Soil properties and infiltration characteristics response to successive rotations of production Eucalyptus plantations in headwater catchments of Phu Tho province, Vietnam

Bui Xuan Dung[1], Kieu Thi Duong[1], Phung Van Khoa[1*], Trieu Duc Tri[1], Nguyen Hung Thinh[2]
[1]*Vietnam National University of Forestry*
[2]*Department of Forestry and Forest Ranger, Ministry of Agriculture and Environment*

Tính chất đất và đặc điểm thấm nước phản ứng với các chu kỳ kinh doanh rừng trồng Bạch đàn sản xuất ở vùng núi đầu nguồn tỉnh Phú Thọ, Việt Nam

Bùi Xuân Dũng[1], Kiều Thị Dương[1], Phùng Văn Khoa[1*], Triệu Đức Trí[1], Nguyễn Hưng Thịnh[2]
[1]*Trường Đại học Lâm nghiệp*
[2]*Cục Lâm nghiệp và Kiểm lâm, Bộ Nông nghiệp và Môi trường*
**Corresponding author: khoapv@vnuf.edu.vn*

https://doi.org/10.55250/jo.vnuf.10.2.2025.050-060

Article info:
Received: 21/07/2025
Revised: 25/08/2025
Accepted: 29/09/2025

ABSTRACT

This study investigates the responses of soil properties and infiltration characteristics to successive rotations of production Eucalyptus plantations in headwater catchments of Phu Tho province, Vietnam. Fifteen plots (500 m² each), representing five rotation cycles (from first to fifth) and a natural forest control, were established. Soil physical properties (hardness, dry bulk density, porosity), chemical properties (pH, total organic carbon, total nitrogen, phosphorus, potassium), and infiltration dynamics (measured using double ring infiltrometer over 120 minutes) were assessed following Vietnamese national standards (TCVN). Results show a progressive increase in soil compaction across rotations: penetration depth declined from 9 mm in the first rotation to 4 mm in the fifth rotation, and porosity decreased from 38.13% to 28.95%, compared with 46.72% in natural forest control. Chemical fertility also decreased: total organic carbon fell by 39% (from 1.55% to 0.94%), total nitrogen by 33% (from 0.18% to 0.12%), phosphorus by 45%, and potassium by 62% across rotations, while pH declined from 3.61 to 3.26 (natural forest pH 3.71). Infiltration rates followed the same trends, with the average 5 minute rate dropping from 72 mm in the first rotation to 33 mm in the fifth, and the cumulative infiltration over 120 minute decreasied from 1,808 mm to 812 mm (natural forest: 2,065 mm). These findings demonstrate that successive Eucalyptus rotations without restorative interventions significantly degrade soil structure, nutrient status, and hydrological function.

Keywords:
Infiltration capacity, short-rotation, soil chemical properties, soil physical properties, successive eucalyptus rotations.

TÓM TẮT

Nghiên cứu này đánh giá những thay đổi của tính chất hóa lý và khả năng thấm nước theo các luân kỳ kinh doanh rừng trồng sản xuất Bạch đàn (Eucalyptus) tại các lưu vực đầu nguồn thuộc tỉnh Phú Thọ, Việt Nam. Mười lăm ô nghiên cứu (500 m² mỗi ô) được thiết lập, đại diện cho năm chu kỳ kinh doanh Bạch đàn (từ chu kỳ thứ nhất đến chu kỳ thứ năm) và một ô đối chứng là rừng tự nhiên. Các chỉ tiêu về tính chất vật lý của đất gồm độ chặt, dung trọng, độ xốp, tính chất hóa học của đất gồm pH, tổng các-bon hữu cơ, tổng nitơ, phốt pho, kali và khả năng thấm nước được đo đạc theo tiêu chuẩn quốc gia Việt Nam (TCVN). Kết quả cho thấy đất có xu hướng bị nén chặt dần qua

Từ khóa:
Khả năng thấm nước của đất, luân canh bạch Đàn liên tiếp, luân canh ngắn, tính chất hóa học của đất, tính chất vật lý của đất.

