old Acacia plantation. Soil erosion and runoff were monitored during rainy season from April to September 2018. The main findings include: (1) Runoff coefficient at Acacia 1-year-old down and up ranged from 0.36% - 0.46% with the average 0.41%. Acacia 5-years-old, down and up was 0.35% - 0.39%, averaged 0.37%. It shows the slightly differences between the locations of two years due to the different ground cover but not statistically significant different; (2). Soil erosion in Acacia-1 and Acacia-5 year old were 21.84 and 14.20 ton/ha/6months, respectively. The data for soil erosion was statistically significant different between two ages of Acacia plantation. Soil erosion at the study site was very high within strong erosion base on TCVN5299: 2009; (3) Both runoff and soil erosion had strong relationship with precipitation ( $R^2$  range from 0.52-0.85, with P-value = 0.00). This result suggests that more concerning and applying suitable management for reducing the negative impact of Acacia plantation at the headwater of Vietnam is necessary.

**Keywords:** Acacia plantation forest, runoff generation, soil erosion, vegetation cover.

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<https://doi.org/10.25073/2588-1094/vnuees.4353>

## 1. Introduction

Soil loss induced by runoff in mountainous areas has long been recognized as a main cause of soil degradation as well as other down-stream water problems [1, 2]. Erosion is occurring strongly and seriously, every year, thousand tons of fertilized soil are washed away and then will be carried to the low land area by the river or stream [3]. It does not only directly affect the agroforestry production activities but also affect the environment and the life of the downstream communities as land degrades rapidly in all aspects: chemistry, physics, and biology [4].

Soil erosion has been being an environmental concern in such countries as China and those bordering the Mediterranean Sea for millennia [5]. The potential of estimated soil loss is about 0.38 mm/year. The most seriously affected region in the world is the Southeast Asia. It nearly 60% of present soil erosions are induced by human activity, global warming, the increasing trend of precipitation and population growth [2]. Erosion happens quite frequent in Asia, Africa and South America with the soil mass from 30 to 40 tons per hectare for every year. In 1997 during the flood season on lower forest and floodplain in Cambodia, 84.6 million tons of soil were washed from the Lancang Jiang to the lower Mekong. The annual sediment load of the basin was estimated around  $67 \times 10^6$  tons/year at Chiang Saen [6].

Runoff generation and soil erosion mostly occur at the headwater area [7]. In recent years, the mountainous areas in Vietnam have lost a large amount of soil due to erosion. According to land use analyzed, Vietnam has about 25 million ha for steep land with huge potential for erosion, about 10 ton/ha/year [8]. According to systematic monitoring from 1960 until now, there is 10-20% of area affected by erosion from moderate to strong [1].

Runoff and erosion are determined by a number of cite factors such as precipitation, soil properties, topography and especially vegetation cover [7, 9]. Many previous studies have proved the roles as well as the impacts of vegetation on protecting soil and water resources [7, 10-13]. In general, natural forest land has the ability to

penetrate and retain water well due to its high water consumption, strong roots rooted deep into the soil, while natural forests also have a thick mater of thick soils, from which soil erosion was significantly reduced [14, 15]. In the past, many studies have found that in the forested watershed, ground flow and saturated overland flow were the main flows [14]. Further, there are many studies which found that the stems of plants can trap runoff then reduces the amount of soil eroded [16, 17]. However, in recent years, the large area of natural forest has been replaced by the low quality planted forest, and these forest can not well performed the function of soil protection and water regulation [3]. Under the poor ground cover condition, the impact of raindrop will be higher, the amount of runoff runoff and soil erosion will be larger [7,12,18, 19].

Previous studies have also concluded that the ability to regulate water and reduce erosion varies depending on tree species, behind, the different ages of tree also determine the process of runoff generation and soil erosion in different ways [3, 20]. Runoff and soil erosion are also governed by the canopy cover. Forests with more layers have higher ability to retain water and soil than forest with just one canopy layer, the amount soil erosion will be three times higher than the forest with three canopy layers. The change in canopy cover may result in the change in understory vegetation, the amount of through fall and the impact of raindrop [7, 21].

In Vietnam, about 24% of the forest area is planted forest, in which *Acacia mangium* is a popular crop, which brings high economic value [22]. *Acacia mangium* is a native species in northern Queensland (Australia), found in Iran Jaya, Maluku, Indonesia. This is a fast-growing species, which is widely used for various purposes such as timber, firewood, tannery, and agroforestry and soil improvement. From the economic and social benefits of Acacia, the Acacia plantation area is expected to increase every year. The area of plantation forest tends to increase annually [22]. In the mountainous areas of Vietnam, due to the sloping hilly terrain combined with large annual precipitation, surface runoff and erosion are serious issues in

the management of land and water resources. Additionally, the indigenous people are tending to growth more industrial plantation – especially Acacia as it can improve their livelihood. However, the lack of a database reflects the relationship between Acacia plantations and the generation of surface runoff and erosion in Vietnam, leading to difficulties and challenges in the development of plantation forest models to achieve the best environmental performance. To further clarify this issue, and present the solutions, we conducted this study on *Runoff generation and soil erosion at different ages of Acacia plantation in Hoa Binh province, Vietnam.*

**2. Study site and methods**

*2.1. Study site*

The planted Acacia forests in Chanh village,

Truong Son commune, Luong Son district, Hoa Binh province were chosen to be the monitored area. The coordinate is 20°51'N 105°27'E (Fig. 1). The total area of this commune is 3060 ha, in which forest accounts for 2610 ha with the total area of Acacia plantation forest is up to 1360 ha occupied 52 % of total areas. The rainy season is normally from May to October with both a high frequency and intensity of rainfall. In August and September, rainfall reaches the peak at values from 300-400 mm per month. The rainfall during this period accounts for 84–90% of the annual rainfall. The frequency and intensity of the rainfall are concentrated over a short period where rainstorms and super rainstorms are major contributions to the landslide hazard in the area [23]. Generally, average precipitation ranges from 1520-2255 mm per year [24].

