SOIL INFILTRATION RESPONDS TO POST-HARVESTING PRESCRIBED BURNING OF ACACIA PLANTATION IN A HEADWATER MOUNTAIN

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SUMMARY

To determine the responses of soil infiltration characteristics to post-harvesting prescribed burning of Acacia plantation forest in a headwater mountain of Vietnam. The field experiment for infiltration measurement was established at different stages (including 5-year-old Acacia forest, after harvesting, after prescribed burning and planting new young forest) from August to October 2020. A number of affecting factors were determined, including vegetation characteristics and soil physical characteristics of Acacia plantation. The main findings included: (1) Total time for one process from harvesting to planting new forest was nearly 30 days. Both factors of vegetation and soil properties changed during four stages; (2) The infiltration rate of all locations in all stages followed the trend of decreasing after harvesting, burning, and recovering after planting new forest. The infiltration accumulation, initial rate, and stable rate was highest in 5-year-old Acacia plantation (525.8 mm, 20.2 mm/min and 2.9 mm/min, respectively), and then decreased continuously to lowest position after burning (211.1 mm, 10.1 mm/min, 1.2 mm/min, respectively) and recovered when new forest was planted. The factors affect to soil initial infiltration were understory cover, dry bulk density and porosity. Besides, the factors influence stable rate were understory cover, canopy cover, dry bulk density, percentage of silt and clay in soil; (3) These findings suggest that improving soil quality and temporal infiltration rate are necessary during-after forest harvesting and soil treatment periods of Acacia plantation in headwater mountainous areas.

Keywords: Acacia plantation, after harvesting, headwater, infiltration, prescribed burning.

1. INTRODUCTION

Soil infiltration is a process involving where water soaks into or is absorbed by the soil, which occurs in both soil science and watershed management field (Partten, 1908; Charles, 1932 and Horton, 1933). Soil infiltration is one of the important hydrological components and processes in water balance (Horton, 1993). The rate of infiltration is transferred through the soil depends heavily on surface conditions especially forest environment which has different surface conditions can exist and have different effects on infiltration (Robichaud, 2000). Soil permeability affects to the generation of overland flows and groundwater flows. When the infiltration rate is fast, the dominant underground flow will reduce the risk of soil erosion. In contrast, slow and poor water permeability leading to big surface runoff can cause landslides and floods (Dien, 2006 and Hai, 1993). Therefore, in order to effectively manage soil and water resources, maintaining the infiltration of the soil is very important (Dung, 2016).

Prescribed burning is known as a treatment method used to manage vegetation after harvesting. The reasons why the forestland owners usually use prescribed burning is that it is a relatively inexpensive and effective vegetation-conversion technique to reduce accumulated fuel and alteration of fuel continuity (Baeza et al., 2002 and Fernandez et al, 2008). Prescription burning can affect the potential of forest land production by reducing water retention, rapid erosion, and reduced soil permeability and fertility (Wells et al., 1979). Besides, fire can be reducing the infiltration rate and increase soil erosion because of destroying soil-protecting vegetation and litter leading to decrease porosity as a result of organic matter loss and the associated breakdown in soil structure (Hendricks et al., 1994 and Wahlenburget et al., 1939). Annual prescribed burning did reduce the infiltration capacity by 38 percent while removed litter by raking only caused 18 percent (Arend, 1941). When the water permeability of the soil decreases due to burning will lead to unpredictable consequences. After the fire, the soil wettability that was both low- and high-severity burns approached that of unburned soil (Robichaud, 2000).

Luong Son is an Eastern district of Hoa Binh province with a large area of planted forests in the head watershed. Acacia species account for the majority of the plantation area of 92% and are the main source of income for local people due to suitable natural conditions, rapid growth and short rotation (Dung and Thanh, 2021). After harvesting, vegetation is cleared, then burned, even branches, and leaves after exploitation are also burned before afforestation. (Duong and Trieu, 2007; Dung and Thanh, 2021). In Vietnam, studies on soil water permeability due to soil treatment before reforestation are limited. No more studies have been implemented on the soil permeability after burning vegetative residuals after harvesting. Therefore, the study titled "*Soil infiltration responds to post-harvesting prescribed burning of acacia plantation in a headwater mountain*" was conducted. The majority of studies thus, focused on comparing the infiltration rate of acacia plantation at different ages and natural conditions. Based on the research results, the comparison of the infiltration of soil before and after burning of the vegetation is determined, which is the basis to propose solutions to manage the sustainable Acacia plantation model in headwater mountain.

