CLEAR-CUTTING OF ACACIA PLANTATION IN A HEADWATER CATCHMENT OF VIETNAM: ENVIRONMENTAL IMPACTS AND SOLUTIONS FOR SUSTAINABLE MANAGEMENT

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SUMMARY

To assess impacts of clear-cutting at a pure Acacia plantation on soil and water quality, a 7-year-old Acacia forest within the area of 2.5 ha in Hoa Binh province was selected to investigate at 2 stages: before and after clear-cutting. 03 standard plots (500 m^2/plot) at 3 positions (downhill, mid-hill and top-hill) for determining forest characteristics, 30 sampling subplots (1 m^2/plot) for monitoring forest covers and some soil properties. 15 of 30 subplots were used to measure infiltration; and 4 points along forest flow were chosen to take water sampling for assessing water quality. Main findings include: (1) Forest cover decreased within the removal of tree, reduction of understory vegetation cover, litter and biomass ranged from 10 to 20%; (2) Soil quality decreased by 8.35% dropped of porosity due to the rise of 8.57% in dry bulk density; (3) Soil nutrients: Organic matter, total Phosphorus and Nitrogen amount decreased at the proportion of 20.91%, 62.86% and 27.86% respectively after clear-cutting; (4) Total infiltration rate decreased after harvesting. The positions that had high infiltration rate before clear-cutting tended to infiltrate noticeably less (Downhill: reducing from 397.7 mm to 201.2 mm); (5) Soil erosion increased significantly after cutting and was remarkably higher in comparison with other research results due to the slope of researching area; (6) Most water quality indicators were at acceptable values, however, TSS and COD were 180-time and 5.6-time higher than water standard at B1 category (water for irrigation) according to QCVN 08:2015/BTNMT; (7) Some solutions suggested for sustainable management are (a) replacing production planted forest at researching site by protection forest or natural forest or (b) remaining commercial plantation forest but adjust management methods.

Keywords: Acacia plantations, clear-cutting, environmental impacts, Luong Son district, soil quality, water quality.

1. INTRODUCTION

Since the 20th century, Acacia plantation model has become popular in Vietnam while Acacia and Eucalyptus forests accounting for 70% of the plantation area because of its fast growth rate, short rotation and low cost (Nghia, 2003; Tuan, 2013). According to National Agricultural Extension Center (NAEC), Acacia trees have the characteristics of fast growth in diameter, height and shape (with straight trunk, small branches, good growth and development), wide ecological range, good resistance to pests and diseases, and the ability to adapt to many different site conditions and soil types. There have been many studies on Acacia plantations done. Research results show that at young age, Acacia plantations are at higher risk of erosion due to lack of vegetation cover (Dung et al., 2019; Casermeiro et al., 2004) and other effects. As a result of vegetation treatment, the older the Acacia forest is, the better it is to protect the soil (Kabiri et al., 2015).

Hoa Binh is a mountainous province located in the Northwest of Vietnam with steep hilly terrain, high annual rainfall. Runoff and soil erosion are two serious problems in the management of land and water resources here. The average loss of topsoil from erosion is 84.6 tons/ha/year (Baohoabinh.com, 2012). To solve this problem, Department of Science and Technology and Center for Geo-Environment of Hoa Binh province have implemented projects to plant pure Acacia afforestation to green-up bare land in the watershed of Luong Son district. According to statistics outcome of Luong Son District People's Committee in 2016, 92% of planted forest area in the area is covered by Acacia pure forest. However, due to economic benefits, a short-term Acacia plantation model (from 5 – 7 years) is preferred by most households and forestry companies. This rotation starts by the stages of ground preparation and bud generating in the first 3 – 4 months. In next 3 years, thinning process is carried out to ensure the good size and quality

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of trees. During a year after that, the forest is maintained to grow evenly. Eventually, mature Acacia plantation forest is clear-cut for harvesting at the stage of the 5th – 7th year, which makes the most impacts on surrounding environment quality through the process of making skid-trail, cutting down all mature trees and transferring harvested timbers.

In fact, there have been studies on environmental impacts of harvesting at Acacia plantations. However, there are limitations as they might not be conducted under uniformed weather conditions or not yet mentioned about the relationship between Acacia planted forest characteristics and environmental factors responding to clear-cutting process. The question raised is: What are the impacts of pure Acacia plantations on soil and water resources, especially the change of soil and water quality between before and clear-cutting period? To clarify these listed issues, the research titled "Clear-cutting of Acacia plantation in a headwater catchment of Luong Son, Hoa Binh: Environmental impacts and solutions for sustainable management" was conducted. The study focused on comparing characteristics Acacia planted forest, soil and surface water quality at the forest before and after clear-cutting period. Thus, based on research results, potential solutions to manage Acacia plantation forest sustainably were proposed.

2. RESEARCH METHODOLOGY

2.1. Study site

The research was conducted at Cao hamlet, Cao Ram commune, which is located in the northeast of Luong Son district, Hoa Binh province with the coordinates of 20°48'26.9" North, 105°30'40.1" East (Fig 1). Cao Ram commune has an area of 75.67 km². In 2018, its total population reached 10,082 people with a density rate of 133 people/km². It is in the midland and mountainous region of northern Vietnam, so it has a very rich and diverse terrain. Low mountain terrain, with an altitude of 200 – 400 m above sea level, is made up of limestone and sediments. Because it is a midland region where the transition between plains and hills takes place, the climate here is characterized by monsoon tropical type. The average annual temperature is from 22.9 to 23.3°C with the average rainfall from 1,520.7 to 2,255.6 mm/year. The system of rivers and streams here is evenly distributed with good drainage capacity, which is very convenient for the construction of flood-controlling and irrigating reservoirs to support agricultural and forestry production.

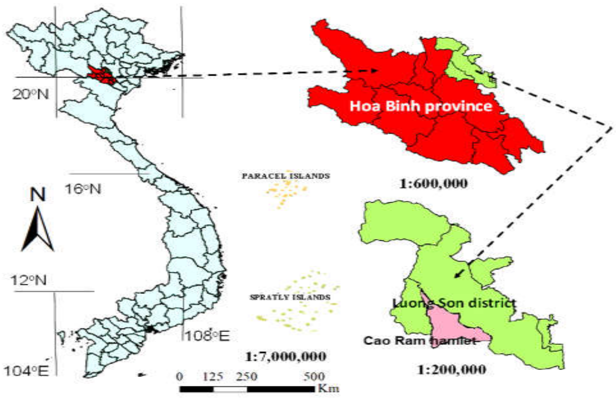

Figure 1. Study site

2.2. Research methods

- *Field Observation*

Acacia forest selected for investigation was a 7-year-old plantation forest with an area of 2.5 ha located in Cao hamlet, Cao Ram commune, Luong Son district, Hoa Binh province. The average elevation of the study area ranged from 62 to 124 m above sea level. The average slope was about 35.47°. The research was conducted through two harvesting stages: before clear-cutting and after clear-cutting. Assessing environmental impacts based on two processes: (1) Monitoring impacts on soil resources: erosion level, permeability, soil properties among different elevations A(Positions from 1-10: downhill; 11-20: mid-hill; 21-30: top hill) (Fig. 2) and (2) Checking surface water quality at a flow through the forest.