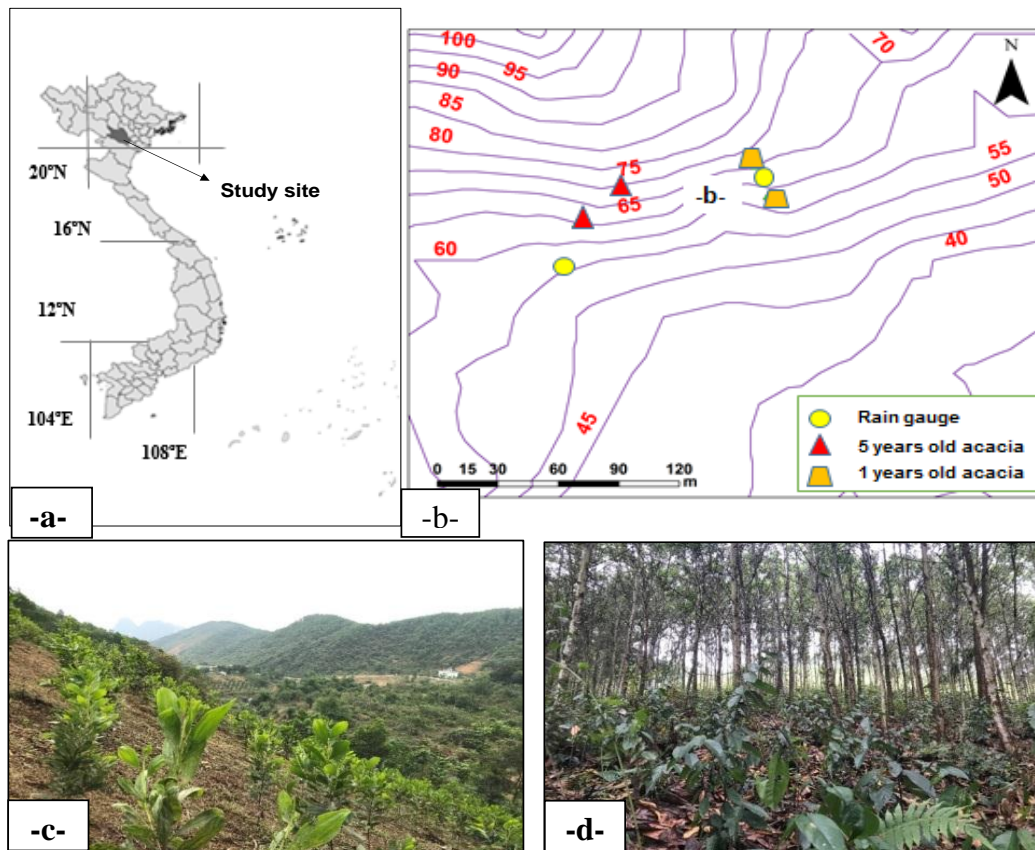


Fig. 1. The map of the study site: a) Location of Hoa Binh province on Viet Nam map, b) Contour line map of four plots location; c) Acacia 1-year-old; d) Acacia 5-years-old.

## 2.2. Methods

### 2.2.1. Plots design for an experiment

Four plots were installed at two different ages of five years old and one-year-old Acacia plantation. At each age, in order to see the amount of runoff and erosion at different elevations, one plot was set up at the down-hill and the other one was located at the upper-hill (Fig. 2 and Table 1). Among 4 plots, the slope and porosity of plots were not so different, ranging from 26<sup>0</sup>-29<sup>0</sup> and 52-59%, respectively (Table 1). However, canopy cover of plot was smaller at 1-age (50-52%) and higher at five-year old Acacia (86-87%), while ground cover was higher at 1- age (91-93%) and smaller at five-years old Acacia plantation (36-39%). In the contrary, 2 plots at 1-year-old forest had lower percentage of litter fall (8.5-9.5%) than that at 5-years-old forest (27.6-25.0%) (Table 1).

The plot design was 3 m in Width x 5 m in Length x 0.3 m in Height in the size and it was bordered by an aluminum sheet. The aluminum sheet was buried 0.1 m deep into the soil, and to make sure that it could firmly stand even in heavy storm condition with a large amount of runoff and strong wind, steel wires and bamboo sticks were propped up surrounding the aluminum sheet. At the down end side of the plot, an aluminum gutter was installed to catch the water and soil from the plot. The aluminum gutter was 3.0 m in length, 0.2 m wide and 0.2 m in height, noted that, at the side where the gutter meet the plot, the length of the sheet was longer, so that it could be buried into the plot to ensured that runoff accumulated at the end of the plot would move to the gutter but not leached out. The gutter was connected with a container, which had a volume of 180 L, by a plastic tube. To get the accurate result, the gutter and the

container was covered above to make sure the rain did not fall inside (Fig. 3).

To measure runoff, we used a graduated cylinder (volume 1000ml). The soil left in the container after filtering as well as the soil left in the gutter and the plastic tube then be taken to the laboratory to dry (at 105°C for 24 hours) and weight in order to determine the amount of soil erosion (g) from each plot. To calculated runoff depth, dividing the amount of runoff by the plot area. Considering the particle density of soil is 2.65 g/cm<sup>3</sup>, dividing the amount of soil loss by dry bulk density and then keep dividing by the area of the plots to identify the soil loss height. Field observation was conducted from April to September, 2018.

Rainfall was monitored by using US standard plastic rain gauge. The rain gauge was installed in an open area near the plots. Runoff coefficient was calculated following the formula:

$$\text{Runoff coefficient} = \frac{\text{Total Runoff Depth}}{\text{Total Storm Precipitation}} \times 100\%$$

The plot's coordinate, elevation was recorded by GPS Garmin 60CSX. The slope angle of plots was recorded by Meter Angler, an android's application from the phone. As well as the understory vegetation cover and canopy cover were estimated by android's application Canopy Cover Free and Glama, respectively. To determine the porosity of soil at each plot, soil samples were taken by using Bulk density tube and analyzed in the laboratory. For the data analyzed, we used T-test with confidence 95% to compare the difference between plots in different locations and age in SPSS 23.0 version. To check the relationship among runoff, soil and precipitation we used correlation and linear regression function in SPSS 23.0.