2. RESEARCH MOTHODOLOGY

2.1. Study site

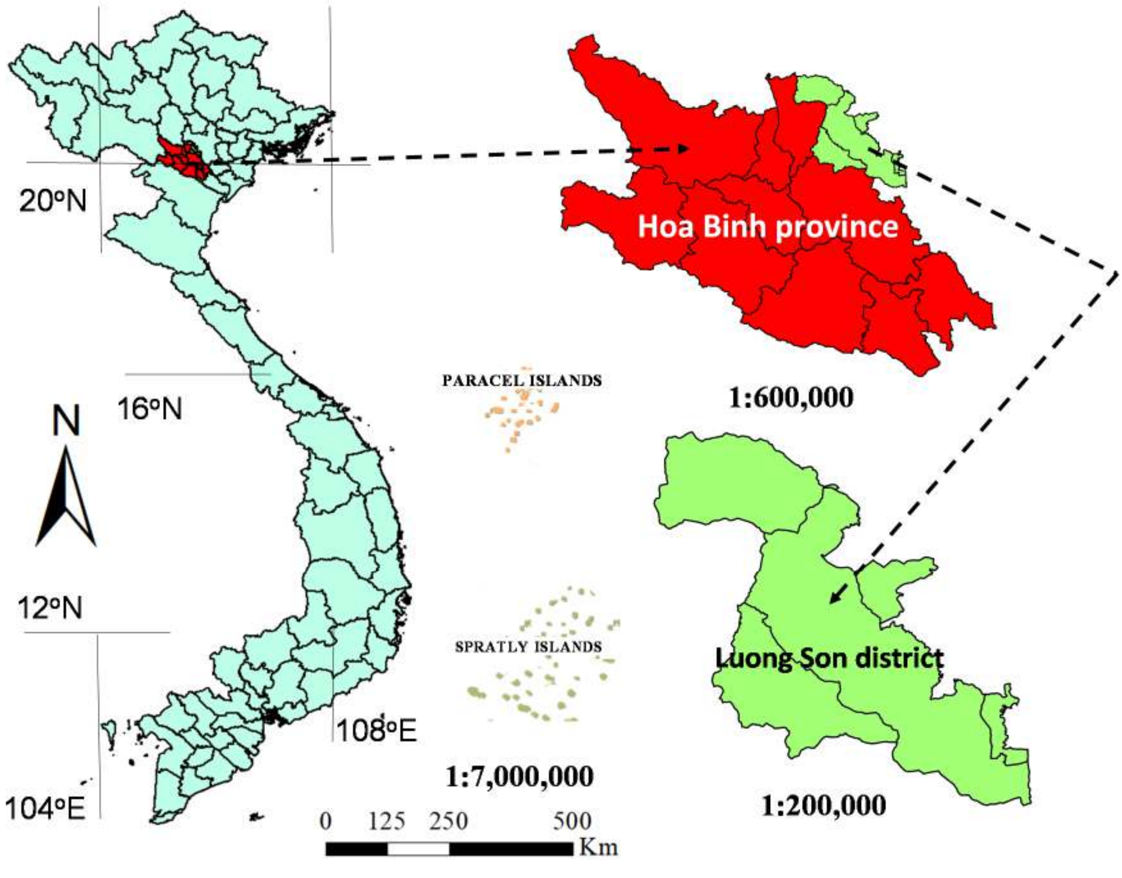


Figure 1. Map of study site

Luong Son district is located in the midland region - the transition area between the delta and the mountains, so the terrain is very diverse (Fig. 1). Low mountainous terrain with floor height of about 200 – 400 m is formed by magmatic rocks, limestone and terrigenous sediments, with a dense network of rivers and streams. The climate in Luong Son is a monsoon tropical climate, characterized by distinct seasons. The rainy season starts from April to October, the rainfall accounts for 91% of the annual rainfall. Annual average rainfall is 1,520.7 – 2,255.6 mm, rainfall mainly from May to October, the remaining months of the year rainfall are negligible. The average temperature is 22.9 – 23.3°C. The hottest month is 35°C (June & July). The coldest month is 8°C (January).

The total forest land area is 18,733.19 ha, accounting for 49.68% of the natural area. The natural forests of the district are quite diverse and rich with many kinds of precious woods.

But due to human impacts, forests have lost too much and replaced them as secondary forests. Forest area is distributed in all communes in the district.

2.2. Method

2.2.1. Soil infiltration measurement

Soil infiltration is measured in 4 stages: mature-age forest, after harvesting (before burning vegetation), after burning vegetation and soil preparing for new Acacia planting cycle. 3 selected points were measured the infiltration at the height of the top hill, middle hill and the downhill. The coordination of these locations were 20.841667N, 105.451392E (Fig. 2).

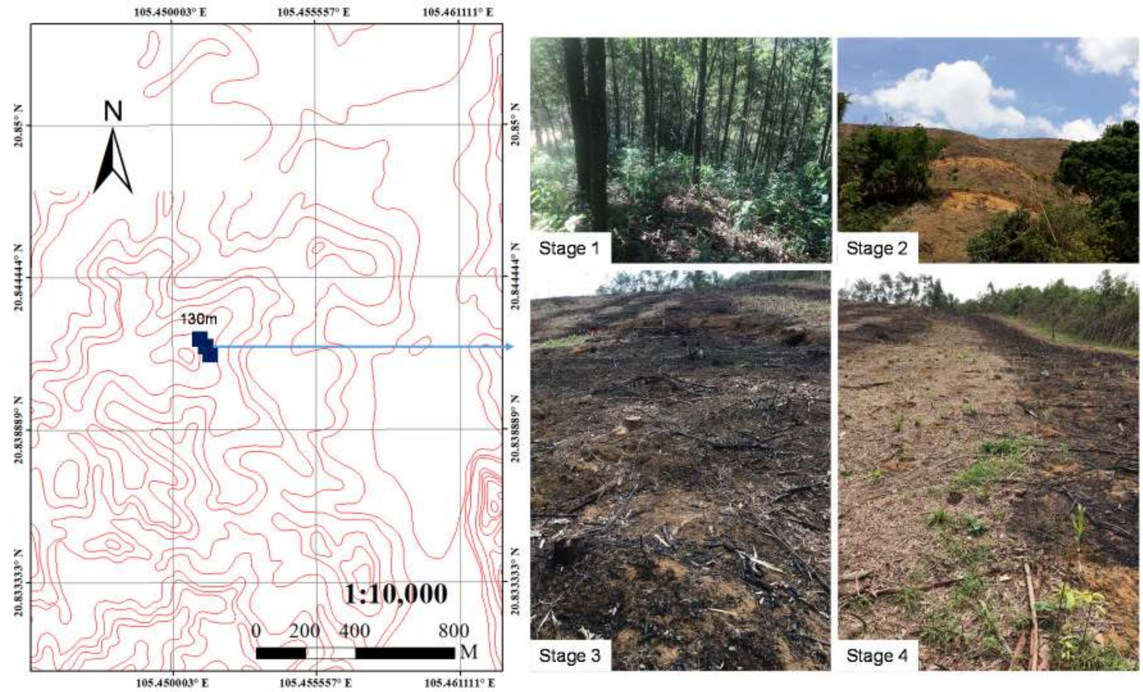


Figure 2. Contour map of study site

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 to near soil level. In generally, 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 10 cm nail (Fig. 3).