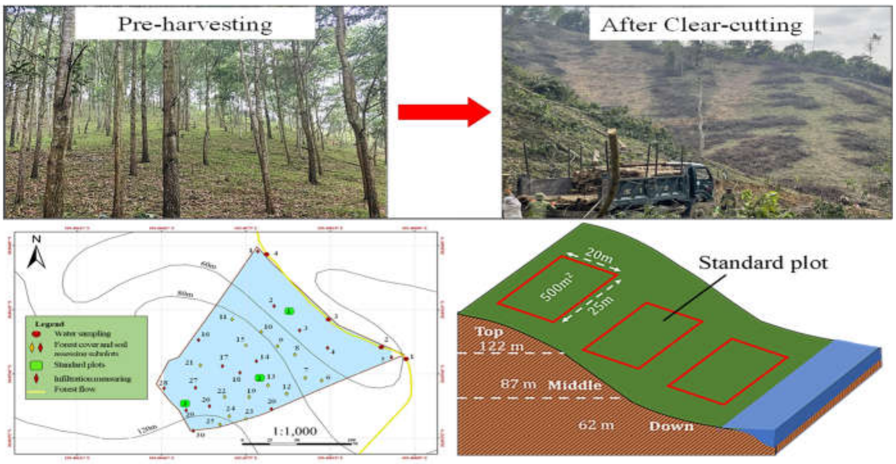

Figure 2. Field observation arrangement

Determining structural and growth characteristics of Acacia forest before and after clear-cutting

3 standard plots with an area of 500 m^2/plot (25 x 20 m) were established at the altitude of 62 m - 87 m - 122 m, corresponding to the downhill – mid-hill – top-hill positions (Fig. 2). In each standard plot, Acacia forest structural parameters, including diameter at breast-height (DBH) and total height of trees (H), were measured by a ruler tape and a Blume-Leiss.

In addition, 30 sampling subplots of 1m^2 area were established at downhill, mid-hill and top hill to investigate the indicators of canopy cover, understory vegetation cover, and litter cover (Fig. 2). In each plot, all grass, shrubs and fallen leaves on the ground were cut and weighed – after measuring soil erosion – to determine biomass of understory vegetation and litter cover.

Investigating soil characteristics before and after clear-cutting

At each subplot pH and soil moisture were directly measured. Then soil in the surface layer of the same subplot was taken for sampling to analyze about physical and chemical properties. Soil samples were stored in separately labeled zip bags and bring to laboratory for analysis. Soil physical parameters include dry bulk density, particle density and porosity; chemical parameters include organic matters, organic carbon, total phosphorus, and nitrogen amount.

Soil infiltration measurement

15/30 subplots were randomly selected to measure soil permeability, evenly distributed among three areas of down, mid-hill, and top hill. At each selected position, a double-ring infiltrometer was used to measure the temporal infiltration characteristics of different condition covers. Ring was 20 cm diameter and made from steel with sharpened bottom edges. A big hammer was used to place rings into the soil with a depth of 5 cm. Grass was cut until nearly to soil level. In general, the water level was kept at or above 5 cm depth (plug a sharp nail into center of the inner ring, then keep the nail 5 cm above the soil). Cylinder was used to pour the water slowly into the ring of 5-cm initial water above the topsoil, with a 10-cm nail (Fig. 3a).

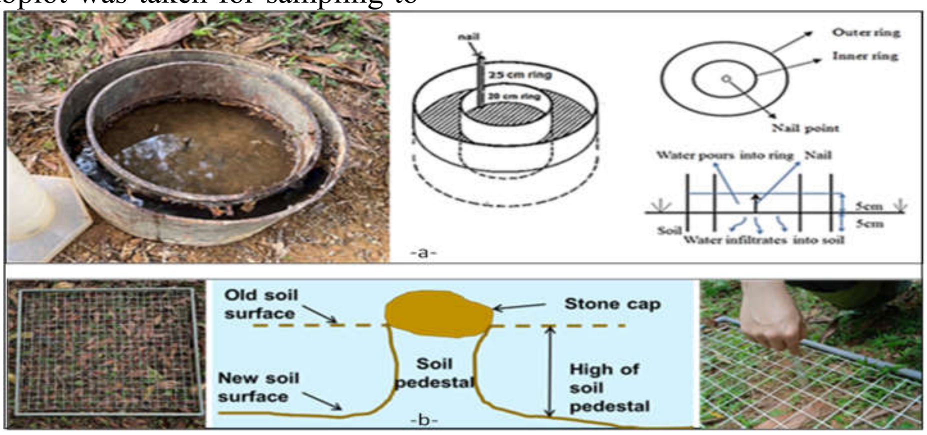

Figure 3. (a) Soil infiltration and (b) soil erosion measurement

Soil erosion measurement

In each subplot, the thickness of eroded soil layer was measured using pedestal measurement method. A grid, divided into 400 cells of 25 cm^2 (5 x 5 cm), was placed in the subplot. A ruler was used to measure the difference between the height of pedestals (rocks, gravel, fallen leaves layer, understory vegetation) compared to the surrounding soil. This difference represented the amount of soil eroding due to the lack of cover (Fig. 3b). The result of soil erosion at each subplot was the average value measured at 400 square cells.

The study applied, as well, a soil erosion prediction equation under forests of Vuong Van Quynh et al. (1996, 1997, 1999) to evaluate the ability of soil protection and erosion control for pure Acacia plantation models in headwater regions. Forecast equation was as below:

$$\mathbf{d\ (mm/year)} = \frac{2.31 \times 10^{-6} K\alpha^2}{(\frac{TC}{H}+CP+TM)^2 X} \quad \mathbf{(1)}$$

In which:

d: The intensity of erosion (mm/year);

α : Slope level (degree);

H: Tree's total height (m);

TM: Litter cover;

CP: Understory vegetation cover;

X: Soil porosity;

TC: Canopy cover;

K: Rain erosion index, also known as a measure of rain's ability, to cause soil erosion.

The amount of soil erosion was converted to units of tons/ha/year according to the following formula:

M = Erosion Thickness x Density x Area (2)

The result was compared with TCVN 5299:2009 to determine the level and status of erosion.

Assessing water quality before and after clear-cutting

For water quality indicators, surface water samples were collected at 4 positions: 1 point before the water flew into the forest, 2 points in the part at forest area, and 1 point after the water flew out of the forest. Water quality parameters analyzed at the laboratory include pH, TSS, COD, total amount of nitrogen and phosphorus. Sampling and analysis procedures comply with regulations of Ministry of Natural Resources and Environment. Those indicators were compared with QCVN 14:2008; QCVN 40:2011; QCVN 08:2015 standards of MONRE on surface water for class B1 (water used for irrigation purpose).