Table 1. Observation plots characteristic at the study site

Parameters	1-year-old Acacia		5-years-old Acacia	
	1-down	1-up	5-down	5-up
Slope (°)	28	29	26	27
Elevation (m)	57	73	60	72
Canopy cover (%)	50.5	52.11	85.89	86.9
Ground cover (%)	90.5	92.56	36.2	38.9
Litter fall (%)	8.5	9.5	27.6	25.0
Porosity (%)	54	52	56	59
Soil texture	clay loam	clay loam	clay loam	Clay

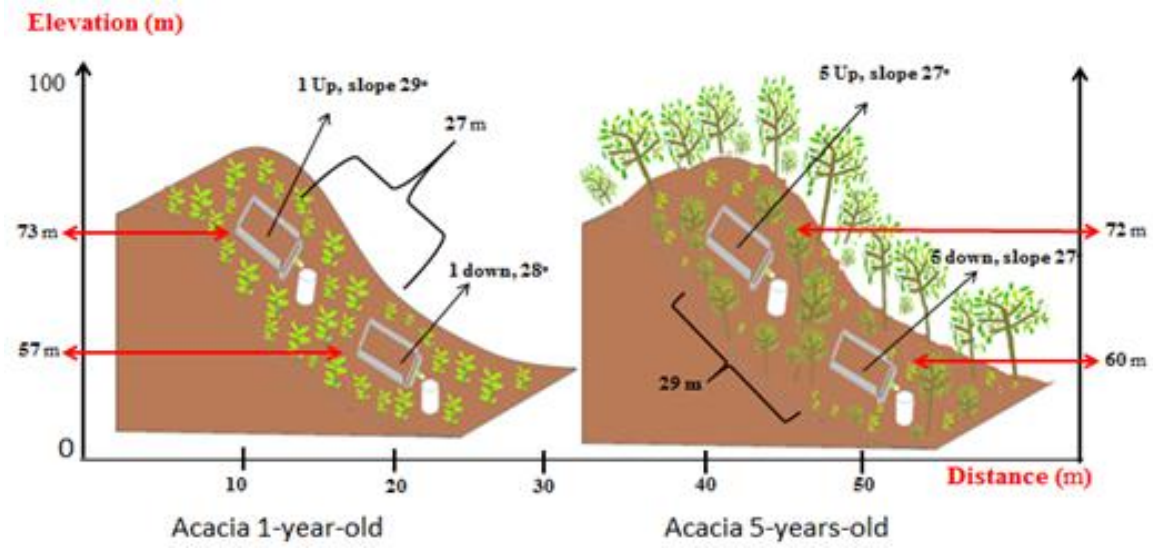


Fig. 2. The model illustrates elevation, slope, and distance of four plots at the study site.



Fig. 3. Picture at plot 1-down and 1-up of Acacia 1-year-old and plot 5-down and plot 5-up of Acacia 5-years-old plantation at the study site.

### 3. Results and discussion

#### 3.1. Runoff generation at two different ages of Acacia plantation

There were 55 storm events has been collected for 6 months from April to September 2018. The lowest rainfall was 2.25 mm and the highest was 117.50 mm. Average rainfall was 34.3 mm storm<sup>-1</sup>. At all 4 plots, the threshold of storm event to induce runoff was 10.9 mm at the beginning of the rainfall season (May 16) and this amount dropped to 7.5 mm at the latter of

the rainfall season (June 11). The runoff generation responds quickly to precipitation input. Higher precipitation got higher runoff in all plots (Fig. 4). However, generated runoff varied from upper plots to down plots and from Acacia plantation 1-year-old to 5-years-old (Fig. 4). Average runoff coefficient range from 0.36% (1-Down) to 0.46% (1-Up) with the average 0.41% (Fig. 4), while runoff coefficient range from 0.35% (5-Down) to 0.39% (5-Up) with the average 0.37% (Fig. 4).