các chu kỳ: khả năng cắm sâu giảm từ 9 mm (chu kỳ thứ nhất) xuống còn 4 mm (chu kỳ thứ năm), và độ xốp giảm mạnh từ 38,13% xuống 28,95%, so với đất rừng tự nhiên là 46,72%. Mức độ màu mỡ của đất cũng suy giảm rõ rệt: tổng Cac-bon hữu cơ giảm 39% (từ 1,55% xuống 0,94%), tổng Nitơ giảm 33% (từ 0,18% xuống 0,12%), Phốt -pho giảm 45%, và Kali giảm 62% qua các chu kỳ, trong khi pH đất giảm từ 3,61 xuống 3,26 (rừng tự nhiên: 3,71). Tốc độ thấm nước cũng giảm tương tự, với tốc độ trung bình 5 phút giảm từ 72 mm (chu kỳ thứ nhất) xuống 33 mm (chu kỳ thứ năm) và lượng thấm tích lũy sau 120 phút giảm từ 1.808 mm xuống 812 mm, trong khi đó rừng tự nhiên đạt tới 2.065 mm. Những kết quả này chỉ ra rằng, việc trồng rừng Bạch đàn luân canh liên tiếp mà không có biện pháp phục hồi đất phù hợp sẽ làm suy giảm nghiêm trọng tính chất hóa lý và năng lực thấm giữ của đất. Điều này sẽ làm cho chất lượng đất suy giảm, khô hơn và mực nước ngầm sẽ giảm dần sau mỗi chu kỳ kinh doanh.

1. INTRODUCTION

Soil is a vital and finite natural resource that plays a role in sustaining ecosystem functions, including water regulation, nutrient cycling, and forest productivity. However, increasing land-use pressure which is particularly from intensive forestry has accelerated soil degradation worldwide. Fast-growing monocultures like Eucalyptus are widely planted due to their short rotation cycles and high economic returns, but successive planting without restorative measures can lead to soil compaction, nutrient depletion, and reduced infiltration capacity [1].

In Eucalyptus systems, infiltration dynamics and soil structure often decline over time. It was observed that early-stage plantations can restrict water flow due to dense root mats, while later stages may suffer from increased bulk density and reduced porosity [2]. These negative effects are further exacerbated by repeated clear-cutting and burning cycles, especially in short-rotation regimes. Despite global concern, little research has addressed how these changes manifest under tropical headwater conditions, where soil sensitivity is often high.

Vietnam has embraced plantation forestry for economic growth, with production forests which are dominated by Acacia and Eucalyptus covering over 4 million hectares [3]. However, concerns are growing over the sustainability of these practices. Studies have linked repeated short-rotation forestry to increased erosion and declining soil and water function, with impacts varying by plantation age [4, 5]. Yet comprehensive studies on how successive Eucalyptus rotations affect both soil properties and hydrological function in Vietnam remain limited. To address this gap, this study examines soil physical and chemical characteristics and infiltration capacity across successive Eucalyptus plantation cycles in the headwater regions of Phu Tho province, Vietnam.

2. RESEARCH METHODS

2.1. Study site

This study was conducted in two sub-catchments located in the northeastern region of Vietnam, specifically within the management areas of Tam Thang and Yen Lam Forestry Companies, situated in Tam Nong district, Phu Tho province. Both companies have a well-established history of managing Eucalyptus-based production forests and are currently operating plantations across their third to fifth rotation cycles.

With 15 plots distributed across five different rotation cycles (the first rotation to the fifth rotation), and in each rotation, stands of different ages were initially surveyed; however, for cost efficiency, only one or two representative ages per cycle were selected for detailed measurement. The selected stands ranged from 5 to 6 years old at the time of soil and infiltration measurements which were typically 1 - 2 years before harvesting. Each plot maintained a planting density of 1,600 trees per hectare. Canopy cover ranged from 0.6 to 0.9, with most plots showing a consistent litter and ground coverage of 100%. The top height of trees varied significantly among plots and rotation, ranging from 4.0 m to 29.5 m, with average heights between 9.4 m and 12.6 m. Similarly, the diameter at breast height (DBH) exhibited variation, with values ranging from 6.4 cm to 21.7 cm.