- *Data analysis*

Collected data was statistic, calculated and charted on Excel and SPSS software. Besides, the correlation matrix between erosion and infiltration rate with soil and plant properties was built on RStudio. ArcMap software was used to perform study area and interpolate soil infiltration map with IDW (inverse distance weighted) technique by interpolating the difference of soil permeability before and after clear-cutting at points in the forest.

The results of infiltration change were interpolated by IDW method for the whole area on ArcGIS 10.4 software. The formula was:

$$\boldsymbol{Z(So)} = \frac{\sum_{i=0}^{n} Z(Si)\lambda i}{\sum_{i=1}^{n} \lambda i} \text{ (Theobald, 2009) } \mathbf{(3)}$$

In which:

Z(So): The value of the i^{th} point;

So: The position to be interpolated;

n: The number of known points within a certain distance from the position to be interpolated;

λi is the weight of i^{th} point: λi = 1/di;

p (di is the distance between point I and So, P is the exponent of the distance).

The change of soil infiltration was, as well, shown by overlaying technique to performs a comparison between two stages. Differences at infiltration measuring positions were calculated by subtracting the rate after clear-cutting from that of pre-cutting stage. Then the layer which shown these differences was shown on the interpolation map, where a negative value represented a decrease, while contrarily, a positive value expressed an increase of infiltration rate.

3. RESULTS

3.1. Characteristics of Acacia plantation forest response to clear-cutting

- *Forest Cover*

Before clear-cutting, the average rate of canopy cover, understory vegetation cover and litter cover were 39.76%, 18.22% and 70.53%. After harvesting, the canopy cover was removed and equal to 0%. The average understory vegetation cover and litter cover after cutting were 15.98% and 55.82% respectively.

Compared between the cover before and after clear-cutting, it's easy to see that all of the forest cover decreased, especially the cover of litter sharply dropped. Litter cover was the largest proportion compared to canopy cover and understory vegetation cover with the range from 58% to 86% before cutting and from 40.5% to 70.5% after harvesting. In the harvested stage, litter cover decreased about 19.2% on average compared with understory vegetation (13.7%). The chart also shows that the vegetation cover under the forest in this forest was not high, ranging from 8.5% to 26.06% for pre-harvest stage and from 8.2% to 24.19 % for harvesting stage (Fig. 4a).

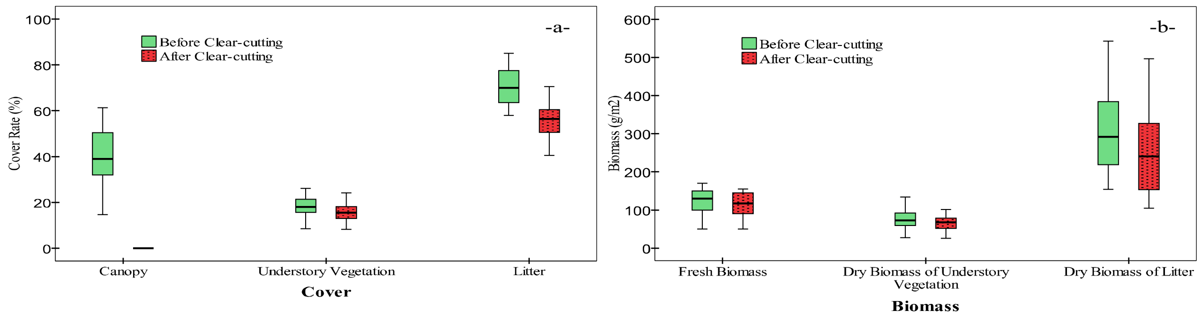

Figure 4. (a) Forest cover (%); (b) Ground cover biomass (g/m2) before and after clear-cutting

- *Ground cover biomass*

At pre-harvest stage, forest biomass ranged from 27.82 g/m^2 to 542.83 g/m^2 and at harvesting stage it ranged from 25.47 g/m^2 to 496.28 g/m^2. In general, both before and after the clear-cutting stage had the trend with high dry biomass of litter and low dry biomass of understory vegetation (Fig. 4b).

3.2. Soil characteristics response to clear-cutting

- *Physical properties of soil*

Before harvesting, the range of particle density was from 2.15 g/ml to 2.84 g/ml and dry bulk density ranged from 1.18 g/ml to 1.48 g/ml among different positions. The change in soil properties was detected due to the change of Acacia forest status. There was a slight rise of 3.4% in soil particle density at the forest. Average particle density rose 0.07 g/mL. Dry bulk density also increased 0.2 g/mL on average, which means 13.3% higher. Soil density shown soil compaction, basing on soil composition, organic matter content, soil texture. Depending on soil type and in different soil layers, soil porosity is different as soil composition and cultivation techniques were not the same. Owing to the rise in particle and dry bulk density, average soil porosity at the forest decreased from 46.30% to 43.34%. In addition, temporal soil moisture – which was measured directly on field – decreased sharply by 42.7% after clear-cutting. (Fig. 5).

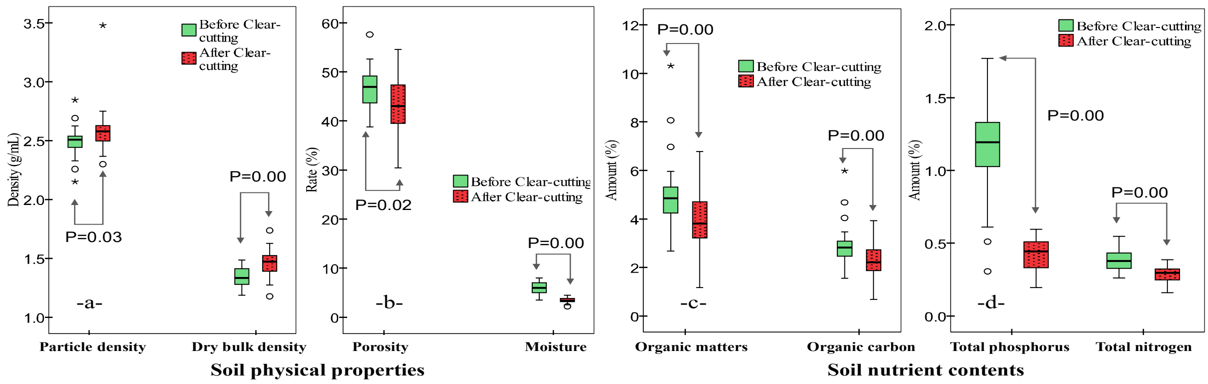

Figure 5. Soil properties before and after clear-cutting (a) Particle density and Dry bulk density (g/ml); (b) Porosity and Moisture (%); (c) Organic matters and Organic carbon (g/ml); (d) Total Phosphorus and Nitrogen amount (g/ml)

- *Nutrient contents of soil*

In general, average soil organic matter and organic carbon before clear-cutting was 5% and 2.9%, respectively. On the figure, it is clear to see that all soil nutrients decreased after clear-cutting. Organic matters had a high decrease from 5% to 3.9% in average of 20.91% while organic carbon decreased by 21.03% (Fig. 5c)

Before clear-cutting, there is a large difference between total phosphorus and total nitrogen indicator with average value was 1.14% and 0.38%. After cutting, this difference reduced to 0.15%. In the correlation box chart between the percentages of total Phosphorus and Nitrogen, there was a sudden drop of total Phosphorus by 62.86%. Before cutting, the Phosphorus index ranged from 0.3% to 1.8%, but immediately, after harvesting, the percentage of Phosphorus reached the lowest value at 0.2%. In contrast, percentage of Nitrogen did not change as much as Phosphorus after clear-cutting process, but still decreased by 27.86%. After clear-cutting, the range of Nitrogen ranging from 0.16% to 0.38% (Fig. 5d).