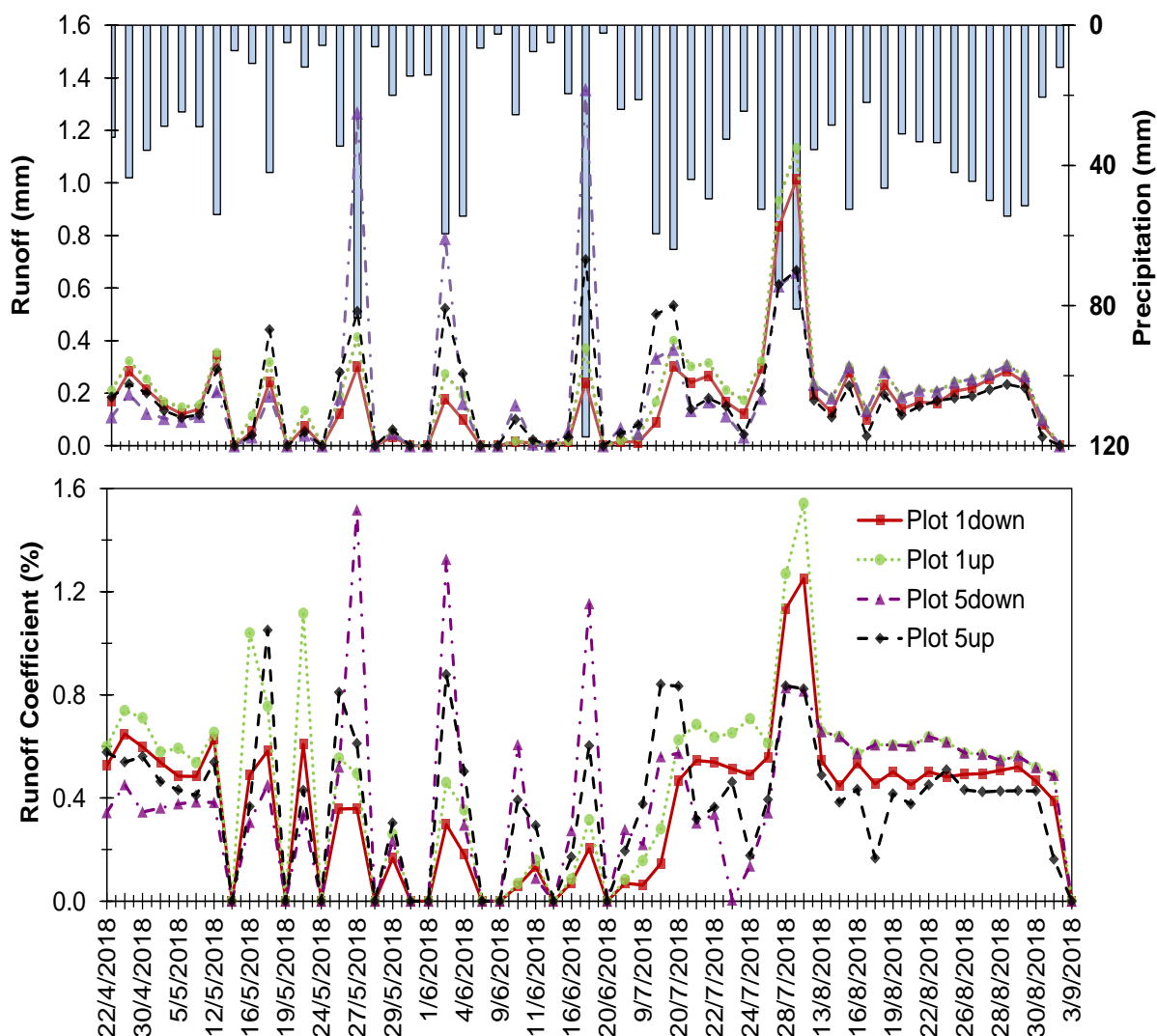


Fig. 4. Runoff and runoff coefficient from four plots at the study site.

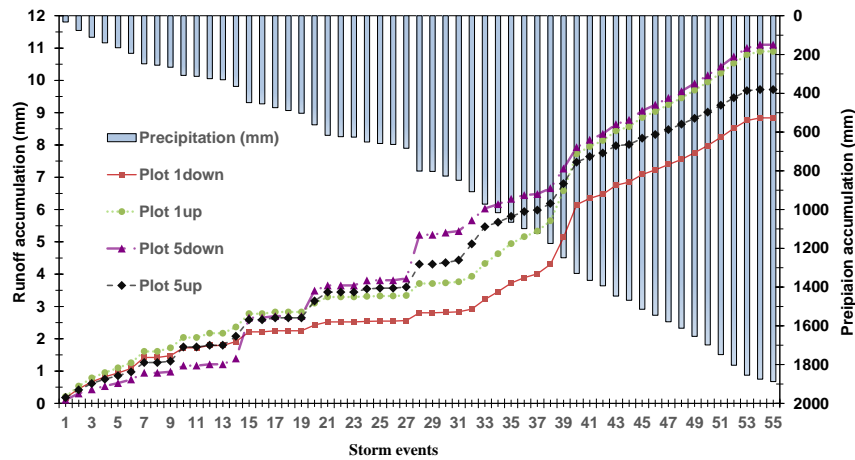


Fig. 5. Runoff accumulation from four plots at the study site.

The total amount of rainfall accumulation of 55 storm events was 1887.4 mm. Runoff accumulation in 1-year-old at plot 1-down was 8.84 mm and 10.90 mm in plot 1-up (Fig. 5). Runoff accumulation of 5-years-old Acacia at plot 5-down and 5-up were 11.11 mm 9.72 mm, respectively (Fig. 5). The ability to generated surface runoff is the highest at plot 5-down, but it slightly different with plot 1-up (1.02 times), plot 5-up (1.14 times) and plot 1-down (1.26 times) (Fig. 5).

The runoff generation is not statistical significant difference between ages and between locations of Acacia plantation (Fig. 6). P-value between plot 1-down and plot 1-up as well as plot 5-down and plot 5-up with were 0.31 and 0.96, respectively. On the other hand, p-value between plot 1 and plot 5 was 0.95 higher 0.05 (Fig. 6). This result suggests age of Acacia and location planted tree did not impact significantly to runoff generation at the study site.

Runoff coefficient showed the slightly different between the locations at two different ages of Acacia plantation due to the different ground cover. The runoff coefficient from four plots highest at plot 1-up is 0.46%, with the canopy cover is 52.11% (Table 1). This reason also mentioned in previous studies. For example, Mohammad and Adam [25] have shown the result that the amount of runoff without a tree or less vegetation was increased the surface flow. Otherwise, Podwojewski et al [26] who studied

on the land-use impact on surface runoff and soil detachment within agricultural sloping land in Northern Vietnam, has reported that the highest amount of surface runoff coefficient because of the lost in the vegetation cover by 35%. These results were similar with Miyata et al [7], who reported that the annual overland flow yield without or less floor coverage plot was 1.7-3.6 times greater than ones from plot that have floor coverage, it was maintaining the soil and responsible for reducing the amount of surface runoff.

In general the amount of runoff from all four plots was small with the amount of runoff accumulation ranged from 8.84mm to 11.11mm. This result might be attributable to the fact that the percent of understory vegetation cover and litter fall in this Acacia forest were high (Table 1). The high ground cover could help reducing overland flow [8, 32]. Behind, the porosity of soil at all the plots were quite high (52-59%) so that soil might have high infiltration capacity, thus the infiltration excess overland flow rarely occur [7, 12]. Furthermore, Acacia tree is the providing source of nutrient and the boosting factor of the microorganism's diversity [27], soil under the Acacia plantation might be fertilized and might have the larger pore, which enable the higher rate of infiltration. Another research on the runoff and erosion from Acacia plantation at the same location also found the very little amount of runoff accumulation at 14.33 mm over 75 storm events [22].