2.2. Method

2.2.1. Soil properties collection and analysis

A total of 15 standard plots with an area of 500 m² each were established in Tho Van, Tam Nong, Phu Tho province. Soil samples collected from the field were analyzed to determine key physicochemical properties. These included pHkcl, total organic carbon (TOC), total nitrogen (TN), total phosphorus (P), and total potassium (K) (using composite samples), as well as physical properties such as bulk density, particle density, and porosity using core samples.

Soil sampling was conducted to ensure site representativeness, with all samples be preserved and analyzed in accordance with current Vietnamese standards. At each standard plot (500 m²), soil hardness was measured at 100 grid-distributed points using the DIK-5553 Push-Cone meter. At the same locations, moisture content, temperature, and pH_KCl were recorded using a multifunctional probe. To assess soil structure, core samples were taken from the 0–10 cm depth using metal rings (7 cm diameter, 10 cm height), following TCVN 5297:1995, TCVN 7538-1:2006, TCVN 7538-3:2006, and TCVN 6647:2007. Given the rotational monoculture of eucalyptus plantations, soil conditions were assumed relatively uniform within each cycle. Thus, composite sampling followed the diagonal transect method (TCVN 7538-1:2006), forming an "X" across the plot. Nine subsamples were collected along each diagonal (18 total) and combined into two composite samples per plot to balance representativeness and analytical efficiency.

2.2.2. Soil infiltration measurement

Soil infiltration capacity was measured using a double-ring infiltrometer with concentric metal rings (20 cm inner, 25 cm outer diameter), 5 cm above the ground after being hammered in with sharpened edges for stable insertion. The outer ring was filled to minimize lateral flow from the inner ring, while a graduated copper tube maintained a constant water level inside. Water was continuously added to the inner ring, and infiltration volume was recorded every minute over 120–125 minutes.

A total of 18 measurements were conducted across Eucalyptus plantations of different rotation cycles and nearby natural forest. In the first rotation, two measurements were made in plantations and one in the natural forest. For the second to fifth rotations, three plantation measurements and one natural forest measurement were taken per cycle. The natural forest served as a reference due to its similar soil, topography, and climate, and because it represented the original land cover prior to plantation establishment.

2.3. Data Analysis

Descriptive statistics (mean, minimum, maximum, and standard deviation) were calculated for all soil and infiltration variables across rotation. Data visualization, including bar charts and line plots, was performed using Microsoft Excel 2019 and R version 4.3.2. Differences between rotation were interpreted based on observed patterns in the data rather than formal inferential tests, due to the limited number of replicates per rotation.