- *Soil infiltration before and after clear-cutting*

In general, infiltration rates at 3 locations had the same trend of high at first (0 – 3rd minute), dropped rapidly from 5th – 15th minute, and became most stable from 80th – 100th minute. As shown in Fig. 6, 1-hour accumulated infiltration rate, initial infiltration rate and stable infiltration rate decreased after Acacia trees had been harvested. The average 1-hour accumulated infiltration rate decreased from 337.4 mm to 187.6 mm with 47.67% of downhill, 44.7% of middle hill and 40.7% of top hill. The initial infiltration rate at downhill dropped most significantly from 15.5 to 8.4 mm/min. Stable rate at downhill also dropped the most with 47.21% (Fig. 6a). Similar to downhill, middle hill and top hill had a decrease in initial and stable infiltration rate but not significantly (Fig. 6). At middle hill, the initial infiltration rate decreased from 15.48 mm/min to 11.2 mm/min while the stable infiltration rate decreased from 2.4 to 1.5 mm/min (Fig. 6b). At top hill, the difference between before and after clear-cutting of initial infiltration rate was 3.94 mm/min and stable infiltration rate was 0.95 mm/min (Fig. 6c).

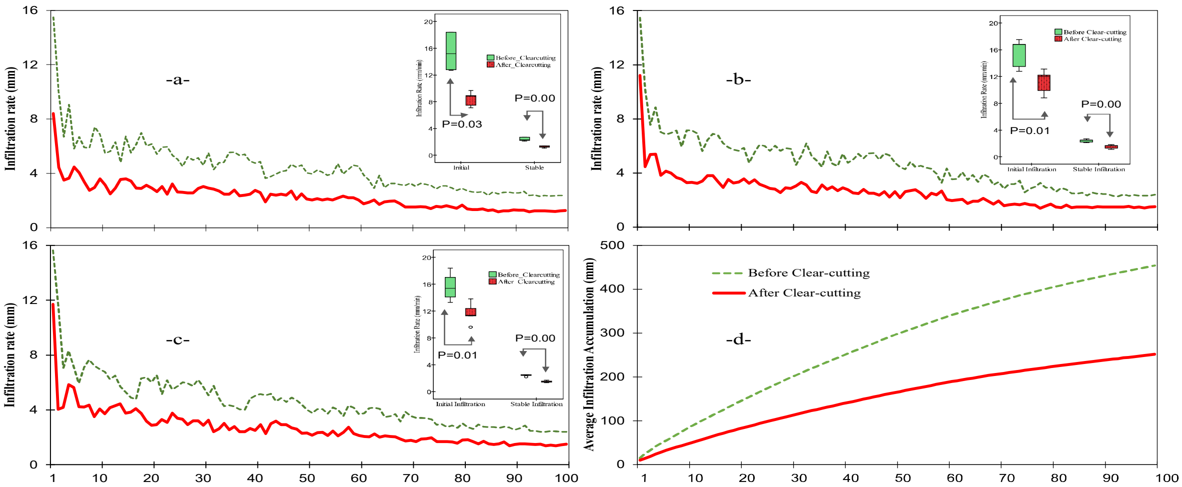

Figure 6. Average infiltration rate (a) at downhill, (b) at mid-hill, (c) at top-hill and (d) Average infiltrating accumulation before and after clear-cutting

Based on interpolation map for the difference between initial infiltration rate, stable infiltration rate and 1-hour accumulated infiltration before and after clear-cutting, areas with light color shown significantly decreasing value. It also meant that the Southeast area at the forest had smallest change in initial and stable infiltration rate with darkest color representing about 0.5 mm decreasing per minute (Fig. 7a & 7b). In contrast, the Northern part of study site expressed in pale color shown that it had the most significant change, especially in 1-hour infiltrating accumulation, from 225 to 260 mm decreasing (Fig. 7c). Down, middle, and top-hill areas were determined by contour lines. Positions that had high infiltration before clear-cutting, like downhill – for illustration, tended to have lower infiltration after clearcutting, and vice versa.

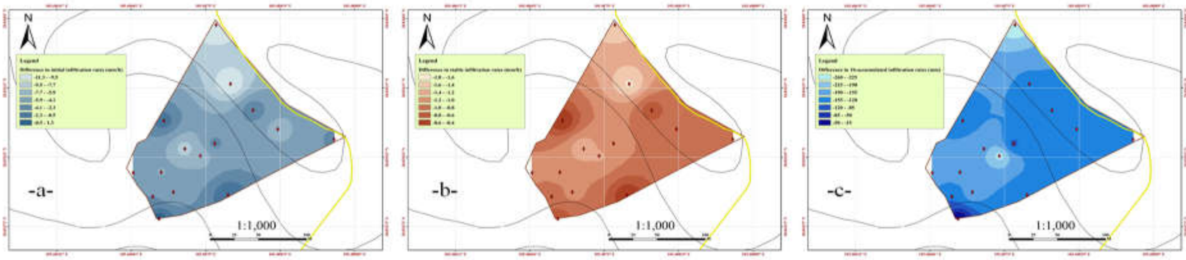

Figure 7. Interpolation maps of infiltration changes responding to clear-cutting of Acacia forest in (a) Initial infiltration rate, (b) Stable infiltration rate, (c) 1-hour accumulated infiltration rate

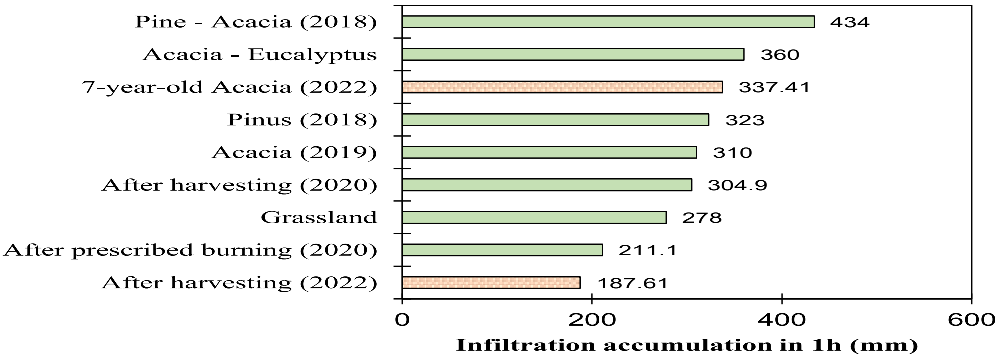

Figure 8. Total infiltration in 1 hour of other studies *(Linh et al., 2019; Hoa and Dung, 2020)*

Compared to the total infiltration in 1 hour among previous studies, the amount of infiltration accumulation in 1h of Acacia plantation ranged from 187.61 to 337.41 mm. Among them, the figure of Acacia plantation after clear harvesting in 2022 was lowest which is less than that of grassland. The mix forests such as Acacia – Pine and Acacia – Eucalyptus had the better situation. Their amount of infiltrated water in 1 hour were 434 and 360 mm, respectively. From this comparison, it is clearly shown that mix Acacia plantation can keep more water than monoculture one.