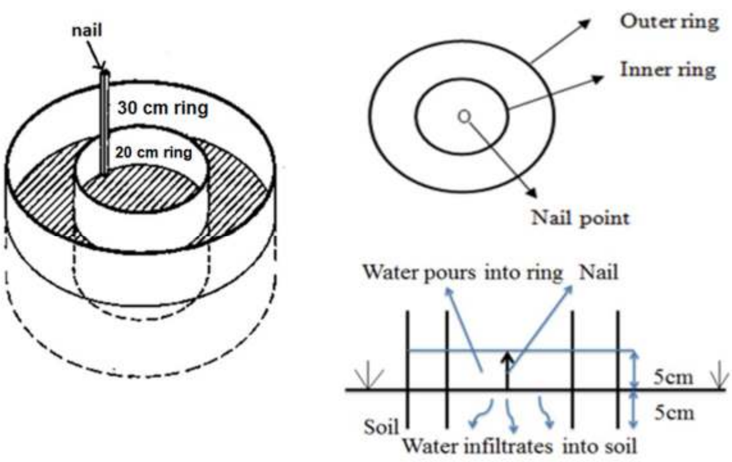


Figure 3. Double-ring infiltrometer

First step is driving the ring into the ground up to the three-inch mark. The best way to do this is to pound a small block of wood laying across the ring with a mallet. Firm the soil around the inside of the ring. Next, put a nail in to the ground of the center of the ring, the nail has the length of 5 cm after plugged into the soil. In general, the water level was kept at or above 5 cm depth (Fig. 3). Finally, using a cylinder to pour the water slowly into the ring of 5 cm initial water above the topsoil, with 10 cm nail and record in each minute during 120 minutes about how many water infiltrates as the following table 1.

Table 1. Soil infiltration data collection

Date:		Implementer:
Location:		Weather:
Initial water level: 5cm		Diameter of ring:
No.	Minute	ΔH (additional water) (ml)
1	0	
2	1	
…	…	
121	120	

2.2.2. Vegetation characteristics and soil properties

There are 5 characteristics of vegetation was investigated: Density of tree, vegetation cover, canopy cover, BDH and total height. Canopy Cover Free was used to determine understory vegetation cover. The equipment and software including GPS, GLAMA, Caliper, Blume Leiss, measuring tape were used to determine slope, coordinate system and grow data (Table 2).

At each infiltration measurement point, take soil samples to compare the differences in the criteria: Particle density, Dry bulk density, Porosity, soil moisture and soil texture – factors affecting soil infiltrations. Total 36 soil samples were taken at 3 locations (top hill, middle hill and downhill) in 3 depth levels (0 - 5 cm, 25 - 30 cm and 55 – 60 cm equivalent to A and B layer, respectively) at 4 stages (mature age, after harvesting, after burning and plating new forest). Vegetation and soil characteristics at the study site was summarized in Table 2.

Table 2. Vegetation and soil characteristics at the study site

Parameters	Stage 1: Before harvesting	Stage 2: After harvesting	Stage 3: After burning	Stage 4: Young forest
Density (trees/ha)	820	0	0	1600
Understory vegetation cover (%)	82	0	0	62
Canopy cover (%)	83.5	0	0	0
DBH (cm)	41.68	0	0	Insignificant
Height (m)	14.56	0	0	0.6
Slope (^{o})	27	27	27	27
Elevation (m)	130	130	130	130
Soil depth (cm)	161	161	159	160
Aspect	South-West	South-West	South-West	South-West

2.2.3. Data analysis

Data was analyzed by Microsoft Excel, IBM SPSS Statistics 23 and R-studio to determine responses of soil infiltration characteristics and impact factors at all location of different stages of Acacia plantation treatments.

3. RESULTS AND DISCUSSION

3.1. Infiltration rate at different stages

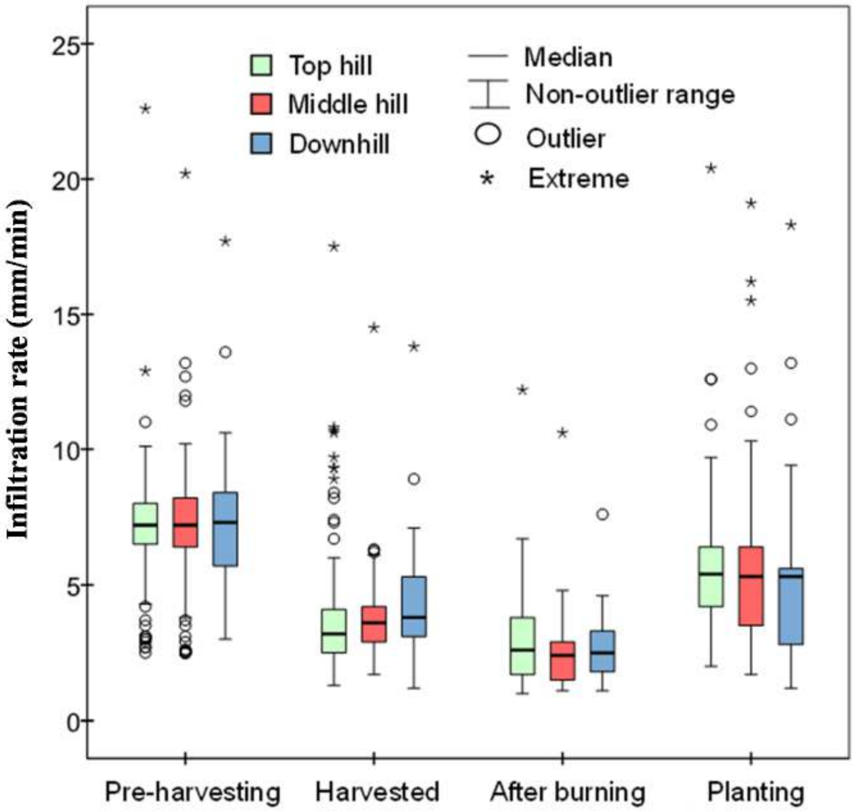


Figure 4. Box plot of infiltration rate at different stages of treatment

The temporary soil infiltration fluctuated during 4 stages. In general, the soil infiltration on top hill, middle hill and downhill did not change too much, but there is a clear difference among these stages (Fig. 4).