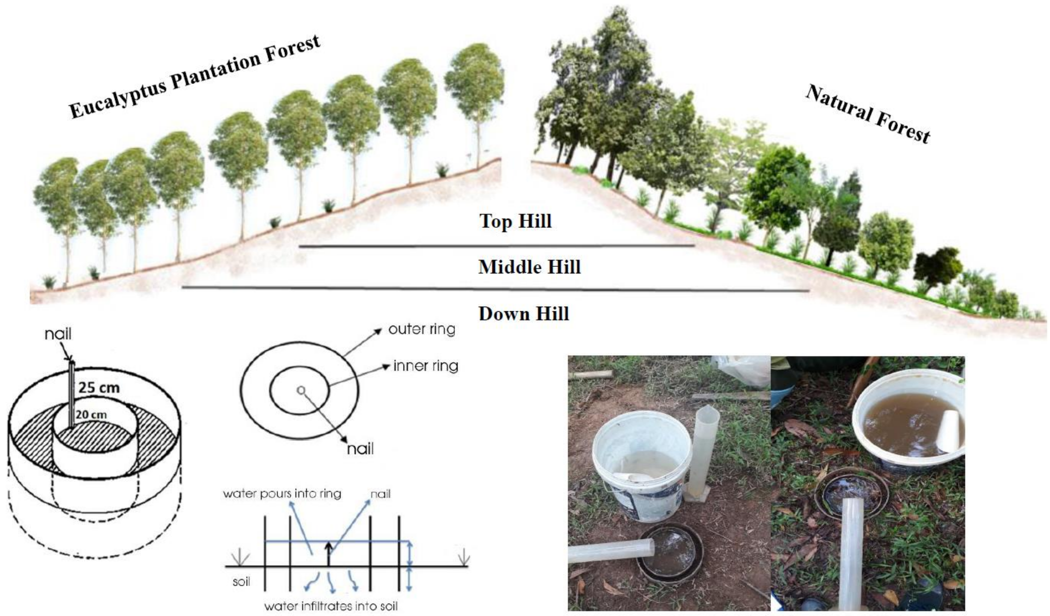

Figure 1. Location and the method used to measure soil infiltration at the study site

3. RESULT AND DISCUSSION

3.1. Soil Properties Characteristics response to Rotation of Eucalyptus Plantation Forest

3.1.1. Response of Soil Physical Properties

Soil hardness increased progressively across successive Eucalyptus rotations, as shown by declining penetration depth—from 9 mm in the first rotation to just 4 mm in the fifth. This trend reflects rising compaction. Similarly, soil porosity decreased from 38.13% to 28.95% across the same period, compared to 46.72% in natural forest (Fig. 2). These changes indicate a steady degradation of soil structure likely driven by compaction and reduced organic inputs.

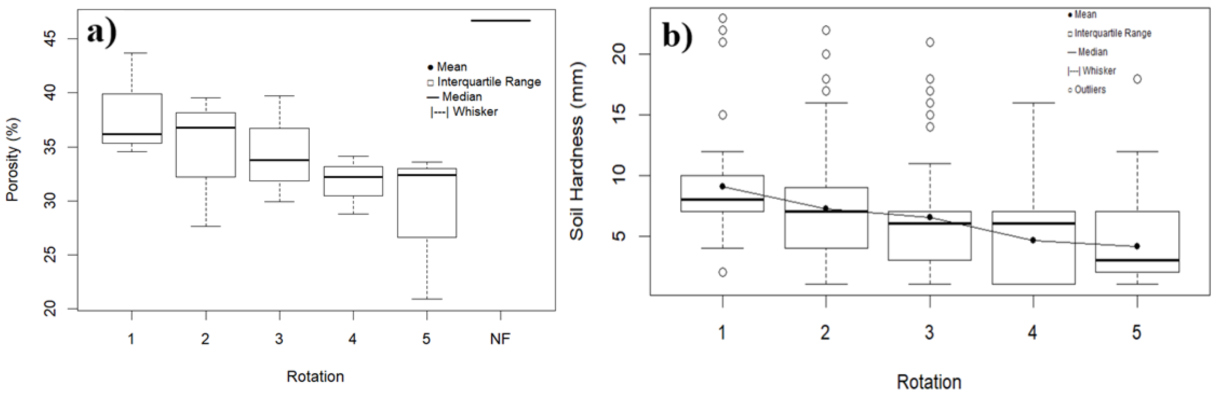

Figure 2. Responses of (a) Porosity and (b) Bulk density density to the rotation cycle of Eucalyptus production plantations in Phu Tho

Recent studies confirm that repeated Eucalyptus harvesting degrades soil hydrology and fertility. Bulk density increases, while porosity, water-holding capacity, and organic matter decline [6, 7]. It was found that fourth-rotation stands had higher bulk density and lower porosity than first-rotation ones, with reduced capillary pores and aggregate stability [6]. Similarly, it was reported nutrient depletion and soil compaction under short-rotation regimes, contributing to understory loss and exotic species invasion [8]. These structural changes further reduce infiltration and saturated hydraulic conductivity [7].