- *Soil erosion responses to clear-cutting*

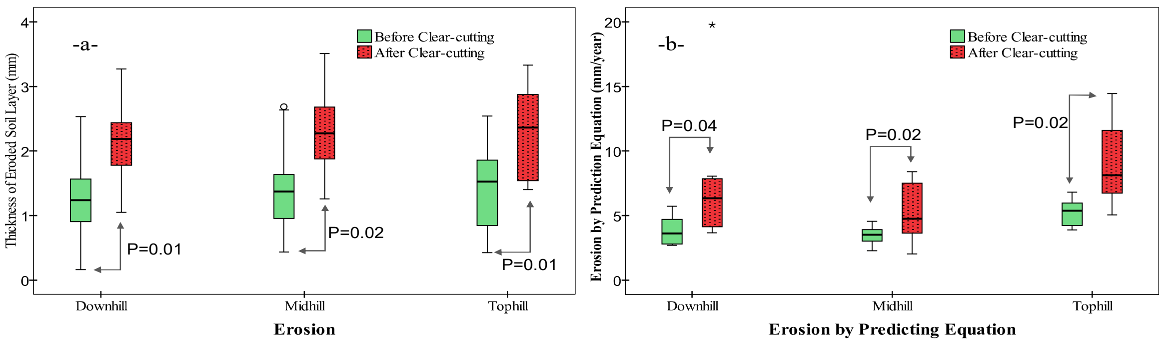

Figure 9. Soil erosion before and after clear-cutting by (a) pedestal measurement and (b) predicting equation

Soil erosion measured by soil pedestal method tended to be higher at top hill and lower at downhill in both stages. Like the amount of erosion measured by pedestal method, erosion rate of prediction model at the top was higher than at downhill and middle hill with the amount of erosion before clear-cutting ranging from 1.4 – 8.6 mm/year and after clear-cutting ranging from 1.8 – 19.8 mm/year. As soil pedestal measurement had shown, the average soil erosion increased 0.9 mm after harvested stage, accounting for 39%. In Table 1, the average predictive erosion before clear-cutting was 53.09 tons/ha/year now increased into 110.75 tons/ha/year after clear-cutting, which was almost double – representing an extremely high eroding status, as comparing with TCVN 5299:2009 standard for soil erosion level. The situation is similar to soil erosion layer thickness measured by pedestal method, it was almost doubled after clear-cutting stage by raising from 1.40 mm (before harvesting) to 2.29 mm on average.

Table 1. Descriptive statistics of soil erosion before and after clear-cutting in comparison with TCVN 5299:2009 standard

		Pedestal Erosion (mm)	Predictive Erosion (mm/year)	Predictive Erosion (ton/ha/year)	Level of Erosion	Status of Erosion
Before Clear-cutting	Mean	1.40	3.89	53.09	V	Highly eroded
	Max	2.69	8.59	123.46		
	Min	0.16	1.36	16.59		
	Standard Deviation	0.66	1.82	27.43		
After Clear-cutting	Mean	2.29	7.38	110.75	V	Highly eroded
	Max	3.51	19.76	343.18		
	Min	1.05	1.76	27.87		
	Standard Deviation	0.66	4.26	71.16		

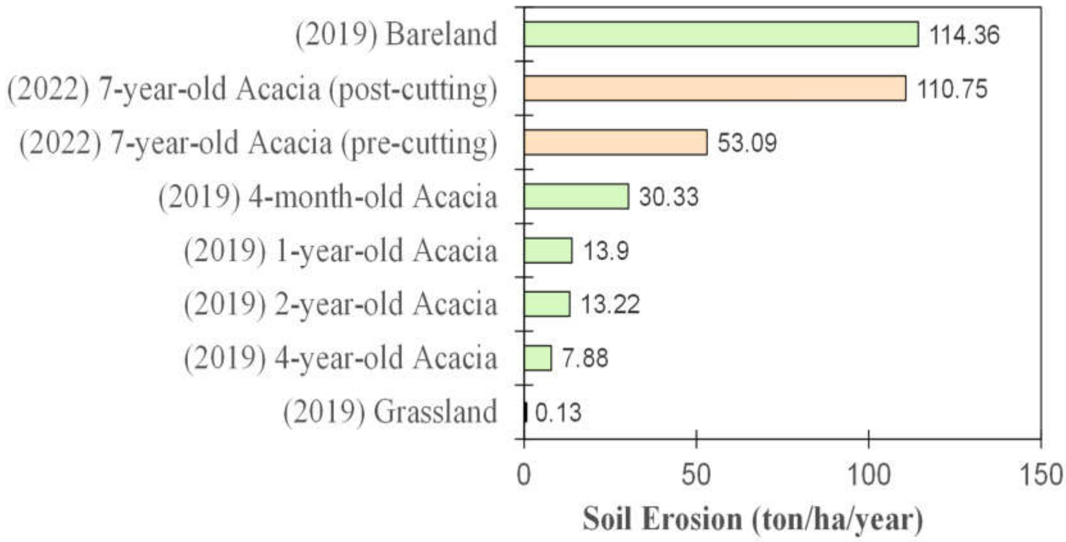

Figure 10. Soil erosion in comparison with a previous study *(Dung et al., 2019)*

As shown in the previous study, soil erosion tended to decrease along with the increase in age of Acacia forest (Dung et al, 2019). Eroding level in compared Acacia forest had dropped from 30.33 to 7.88 tons/ha/year since it was 4 months old until it reached 4 years old. However, the forest at study site reached an extremely high level of soil erosion at the age of 7 years old (53.09 tons/ha/year). This situation might be explained by topographical factors, or slope in particular. At researching site, the slope was recorded to be 35° on average, which was significantly steeper than that of previous study site (24° on average). The intensity of erosion tended to rise gradually with the slope because the slope was a key factor to determine surface flow rate, contributing to the breakdown and movement of soil structure (Hai et al, 2020). After harvesting of Acacia plantation, soil erosion at study site was estimated to be doubled with 110.75 tons/ha/year, which was almost equal to the figure recorded in bare land – 114.36 tons/ha/year (Fig. 10). This problem might be caused by the lack of canopy cover and vegetation cover after clear-cutting, when the soil has less vegetative cover. Raindrops hitting leaves, stems and other plant parts get interrupted and redistributed, thereby reduced the velocity of direct soil impact. Additionally, plants have extensive root systems assist to keep soil and bound it together, reducing displacement. Therefore, vegetation that completely covers the soil is the most effective in controlling soil erosion (Dung and Thanh, 2020).