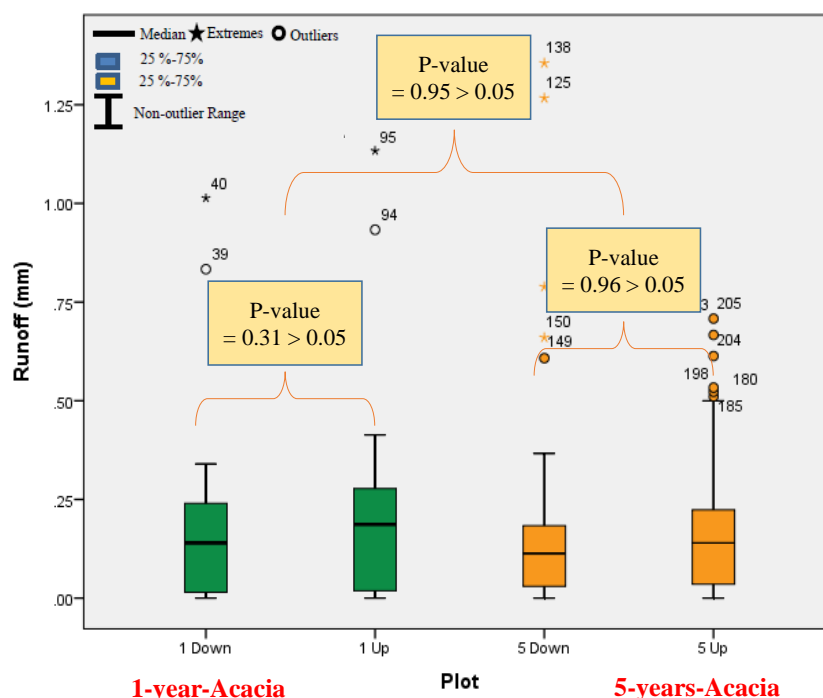


Fig. 6. Runoff fluctuation with statistic significant difference at different ages of Acacia plantation (p-value showed statistical significant difference between 2 plots at  $\alpha = 0.05$ ).

On the other hand, the root systems of Acacia 1-year-old were not strong and smaller than Acacia 5-years-old, that why the rate of runoff was higher at the smaller age of Acacia plantation forest. For 5-years-old the root system was bigger and stronger it has more ability to reduce surface runoff by penetrating soil layer and improve the capacity of soil infiltration. *Acacia mangium* belong to the Fabaceae family, so it absorbed a lot of nitrogen from the atmosphere for storage in the root for fixing batteries [28]. Meanwhile, De Baets et al [29] described the root characteristics of Mediterranean plant species and their erosion-

reducing potential during concentrated on runoff. Many authors studied on the effects of roots on concentrated flow erosion rates [30]. They also agreed that the roots were capable of penetrating the soil layers to improve the soil infiltration capacity, reducing the volume of surface runoff. Furthermore Mohammad and Adam [25] also agree with them the root systems of trees and shrubs play an important role in decreasing runoff by improving soil characteristics, such as soil porosity and organic matter content, thus increasing the infiltration rate and decreasing the runoff.

Table 2. Comparison of the runoff coefficient with other studies (the unit for the first two columns are percentage/6 months while the rests are a percentage/1 year)

Land use type	Runoff (%)	References
5-year Acacia	0.37	This study
1-year Acacia	0.41	This study
Convex road	25.5	Linh (2017)
Bare land	3.74	Cong et al. (2018)
Nature forest	0.25	Valentin et al. (2008)
Bamboo forest	0.28	Valentin et al. (2008)



In comparison, the runoff coefficient from this study is much lower than bare land and convex road but it is more higher than ones of nature forest and the bamboo forest (Table 2). This may be due to location of Acacia. The Acacia was planted in headwater area with high elevation (>70 m) and slope (> 28°). Therefore, runoff generate quicker and higher. Some previous studies showed that tophography factor is also main impact on runoff generation. For example, Lesschen et al [31] was reported that the factors that increase the risk of terrace failure due to runoff were steeper terrace slope. Otherwise, low porosity of soil (52%) also cause low infiltration and higher runoff at the study site. These results agreed with Jouquet et al [32], state that when the soil has higher porosity it will have higher infiltration rate increases leading to reduce the amount of runoff.

### 3.2. Soil erosion at two different ages of Acacia plantation

Soil erosion in all plot responded quickly to precipitation input. Eroded soil gets higher with higher erosion (Fig. 7a). However, soil erosion was different among location and Acacia ages. The soil erosion from Acacia 1-year-old at plot 1-down were ranged from 0.00-545.27g (mean  $154.68 \pm 160.67\text{g}/15\text{m}^2/\text{storm}$ ) and plot 1-up range from 0.00-585.55g (mean  $206.41 \pm 194.38\text{g}/15\text{m}^2/\text{storm}$ ), with the average, was  $180.55 \text{ g}/15\text{m}^2/\text{storm}$ . For Acacia 5-years-old, the amount of soil erosion in plot 5-down range from 0.00-530.23g (mean  $122.24 \pm 133.96 \text{ g}/15\text{m}^2/\text{storm}$ ) and plot 5-up, range from 0.00-530.23g (mean  $122.24 \pm 133.96\text{g}/15\text{m}^2/\text{storm}$ ), with the average was  $117.34\text{g}/15\text{m}^2/\text{storm}$  (Fig. 7a).