In general, the infiltration rule at all points was the same, quickly infiltration in the first minute and then gradually decreasing until the stable rate (Fig. 5). The rules over time change due to the harvesting activities, processing of prescribed burning and soil preparation before planting young forest. Infiltration rate of 5-year-old Acacia plantation before harvesting was highest at 22.6 mm/min at the first minute in top hill. At the middle hill and downhill, the infiltration rate was 20.2 and 17.7 mm/min, respectively (Fig. 5a). In stage 2, after harvesting, the average total infiltration accumulation reduced significantly by nearly 300 mm. The permeation rate was most noticeable at stage 3, after burning of the vegetation. At this stage, the initial infiltration rate at the downhill was lowest at 7.6 mm/min, halved that of the stage 1 at the site (Fig. 5b). The infiltration rate in stage 3 ranged from 1.1 to 5.2 mm/min and the stable action rate was also lowest (Fig. 5c). In stage 4 after preparing the soil for young forest plantations and impacted by the excavation and tilling, the initial infiltration rate recovered to 19 mm/min. The infiltration rate for the rest of the time ranged from 1.4 to 18.2 mm/min and the average rate increased by 0.6 mm/min compared to stage 3 (Fig. 5d).

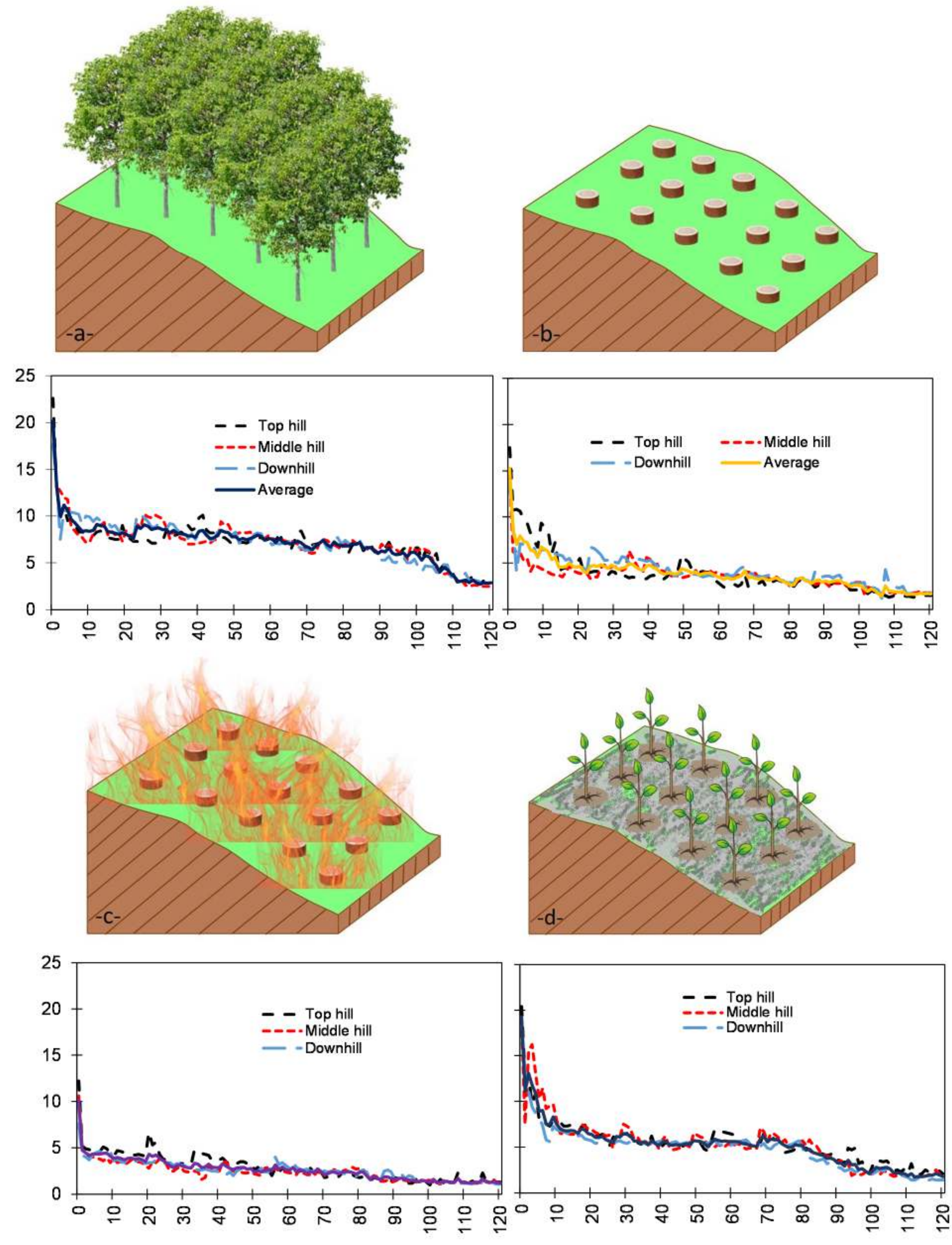


Figure 5. Infiltration rate in different stages: a) mature-age forest; b) After harvesting; c) After prescribed burning; d) Planting new forest

The average infiltration rate in all 4 stages follows the same rule, the high initial rate would gradually decrease and reached a stable rate from the 110th minute to the end of the period. The initial infiltration rate of 5-year-old Acacia forest was highest followed by that of young forest. The initial rate of forest land in stage 3, after prescribed burning was the lowest, and that of stage 2 was the second lowest one. The stable rate of the 5-year-old Acacia forest was 3 mm/min which doubled that of others. Stable rate of the 3 remaining stages ranged from 1.2 to 1.8 mm/min. The highlight of the figure was that the infiltration rate for the first 10 minutes of stage 4 was higher than that of stage 1, but during the period the infiltration rate of the 5-year-old Acacia forest was still the highest (Figs. 5, 6 and 8).