3.3. Water quality responses to clear-cutting of Acacia planted forest

In general, all parameters increased after clear-cutting. While most indicators were acceptable according to Vietnam national standard on water quality, TSS and COD exceeded hugely, which was a warning for water use. pH and TDS of water at study site increased significantly after clear-cutting in the range of standards (QCVN 14:2008; QCVN 40:2011; QCVN 08:2015 of MONRE) while these values in control forest changed insignificantly. Moreover, TDS was recorded for an increase of 93.59% higher than that of before clear-cutting stage. To compare with standards from QCVN system, the amounts of COD and TSS had exceeded seriously. COD at 5.6-time higher than Vietnam standard B1 (irrigation) for domestic wastewater (168 mg/L over standard of 30 mg/L), TSS reached the value which was 180 times higher than the standard stated (9070.67 mg/L over standard of 50mg/L). In preharvest stage, the water quality of the research site was better, TDS and Total Phosphorus indicator even could not be detected. After clear-cutting, soil erosion rose remarkably due to the decrease of vegetation, litter cover, porosity and other factors. It might be a cause for the change of water quality parameters. Surface runoff increased at the forest and carried with it substances taken from forest soil to downhill stream, thus reducing the quality of water at the stream (Fig. 11).

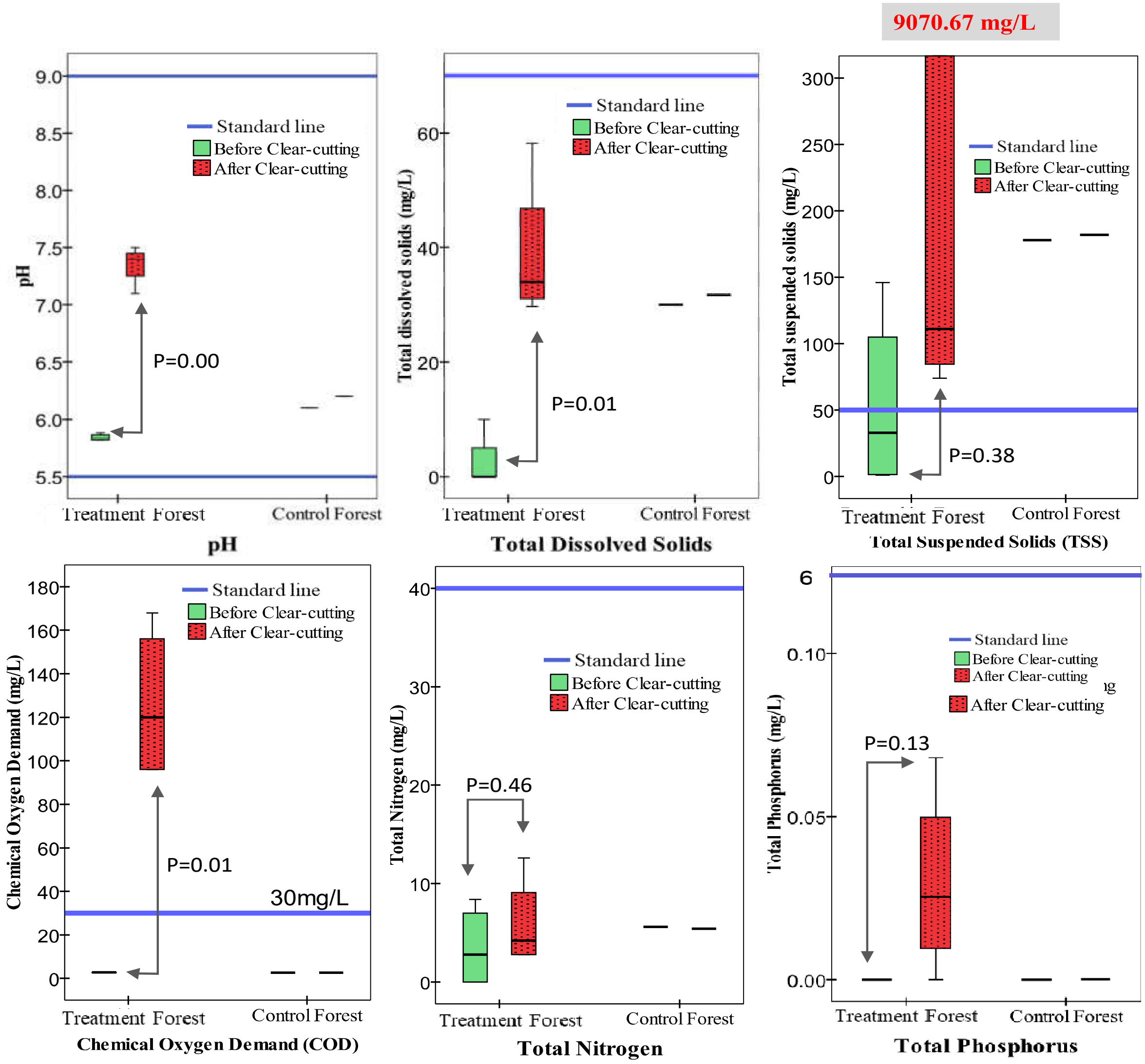

Figure 11. Water quality responses to clear-cutting

4. DISCUSSION

4.1. Correlations of infiltration with soil and vegetation factors

Soil porosity, litter cover and understory vegetation cover had remarkably high correlation with soil erosion. The amount of soil eroded was negatively proportioned (R = -0.95) with soil porosity as less surface runoff when precipitation was infiltrated into highly porous soil. Additionally, ground cover from understory vegetation and litter had high negative-correlation with soil erosion. The explanation for this case was that when the covers were numerous, the root system and litter layer would make soil porosity raise. Soil erosion was positively related to slope and elevation with low correlation of 0.02 and 0.04 respectively.

After clear-cutting, soil erosion depended more on litter cover (R = -0.95) than understory vegetation cover (R = -0.89) and soil porosity (R = -0.88), properly due to the fall in vegetation cover – thus decreased root system – and lower porosity after harvesting process took place. The slope had more effects on the amount of soil eroded with higher R=0.33 than before. Soil erosion, therefore, might increase due to the reduction of understory vegetation (13.7% dropped) and litter layer (19.2% dropped) and correspond with slope.