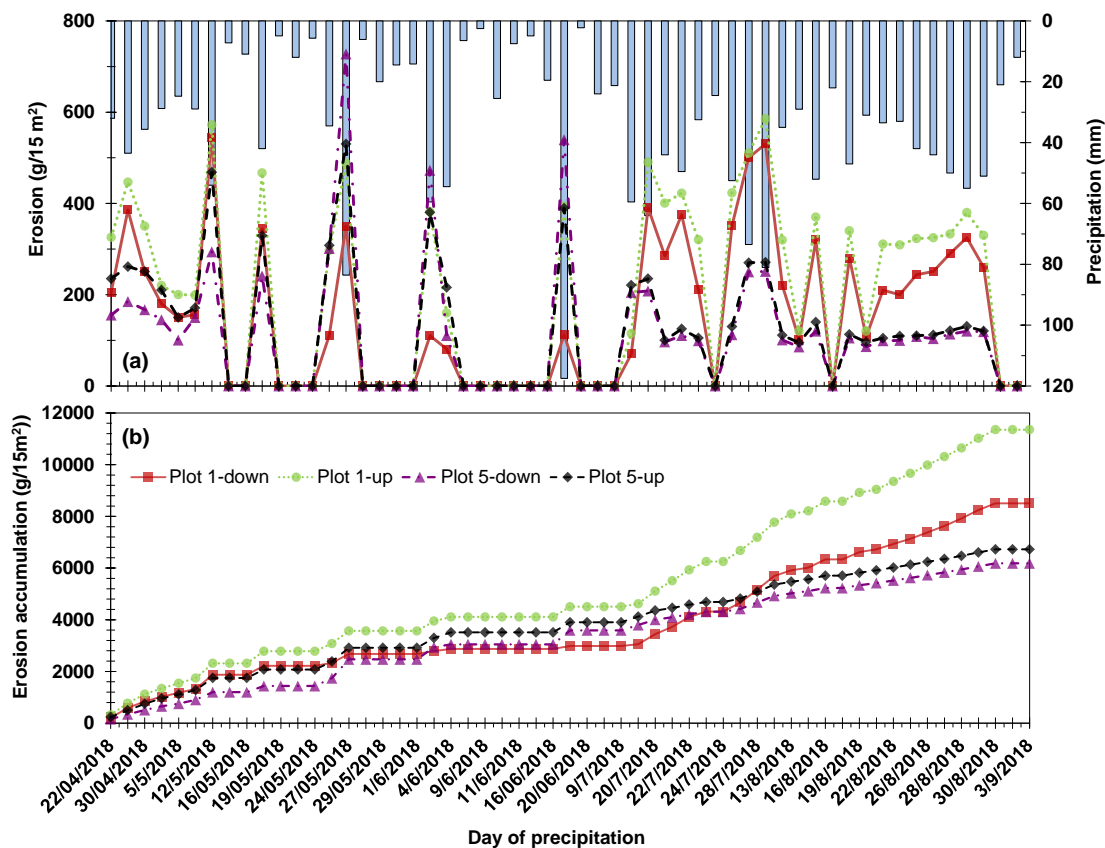


Fig. 7. (a) Soil erosion response to precipitation and (b) soil erosion accumulation from four plots at the study site.

The soil erosion accumulation during monitor period from 1-year-old Acacia plantation at down plot was 8505.6 g/15m<sup>2</sup> and the upper plot was 11352.4g /15m<sup>2</sup>. For Acacia 5-years-old at plot 5-down and plot 5-up were 6183.9 g/15m<sup>2</sup> and 6723.1 g/15m<sup>2</sup>, respectively. According to the total amount of meantime, the amount of soil erosion was highest in plot 1-up with 11352.4 g/15m<sup>2</sup>, compared to the other plots, this number was 1.33 time higher than plot 1-down, 1.69 time higher than plot 5-up and 1.84 time higher than 5-down (Fig. 7b). As the result from T-test, the soil erosion is not statistical significant difference between location of Acacia such as plot 1-down and plot 1-up as well as plot 5-down and plot 5-up with (Sig. value = 0.13 and sig. value = 0.71, respectively) (Fig. 8). While soil erosion at different ages of Acacia is statistics significant difference with the Sig. value 0.004 less than 0.05. So it means that Acacia ages impact differently on soil erosion (Fig. 8).

The average amount of soil erosion in Acacia year-1 was 180.54 g/15m<sup>2</sup> (equal to 0.012 kg/m<sup>2</sup> or 21.84 ton/ha/6months). While at the 5-year-old Acacia plantation this amount was smaller

with the average of soil erosion is 117.34 g/15m<sup>2</sup> (0.078 kg/m<sup>2</sup> or 14.20 ton/ha/6months). Comparing to TCVN: 5229: 2009 [33] the soil erosion in year-1 and year-5 were classified into category IV with strong soil erosion (Table 3). Erosion between 5 year old Acacia and 1 year old Acacia is statistical significant difference at  $\alpha = 0.05$ . The reason may be due to canopy cover and ground cover at different ages. Canopy cover of the age of Acacia 5-years-old (87%) was larger than that of Acacia- 1 year old (51%). Canopy cover or vegetation when it was larger have the ability to protected soil from erosion, tree leaves and branches intercept and diminish rain and wind energy, while the canopy of the tree, leaves, and branches cover the soil will reduce the impact of raindrop preventing soil and decreased soil eroded [34]. Additionally, increasing in the cover of tree and vegetation when the age of tree came older also decreased the soil erosion. These results agree with various studied, which have examined that the behavior of the vegetation ground cover and littler have a negative correlated with the percentage of the process flow of soil erosion [21, 35, 36].

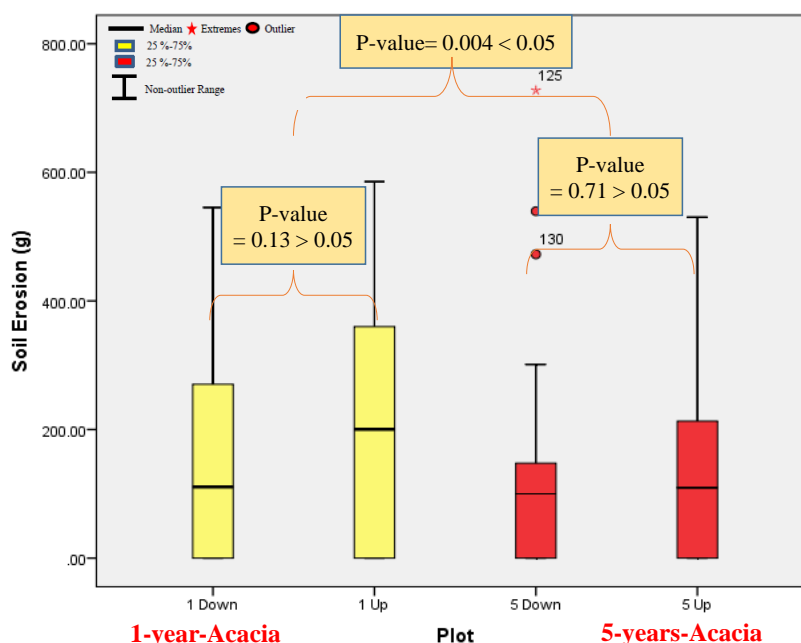


Fig. 8. Soil erosion fluctuation with statistic significant different at different ages of Acacia plantation (p-value showed statistical significant difference between 2 plots at  $\alpha = 0.05$ ).