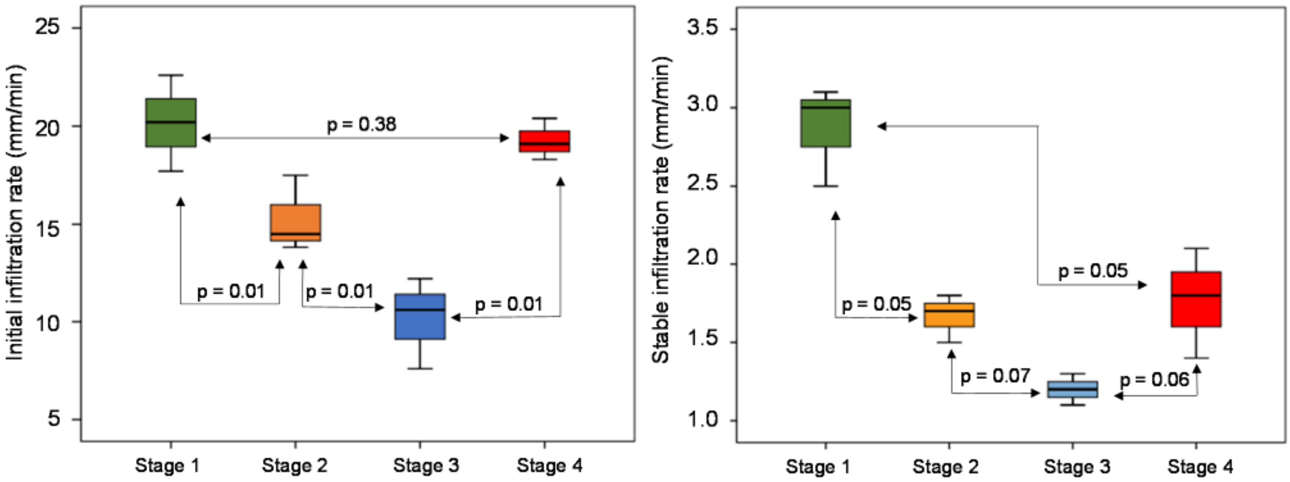


Figure 6. Box plot of initial and stable rate in different stages (mm/min)

The initial infiltration rate was followed the rule: the initial rate of 5-year-old Acacia forest land was highest, and then decreased gradually in the stage of harvesting and dropped to the lowest position in stage 3 - after burning. In stage 4, infiltration rate recovered due to tillage and soil preparation for new planting process (Figs. 6 and 8).

The average initial infiltration rate of 5-year-old Acacia forest was 20.2 mm/min, the maximum rate was 22.6 mm/min, and the minimum one was 17.7 mm/min. The infiltration rate decreased over time. In stage 2, the initial rate was 15.3 mm/min on average. The average initial infiltration rate for stage 3 continued to decrease sharply to 10.1 mm/min. The minimum infiltration rate was 7.6 mm/min at stage 3. The p value when comparing the initial rate of stage 3 with the two before and after stages by T test was 0.01 which less than 0.05, showing the difference among the infiltration rate of each stage was statistic significant. The potential reason could be prescribed burning that cause soil crust and compaction. In stage 4, the initial infiltration rate gradually increased roughly equal to that of the Acacia forest before harvesting (Figs. 6 and 8).

Similar to the initial rate, the stable rate also followed the rule of high infiltration rate in 5-year-old Acacia plantation, gradually decreased after harvesting, and then dropped to the lowest point after prescribed burning and increased again when planting young forests (Figs. 6 and 8). The average stable rate of 5-year-old Acacia forest was the highest at 2.9 mm/min. The maximum average infiltration rate was 3.1 mm/min and the minimum one was 2.5 mm/min. After harvesting, the average stable rate was 1.7 mm/min, decreasing by 1.2 mm compared to the previous stage. At stage 3, the stable rate dropped sharply to 1.1 mm/min, the lowest rate in the process. After preparing soil for the next crop, the stable rate of the forest soil increased significantly to 1.8 mm/min on average (Figs. 6 and 8).

3.2. Total infiltration accumulation in 1 hour

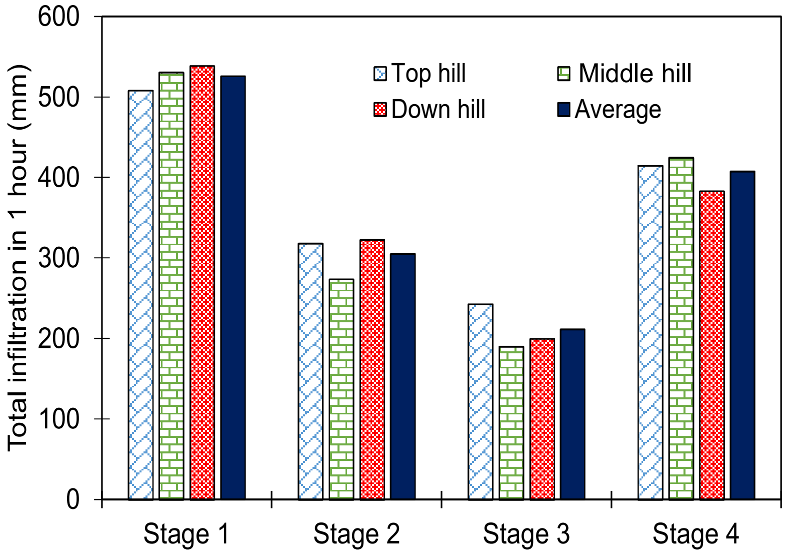


Figure 7. The total infiltration accumulation at different stages

In general, the total infiltration volume per hour of 5-year-old Acacia forest was highest, and then decreased after harvesting and dropped to the lowest point after burning. This data increased again at stage 4 after planting young forest (Figs. 7 and 8).