3.1.2. Response of Soil Chemical Properties

TOC decreased markedly from 1.55% in the first cycle to 0.94% in the fifth cycle, representing a 39% reduction. This decline is likely a result of continuous biomass removal and minimal organic matter return to the soil. In comparison, the natural forest maintained a much higher TOC of 1.70%, highlighting the importance of litter and undisturbed soil processes in sustaining organic carbon levels (Fig. 4). Similarly, Total Organic Matter (TOM) followed a comparable trend, declining from 2.54% to 1.84% from the first cycle to the fifth cycle, whereas the natural forest recorded 2.93%. The reduction in TOM reflects the loss of organic residues and reduced microbial activity, both of which contribute to nutrient cycling and soil fertility.

TN dropped from 0.18% in the first cycle to 0.12% in the fifth, indicating a 33% decline. This nitrogen depletion could have adverse effects on plant productivity and microbial dynamics, particularly given the high demand for nitrogen in fast-growing Eucalyptus species. The TN content in the natural forest (0.19%) further underscores the poor status of plantation soils under successive rotations. P decreased from 0.11% to 0.06%, and Total Potassium (K) dropped dramatically from 0.08% to 0.03% across the five rotations. The sharp decline in K, in particular, may result from nutrient export through harvested biomass, leaching, and the lack of fertilization or residue return. In contrast, natural forest soils had significantly higher P (0.12%) and K (0.21%) levels, suggesting a more stable nutrient reservoir under undisturbed conditions.

Soil pH values showed a gradual decline from 3.61 in cycle 1 to 3.26 in cycle 5, indicating increasing soil acidification. Natural forest soils exhibited a pH of 3.71, which may be due to better buffering capacity and greater accumulation of organic matter. Soil acidification in plantations can further exacerbate nutrient leaching leading to long-term fertility loss.

The impact of rotations on soil organic carbon (SOC) is mixed but generally less severe than for nutrients. Several studies show that longer Eucalyptus rotations can accumulate more soil C. It was found a 22-year Eucalypt rotation stored 107.2 Mg C/ha in 0-60 cm, significantly above the 86.7 Mg/ha in adjacent grassland [9]. Moreover, SOC fractions with slow turnover (alkali-extractable and non-extractable C) tended to grow with rotation length.

In contrast to C, soil N and other nutrients frequently decline under intensive rotations. The results found that total N stocks in the upper soil were lower under 13- and 22-year Eucalyptus stands than in native grassland, widening the soil C/N ratio in longer rotations [9]. In China, multigeneration eucalyptus led to significant drops in soil total N and available P [8]. The study of sequential rotations found that the third generation plantations had markedly lower TN, NH_4-N and NO_3-N (especially in 0 - 20 cm) than the first generation stands [10]. Conversely, available phosphorus (AP) and total P sometimes increased slightly in later rotations in that trial [10]. The declining trend in TOC, TOM, TN, P, K, and pH across successive Eucalyptus plantation rotations in Phu Tho is mainly attributed to continuous biomass removal, minimal organic residue return, and the absence of fertilization. Harvesting operations not only extract nutrients from the system but also reduce litter inputs which are key contributors to nutrient cycling and microbial activity. Additionally, the burning method used prior to replanting may temporarily increase nutrient availability but in the long term contributes to losses and degradation of soil organic matter.