Table 3. TCVN5299: 2009 Method for determination of soil erosion by rainfall

Level	Amount of soil erosion (ton ha <sup>-1</sup> )	Accessing
I	To 1	No erosion
II	Greater than 1 to 5	Slight erosion
III	Greater than 5 to 10	Medium erosion
IV	Greater than 10 to 50	Strong erosion
V	Greater than 50	Very strong erosion

Table 4. Compare the soil erosion among Acacia plantation forest year-1, year-5 (ton/ha/6months) with other land types (ton/ha/year for the rest)

Land use type	Soil erosion	References
5-year Acacia	14.20	This study
1-year Acacia	21.84	This study
Road	839.5	Linh, (2017)
Bare land	178.85	Cong et al. (2018)
Nature forest	2.2	Jain et al. (2001)
Bamboo forest	32.85	Shinohara et al. (2019)
Conifer forest	65.7	Shinohara et al. (2019)

Soil erosion at the study site tended to be smaller than ones of road and bare land (Table 4). For example, Linh [37] and Cong et al [38] found that the bare land and unpaved road at the same study site are much higher than soil erosion in year-5 and year-1 Acacia plantation. Detail the soil erosion in bare land 8.19 times higher than 1-year-old Acacia plantation forest and the unpaved road is 59.12 times higher than year-5 Acacia plantation forest (Table 4). While the soil erosion in year-1 and year-5 Acacia plantation is much higher than the mature forest, with approximately 9.9 times and 6.5 times, respectively. The soil erosion in bamboo forest is not much different from year-1 and year-5 Acacia plantation forest and bamboo forest (Table 4). Conifer forest is by far higher than year-1 and year-5 in term of soil erosion, 3 times and 4.6 times higher, respectively. It is possibly the difference in leaf structure as conifer is needle structure which is weak to against rainfall while Acacia has a bigger leaf which is stronger to against the energy of rain drop to damage the soil structure. From here we can say, the Acacia plantation is strongly against the soil erosion it is closed to the bamboo forest.

### 3.3. The relationship among runoff, soil erosion and precipitation

The runoff from four plots has a strong

relationship with rainfall, R2 range from 0.52-0.85 with P-value=0.000. The high amount of rainfall will be affected to surface flow because the soil was saturated and infiltrations approximately decrease (Fig. 9a). Otherwise, the soil erosion from four plots has a strong correlation with rainfall, R2 range from 0.51-0.67 with P-value=0.000 (Fig. 9b). The soil erosion from 4 plots has a strong correlated with runoff, R2 range from 0.66-0.83 with P-value=0.000. The amount of runoff was high, soil erosion also high because it has a strong correlation (Fig. 10). This finding also agreed with previous studies. Joel et al [39] studied focus on the measurement of surface runoff from plots of two different sizes, gave a quote that the effects to surface runoff it can be considered about the amount of water storage in the soil roughness during storm event it also impacts to runoff. According to the results above, it can say that the runoff from four plots was changed dramatically when the amount of rainfall was higher. There is a close relationship between each rainfall event and the amount of runoff, which depends directly on the type the of vegetation cover it agreed with Mohammad and Adam [40].

Soil erosion was effected from among factors influencing such as storm size. When the heavy rain occurred the raindrop directly to the soil but because of the plot 1-up have 92.56% of understory vegetation cover, so the soil erosion not much higher than plot 5-up. Without vegetation covers, the amount of runoff and soil loss from Acacia 1-year-old will much higher because when heavy rain happened will be drop directly to the soil, which leads to being soil erosion. Many researchers have been studied about the effects storm on the process of runoff and soil erosion [41, 42]. In addition heavy rain more effected to soil erosion. It was agreed with the degree of soil detachment typically correlation with the kinetic energy of raindrop [43]. The effectiveness of a plant cover in reducing erosion by raindrop impact depends upon the height and continuity of the canopy, and the density of the ground cover. The high density of the ground cover can reduce erosion by raindrop impact [44].

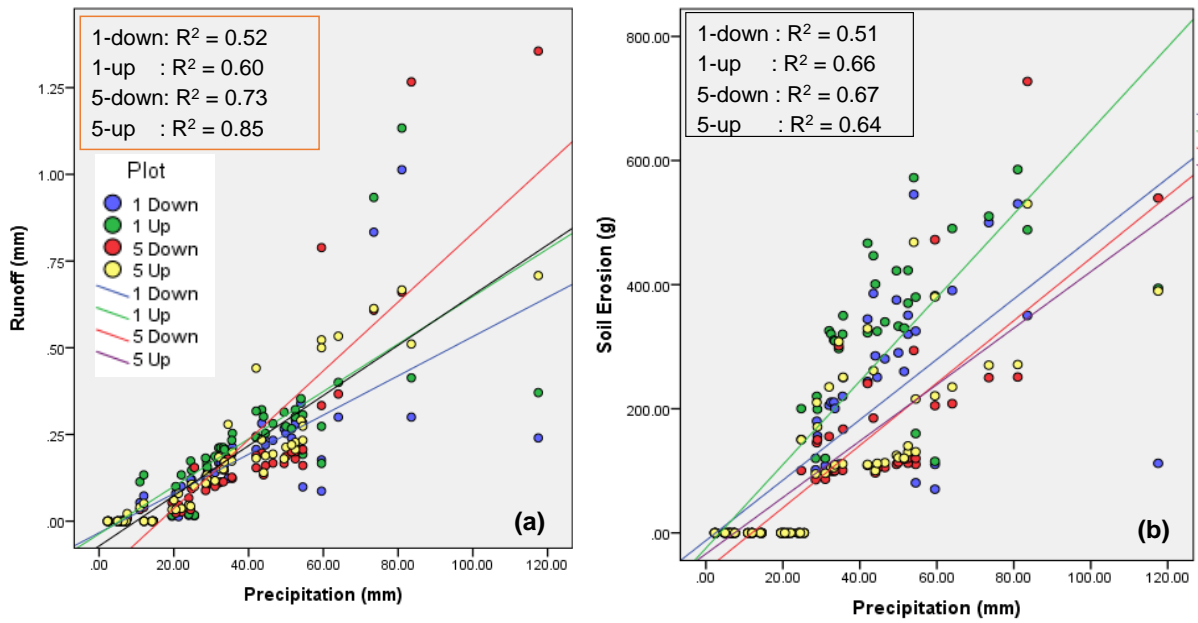


Fig. 9. The relationship between (a) precipitation and runoff; (b) precipitation and soil erosion at different ages of Acacia plantation.