The 1-hour total infiltration accumulation of 5-year-old Acacia plantation was highest at 525.8 mm an average. During this period, the highest accumulation was in downhill (538.8 mm) which was followed by that in middle hill at 530.6 mm. In the period after clear cutting, the total infiltration in 1 hour decreased by 1/3 compared with the previous period (at 304.9 mm on average). The middle hill position had the least total amount of infiltration accumulation at 273.9 mm. Total accumulation continued to decrease and bottomed out in stage 3 at 211.1 mm on average. At this stage, the total infiltration accumulation in 1 hour at to mid-hill was highest at 243.1 mm, which higher than that in downhill by 43.1 mm. The middle hill had the least total permeability at 190.2 mm. In stage 4, the total permeability in 1 hour doubled that in the previous period to reach 407.5 mm (Fig. 7 and Fig. 8).

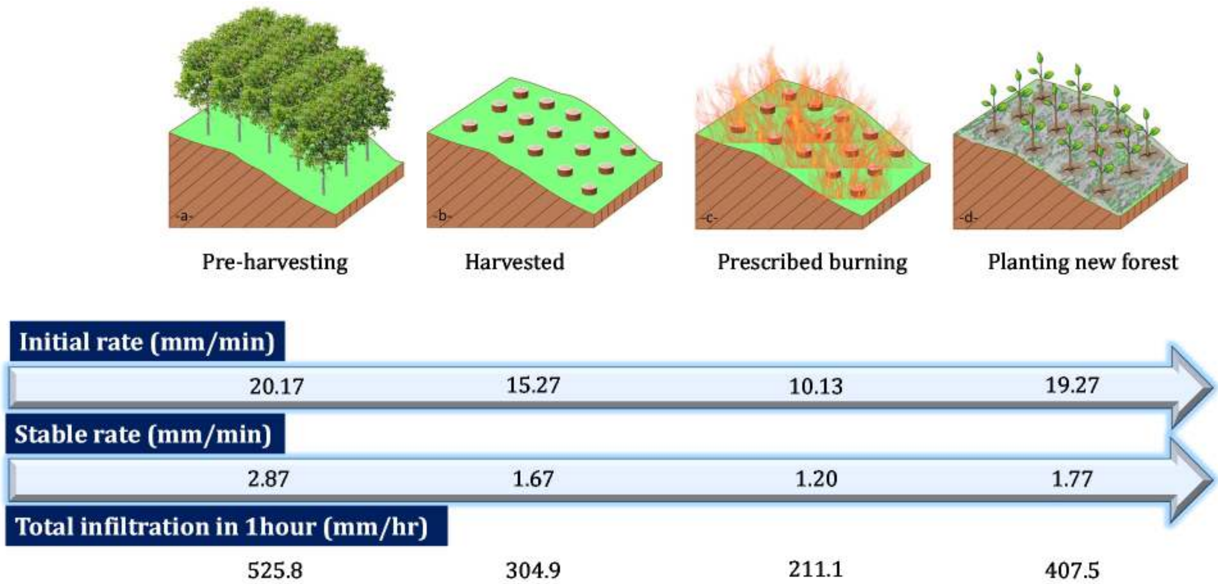


Figure 8. Mean infiltration characteristics summary at different stages of forest management

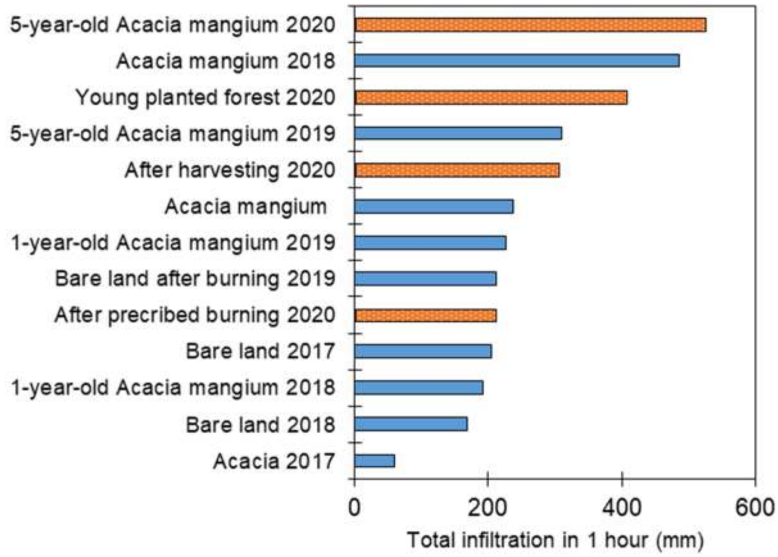


Figure 9. Total infiltration in 1 hour of other studies (Linh et al., 2019; Hoa and Dung, 2020)

Compared to the total water infiltrated in one hour reported by other researches at different locations, the amount of water in the Acacia ranged from 59 mm/hr to 526 mm/hr. In previous studies, the hourly infiltration rate in the area with 5-year-old Acacia plantation was 310 mm/hr. The relative high infiltration rate per hour of the research might be explained by quite high proportion of understory vegetation cover and porosity. In addition, previous studies have proved that the positive relation between porosity and understory vegetation with infiltration capacity, therefore, it also follows the trend to negative correlation between infiltration capacity and possibility of generating overland flow (Hiraoka at al., 2010). The average total infiltration rate in 1 hour of after burning in 2020 is 211 mm, nearly the same with this stage in Acacia plantation in Luong Son in 2019 (Hoa and Dung, 2020). Total infiltration in young forest in 2020 was 408 mm higher than that in 1-year-old Acacia forest in 2019 and 2018 by 181 and 216 mm, respectively. Regarding high amounts of water infiltrated in one hour, the soil under different ages of Acacia trees are expected to reduce the relative amount of saturated overland flow (Fig. 9).