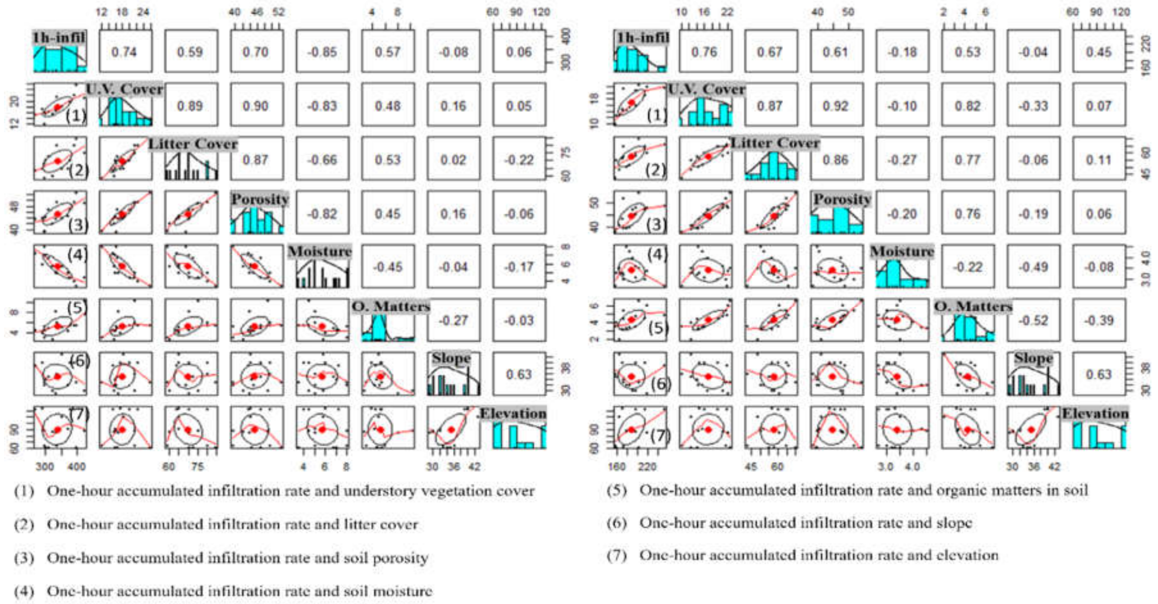

Figure 12. Correlation between one-hour accumulated infiltration rate and other factors (a) before and (b) after clear-cutting

4.2. Correlations of soil erosion with soil and vegetation factors

Before clear-cutting, total infiltration amount in one hour had a tightly positive relationship with understory vegetation cover (R = 0.74), litter cover (R = 0.59), soil porosity (R = 0.70). Besides, 1-hour infiltration rate had a strong negative correlation with soil moisture (R = -0.85), which meant accumulation infiltration might increase while soil moisture decreased. Moreover, the figure showed that there was a correlation between 1-hour infiltration and organic matter amount in soil (R = 0.57).

However, these relationships had changed after the clear-cutting process took place. Permeability of soil in 1 hour then did not depend much on soil moisture anymore (R = -0.18) because moisture was purely a temporary value (varies among different measuring time). Vegetation, litter cover and soil porosity tended to be the key-driven factors that led to changes in soil infiltration capability with correlation index R equaled to 0.76, 0.67 and 0.61 respectively. This also explained for a positive proportion with R = 0.53 of organic matters and soil infiltration rate after the harvesting stage that reducing overland flows (by enhancing infiltration) could help maintain soil nutrients.

After clear-cutting, when all trees were cut down, the decrease of forest cover (from canopy, understory vegetation and litter) made the soil less porous, which meant soil porosity was lower, thus interfering infiltrating ability of the soil at study site. Therefore, 1-hour infiltration accumulation decreased reasonably.

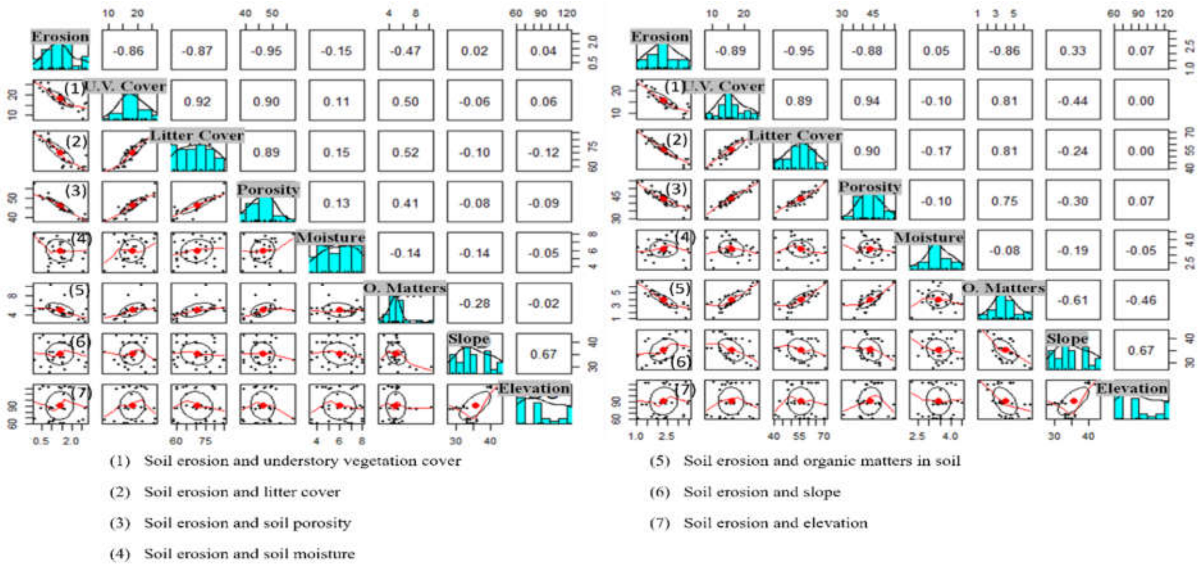

Figure 13. Correlation between soil erosion and other factors (a) before and (b) after clear-cutting

4.3. Solutions for sustainable forest management

Implied from results, managing soil erosion and infiltration rate should be highlighted to minimize negative environmental impacts. Some solutions are suggested as two scenarios below (Fig.14). (1) Replacing production planted forest by protection/mixed forest: With a steep slope of study site, it is difficult to manage the runoff and erosion at the stage of after-harvesting when all canopy cover is removed, and skid-trail is made. Changing forest type into protection planted forest is an ideal solution that can improve forest resilience and protect soil surface better without repeating plant-to-harvest process. Runoff and erosion thus may reduce by time and water quality becomes better as less eroded soil from land surface. (2) The second suggestion is remaining commercial plantation forest. Planting trees perpendicularly with contour line: Because water flows perpendicularly with contour lines, planting trees along contour lines may divide runoff into little flows. Infiltration rate could separate evenly across the hill, which can reduce overland flow rate. Soil erosion by surface runoffs thus can be controlled effectively, which leads to the improvement in water quality. Enhancing ground vegetation cover for soil especially after cutting stage: This approach can reduce the effect of rainfall, thus minimize runoff by being a physical barrier to surface water and contribute to soil porosity by dense root systems. Hence, soil nutrients and water quality would further improve. Plant at alternate stages to change/elongate a plant-to-harvest rotation: Only a half of saplings are planted at first, the rest will be planted later. This way avoids clear-cutting of plantation forest: when the first class of trees are harvested, the second group will be remained in the forest which can help control soil loss with root system, interfere rainfall with canopy, vegetation and litter cover. Improve riparian zone along water source: High erosion reduced water quality after clear-cutting. Riparian zone is the barrier for the stream. By developing riparian zone, the erosion by flow would reduce and water quality would maintain. Avoid prescribed burning after clear-cutting process to maintain forest cover. Prescribed burning of vegetation after harvesting directly affects soil properties, water quality by removing vegetation cover, increasing runoff as well as erosion rate.