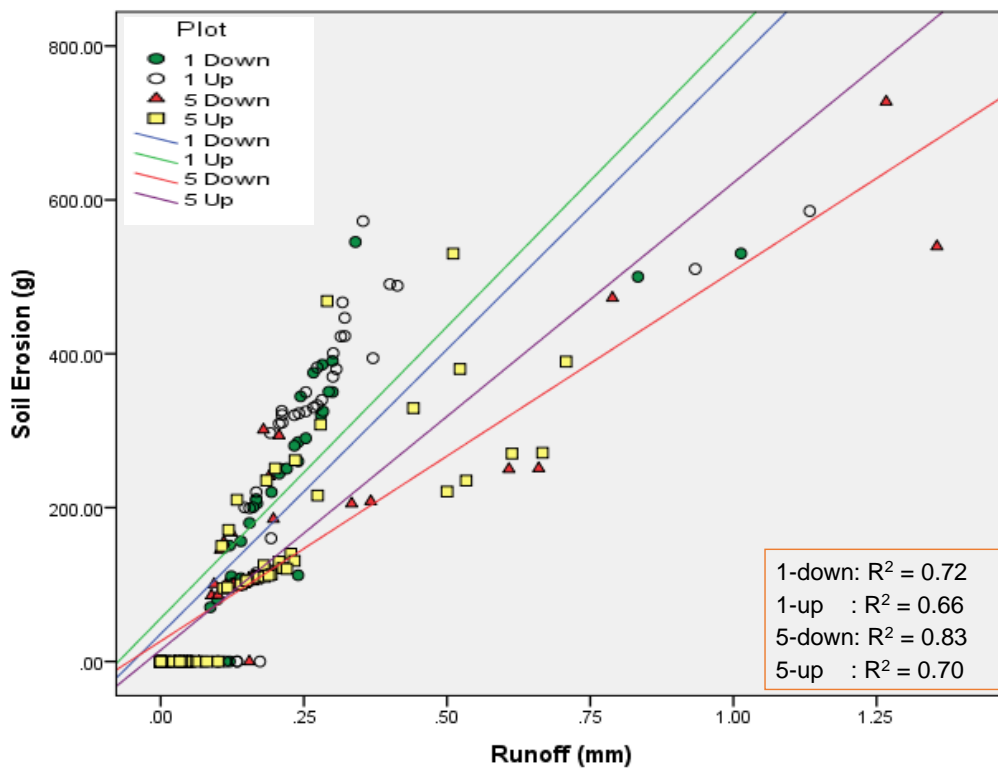


Fig. 10. Correlation between soil erosion and runoff at different ages of Acacia plantation.

#### 4. Conclusion

After conducting the experiment to measure the amount of runoff and soil erosion at two different ages of Acacia plantation in totally 55 storm events during rainy season from April to September 2018, the final conclusions were pointed out:

- Runoff generation is highest in plot 5-down (0.46%), followed by plot 1-up, plot 5-up, and plot 1-down. However, there were not statistically significant difference in term of runoff generation at two different ages of Acacia plantation ( $P\text{-value} = 0.95 > 0.05$ ).

- Soil erosion is highest in plot 1-up (mean  $5423.9 \text{ g}/15\text{m}^2$ ) was 1.33 times higher than plot 1-down (mean  $3952.5\text{g}/15\text{m}^2$ ), 1.69 times at plot 5-up (mean  $3874.8 \text{ g}/15\text{m}^2/\text{storm}$ ) and the lowest one is plot 5-down smaller than plot 1-up 1.84 times (mean  $3431.1 \text{ g}/15\text{m}^2$ ). Soil erosion in Acacia year-1 and year-5 is in level IV, it means strong erosion base on TCVN5299: 2009. There are statistically significant difference between ages of Acacia plantation forest in term of soil erosion ( $P\text{-value} = 0.004 < 0.05$ ).

- Runoff generation and soil erosion had a strong relationship with precipitation. Runoff generation and soil erosion from this study are higher than natural forest and bamboo forest, while it is lower than bare land and convex road.

The amount of runoff generation and soil erosion in Acacia plantation forest was higher than those found by previous studies. Therefore, it should be more concerned and apply sustainable management for plantation forest in the headwater area of Vietnam. Two application solutions were proposed in order to reduce the negative impact of runoff and soil erosion from Acacia plantation forest: (1) Application 1 (Conservation): no commercial plantation forest in the headwater area. Change from bare land to mixed forest, because it will be provided niches for a greater variety of species. Runoff and soil erosion will be reduced when we convert the area to be a natural forest; (2) Application 2 (Commercial): plant Acacia forest but it should be maintaining the understory vegetation cover

on the first year or second-year-old of Acacia plantation forest. Understory vegetation cover is an important factor for controlling runoff and soil erosion, which consists of the detachment and transport the soil particles. Keep the ground coverage it will be reducing the energy of raindrop. Because raindrop is the causes of mechanical breakdown the soil aggregates and soil detachment [45]. Acacia plantation forest for the rotation is 7 years. After harvest, the company burn the forest turn to bare land when having heavy rain occur soil will be eroded. To prevent this, the plantation should be planted in a different year, which harvests in the different rotation that keeps the land cover constantly.

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