3.3. Correlation of infiltration rate with vegetation and soil factors

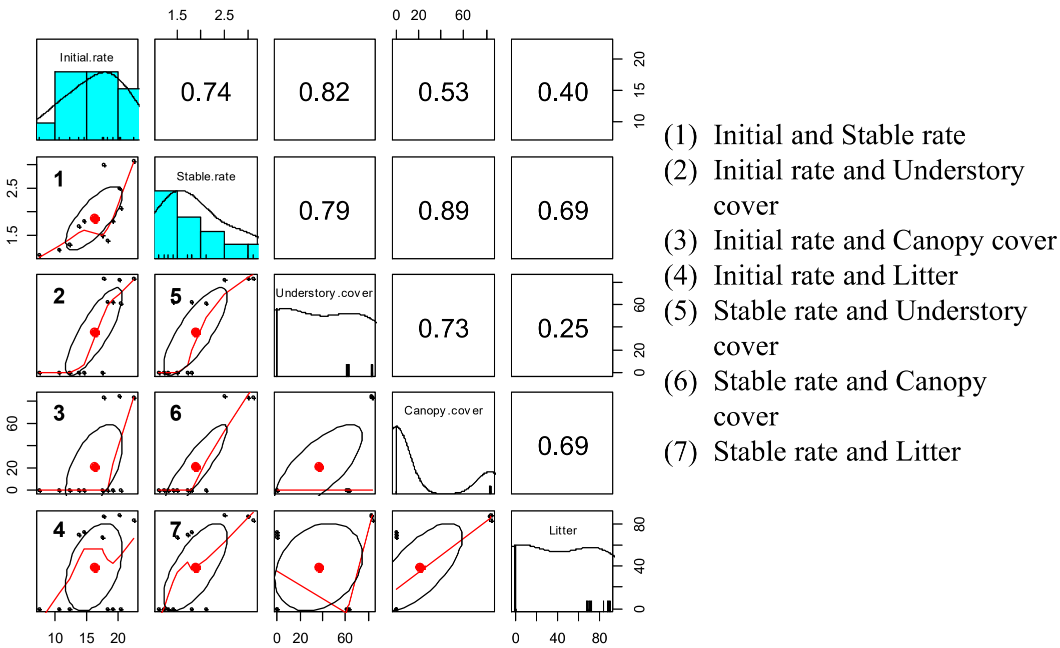
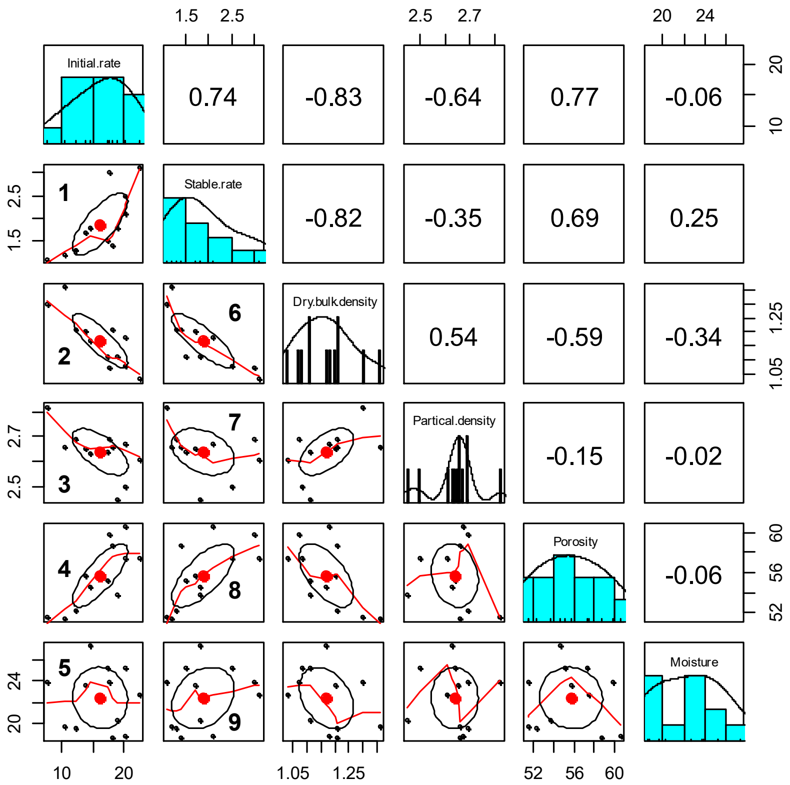


Figure 10. Correlation between initial and stable rate with vegetation factors

Initial rate and stable rate had positive relationship with vegetation factors such as understory cover, canopy cover and litter. Initial rate had a strong positive relationship with understory vegetation with high correlation coefficient (i.e., R = 0.82) (Fig. 10). Initial rate increases when the understory vegetation increases. Meanwhile, the stable infiltration rate was strongly correlated with both understory cover and canopy cover with R was 0.79 and 0.89, respectively. The stable rate had medium correlation with the litter (R = 0.69) (Fig. 10). It can be easily seen that the infiltration rate is highly dependent on the understory cover and canopy cover (Hiraoka et al., 2010). When the rainfall comes, the canopy reduces the force of free water falling, makes soil less fragmented, and surface runoff is reduced. In addition, the understory cover increases soil infiltration by creating many holes in land by the root system. This is also a factor to make recommendations to increase permeability of pure Acacia plantation forest land.