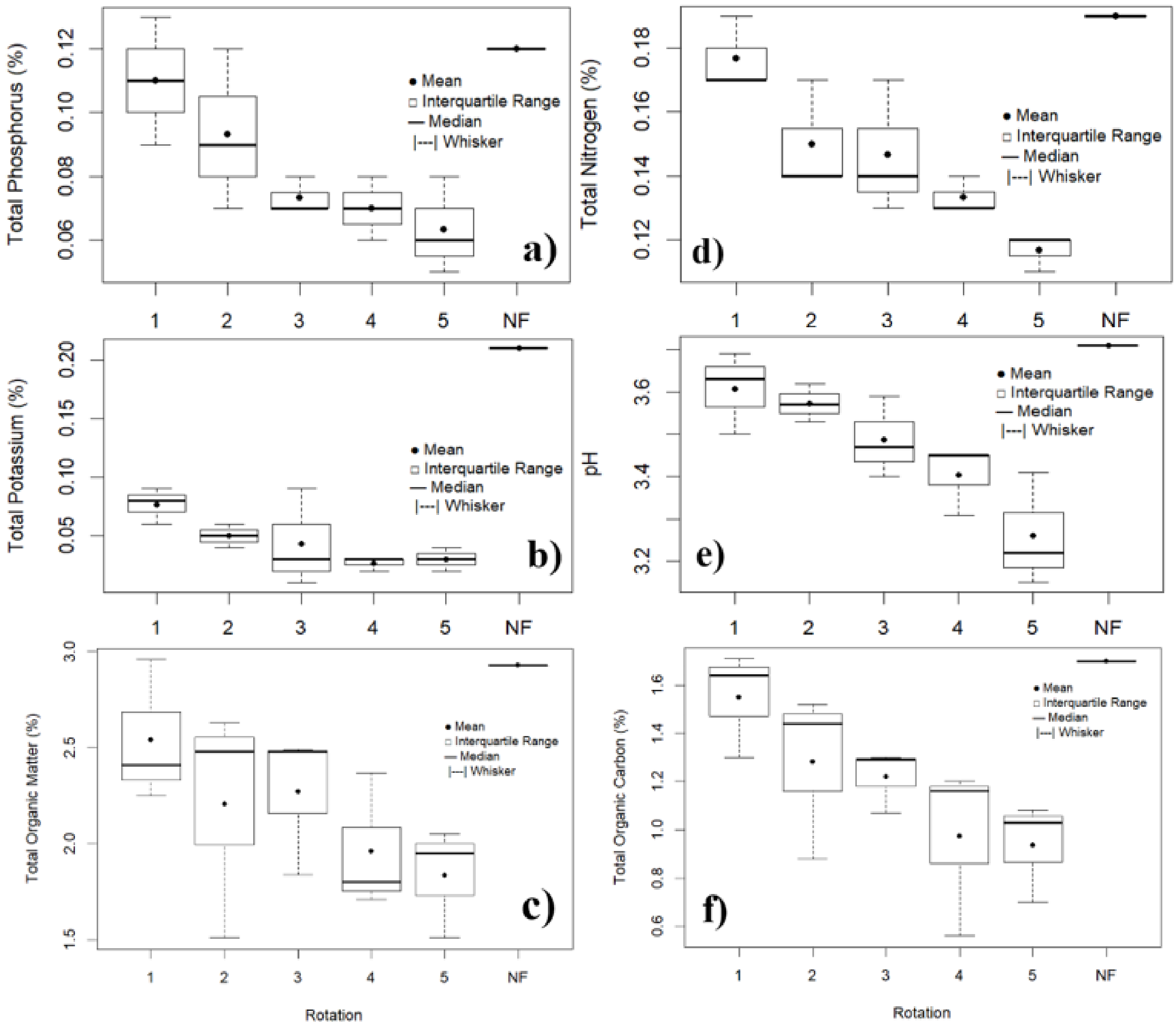

Figure 3. Responses of (a) Total Phosphorus, (b) Total Potassium, (c) Total Organic Matter, (d) Total Nitrogen, (e) pH and (f) Total Organic Carbon to the rotation cycle of Eucalyptus production plantations in Phu Tho

These trends are consistent with the findings from other studies. For instance, it was similarly reported significant reductions in TN and available P under multi-generation Eucalyptus plantations in China [8, 10]. It emphasized the high nutrient demands of Eucalyptus and the cumulative effects of repeated rotations [8]. It was also observed sharp reductions in ammonium (NH_4^+-N) and nitrate (NO_3^--N), particularly in surface layers, which aligns with our data showing a 33% drop in TN [10]. The big decline in K as observed (0.08% to 0.03%), who noted increased nutrient leaching and minimal nutrient return under short-rotation intensive systems [8]. However, some contrasting findings exist such as [10] which observed a slight increase in total P and available P in later rotations - unlike this study result, which showed consistent P decline. This difference could arise from varied site conditions, such as soil type, rainfall patterns, and management intensity. For example, different fertilization regimes or the use of P-accumulating understory species may contribute to such differences. Moreover, variations in rotation length could affect nutrient dynamics: longer rotations may allow more time for partial nutrient recovery, as highlighted in [9], who found increasing soil organic carbon with extended Eucalyptus rotations (e.g. 22 years). In contrast, this study focused on short-rotation plantations (7-years rotation), which likely intensified nutrient depletion.