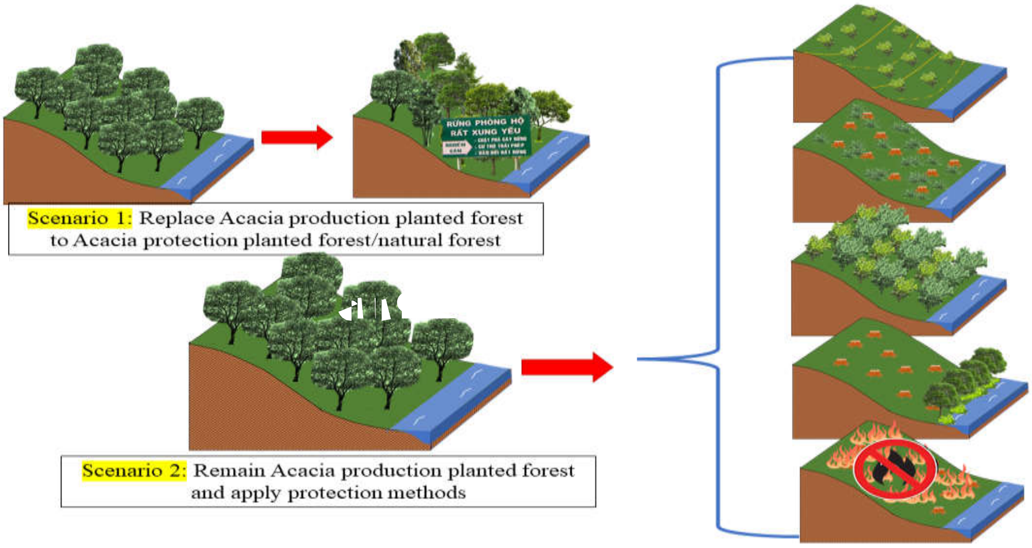

Figure 14. Solutions for sustainable management of Acacia plantation

5. CONCLUSION

Responding to clear-cutting of Acacia plantation forest, vegetation characteristic decreased with reduction of understory vegetation, litter cover and biomass ranged from 10 to 20%. Soil properties decreased 8.35% for porosity due to the rise of 8.57% in dry bulk density and 3.4% increase of particle density. Soil nutrient: organic matter, total Phosphorus and total Nitrogen decreased at the proportion of 20.91%, 62.86% and 27.86% respectively after clear-cutting. Infiltration rate decreased around 40% after harvesting. The positions that had high infiltration rate before clear-cutting tended to infiltrate noticeably less (Downhill: 397.7 mm to 201.2 mm). Soil erosion increased significantly after cutting and almost doubled to compare with other research results due to the slope of the research area (30° - 43°). Remarkable difference between 2 period in terms of water quality, COD and TSS are respectively 5.6-time (with 168 mg/L) and 180-time (with 9070.67 mg/L) exceeding the standard of B1 category from QCVN 14:2008/BTNMT (COD = 30 mg/L, TSS = 50 mg/L); total amount of Nitrogen rose by 25% and Phosphorus increased from non-detected to 0.7 mg/L at the outpoint of researching Acacia forest. Some solutions recommended for sustainable management are described as 2 scenarios: (1) Replacing production planted forest at researching site by protection forest or mixed forests to reduce negative environmental impacts and (2) remaining commercial plantation forest, yet apply some management methods, which are (a) planting trees perpendicularly with contour lines, (b) enhancing ground vegetation cover, (c) planting at alternately stages, (d) improving riparian zone along water source and (e) avoiding prescribed burning after harvesting process.

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KHAI THÁC TRẮNG RỪNG TRỒNG KEO THUẦN LOÀI VÙNG ĐẦU NGUỒN VIỆT NAM: TÁC ĐỘNG MÔI TRƯỜNG VÀ GIẢI PHÁP QUẢN LÝ BỀN VỮNG

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TÓM TẮT

Để đánh giá tác động của việc khai thác trắng rừng trồng keo thuần loài tới chất lượng đất và nước, rừng keo 7 tuổi với diện tích 2,5 ha tại xã Cao Răm, tỉnh Hòa Bình đã được lựa chọn để điều tra ở 2 giai đoạn: trước và sau khai thác. 03 ô tiêu chuẩn 500 m^2 được lập tại 3 vị trí chân - sườn - đỉnh để xác định đặc điểm cấu trúc rừng, lập 30 ô 1 m^2 để đo độ che phủ và một số đặc tính của đất, trong đó 15/30 ô được chọn ngẫu nhiên để đo lượng nước thấm; và 4 điểm dọc theo khe nước chảy qua rừng được chọn để lấy mẫu nước đánh giá chất lượng nước. Các phát hiện chính bao gồm: (1) Độ che phủ rừng giảm sau quá trình khai thác, tỷ lệ che phủ và sinh khối đều giảm từ 10 đến 20%; (2) Độ xốp giảm 8,35%; dung trọng tăng 8,57% và tỉ trọng tăng 3,4%; (3) Chất hữu cơ, Phốt pho tổng và Nito tổng số giảm lần lượt là 20,91%, 62,86% và 27,86% sau khai thác trắng; (4) Tổng lượng nước thấm giảm sau khai thác. Các vị trí có tỷ lệ thấm cao trước khai thác có xu hướng giảm đáng kể (Chân núi: giảm từ 397,7 mm xuống 201,2 mm); (5) Xói mòn đất tăng mạnh và cao hơn đáng kể so với các kết quả nghiên cứu khác do độ dốc của khu vực nghiên cứu cao; (6) Hầu hết các chỉ tiêu chất lượng nước đều trong ngưỡng cho phép, tuy nhiên TSS và COD cao hơn tiêu chuẩn nước loại B1 (nước tưới tiêu) lần lượt 180 lần và 5,6 lần theo QCVN 08: 2015/BTNMT; (7) Một số giải pháp được đề xuất để quản lý bền vững là (a) thay thế rừng trồng sản xuất tại điểm nghiên cứu bằng rừng phòng hộ, rừng tự nhiên hoặc (b) điều chỉnh phương thức quản lý bằng cách trồng cây theo đường đồng mức; tăng cường lớp phủ thực vật và trồng xen kẽ theo từng giai đoạn.

Từ khóa: Chất lượng đất, chất lượng nước, huyện Lương Sơn, khai thác trắng, rừng trồng keo, tác động môi trường.

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