(1) Initial and Stable rate

(2) Initial rate and Dry bulk density

(3) Initial rate and Particle density

(4) Initial rate and Porosity

(5) Initial rate and Moisture

(6) Stable rate and Dry bulk density

(7) Stable rate and Particle density

(8) Stable rate and Porosity

(9) Stable rate and Moisture

Figure 11. Correlation between initial and stable rate with soil factors

For soil properties, the initial infiltration rate was proportional to porosity, inversely proportional to the remaining factors such as dry bulk density, particle density, and soil moisture (Fig. 11). Meanwhile, the stable rate was inversely proportional to the dry bulk density and particle density, proportional to the porosity and moisture. Initial infiltration rate had a strong correlation to porosity with R equaled 0.77. When the porosity was high, the pores in the soil were large from which the initial rate was higher. Both the initial and stable rates were inversely proportional to the dry bulk density with R of -0.83 and -0.82, respectively. Both the initial and stable rate did not correlate much with soil moisture (Fig. 11).

4. CONCLUSION

The process from mature age of plantation for harvesting to planting new forest cycle takes 25 to 35 days, averaged to 30 days at the study site. There are 4 stages including 5-year-old Acacia plantation, after harvesting, after prescribed burning and planting new forest was evaluated. Infiltration rate varied among the stages. Infiltration rate of 5-year-old Acacia plantation was highest, next decreased after harvesting and dropped to the lowest position in stage 3 – after harvesting and then recovered after planting new forest. The total infiltration accumulation in four stages was 868.9 mm, 466.8 mm, 319.1 mm and 627.7 mm, respectively. Total infiltration for 1 hour was also followed the trend and the value was 525.8 mm/hr, 304.9 mm/hr, 211.1 mm/hr and 407.5 mm/hr, respectively. The initial rate of mature age plantation was 20.0 mm/min, then decreased to 15.3 mm/min in stage 2, that figure for stage 3 was 10.1 mm/min and then recovered to 19.3 mm/min. The stable rate of four stages was 2.9 mm/min, 1.7 mm/min, 1.2 mm/min and 1.8 mm/min, respectively. Infiltration rate of the soil follows the trend of the highest value at the beginning and decreases over time. Time to reach the stable rate of the type of oscillation ranges from 110th to 120th minute. Both initial and stable rate have positive relationship with understory vegetation cover. Initial infiltration rate of soil has a strong relationship with understory vegetation (R = 0.82), porosity (R = 0.77) and dry bulk density (R = -0.83), but do not have significant relationship with canopy cover and soil moisture. While stable rate has a strong relationship with understory vegetation (R = 0.79), canopy cover (R = 0.89), dry bulk density (R = -0.82), moderate relationship with litter cover (R = 0.69).

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TÍNH THẤM NƯỚC CỦA ĐẤT PHẢN ỨNG VỚI CÁC GIAI ĐOẠN XỬ LÝ THỰC BÌ SAU KHAI THÁC RỪNG TRỒNG KEO THUẦN LOÀI Ở VÙNG ĐẦU NGUỒN

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TÓM TẮT

Để xác định các phản ứng của đặc điểm thấm nước đối với việc đốt xử lý thực bì sau khai thác rừng trồng Keo thuần loài ở vùng núi đầu nguồn của Việt Nam. Thí nghiệm đo tốc độ thấm nước của đất đã được thực hiện ngoài thực địa ở các giai đoạn khác nhau (bao gồm rừng keo 5 năm tuổi, sau khai thác, đốt xử lý thực bì và trồng rừng non mới) từ tháng 8 đến tháng 10 năm 2020. Một số yếu tố ảnh hưởng đồng thời đã được xác định gồm đặc điểm thảm thực vật và tính chất vật lý của đất dưới rừng trồng Keo. Các kết quả chính bao gồm: (1) Tổng thời gian cho một quá trình từ khai thác đến trồng rừng mới là gần 30 ngày. Cả hai yếu tố thảm thực vật và đặc tính đất đều thay đổi trong bốn giai đoạn; (2) Tốc độ thấm nước của đất ở tất cả các vị trí trong tất cả các giai đoạn tuân theo quy luật là giảm dần sau khi khai thác, đốt xử lý thực bì và phục hồi trở lại sau khi trồng rừng mới. Lượng nước thấm gồm lượng nước thấm trong 1 giờ, tốc độ ban đầu và tốc độ thấm ổn định cao nhất ở rừng trồng Keo 5 năm tuổi (tương ứng là 525,8 mm/giờ, 20,2 mm/phút và 2,9 mm/phút), sau đó giảm liên tục xuống giá trí thấp nhất ở giai đoạn sau khi đốt (211,1 mm/giờ, 10,1 mm/phút và 1,2 mm/phút tương ứng) và phục hồi khi rừng mới được trồng. Các yếu tố ảnh hưởng đến đặc điểm thấm nước ban đầu của đất là độ che phủ của thảm tươi, thảm khô và độ xốp. Bên cạnh đó, các yếu tố ảnh hưởng đến tốc độ thấm ổn định là độ che phủ, độ tàn che, dung trọng đất, tỷ lệ cấp hạt thịt và sét trong đất; (3) Kết quả nghiên cứu đã chỉ ra rằng việc bảo vệ chất lượng và tính thấm nước của đất là rất cần thiết trong suốt giai đoạn khai thác và xử lý thực bì rừng trồng Keo thuần loài ở các vùng đầu nguồn.

Từ khóa: đốt xử lý thực bì, rừng trồng Keo thuần loài, sau khai thác rừng, thấm nước của đất, vùng đầu nguồn.

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