The acidification trend observed in the result (decline from pH 3.61 to 3.26) also supports the findings by [7], who linked soil acidification to nutrient leaching and the absence of base-cation replenishment.

3.2. Responses of Soi infiltration Characteristics to Rotations of Eucalyptus Plantation Forest

3.2.1. Response of Average Infiltration Rate

The average infiltration rate measured over the first five minutes from 24 measurements in Eucalyptus plantations was highest in the first rotation at 72 mm/5 min (Figure 5). The infiltration rate then declined progressively with each successive rotation. Specifically, the rate decreased to 38 mm/5 min in the second rotation, 37 mm/5 min in the third rotation, 35 mm/5 min in the fourth rotation, and 33 mm/5 min in the fifth rotation. The largest decline occurred between the first and the second rotation, with a reduction of 47.22%, while the smallest decline was between the second and third rotation (2.63%). On average, the decrease in infiltration rate between rotations was 5.71%. These results suggest a sharp decline in infiltration after the first rotation, followed by smaller changes in later ones.

The results of [7] confirmed that successive rotations sharply reduced capillary porosity, soil moisture and saturated permeability, directly tying lower water retention to increases in bulk density. Notably, however, infiltration rates in eucalyptus soils remain high [11] review many short-rotation sites and emphasize that water infiltration capacity tends to increase with the age of the stand as fine roots create macropores and organic matter. Thus, while older Eucalyptus stands can promote infiltration by clearing fine pores, successive rotations generally compact the soil, reducing porosity and hydraulic conductivity unless managed (by retaining litter and roots) [7, 10].

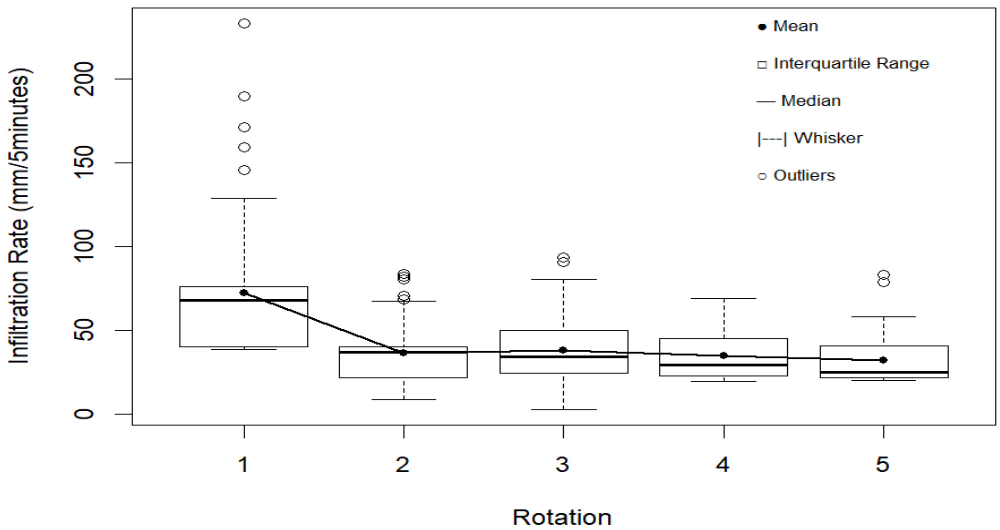

Figure 4. Variation of Average Infiltration Rate Across Eucalyptus Plantation Cycles

3.2.2. Response of Infiltration Rate and Cumulative Rate over time

In all five Eucalyptus rotations as well as in the natural forest, infiltration rates decreased over time. The highest values occurred during the initial phase and then stabilized after approximately 120 minutes (Figure 6). The initial infiltration rate was highest in the first rotation at 150 mm/5 min, followed by 98 mm (the second rotation), 81 mm (the third rotation), 69 mm (the fourth rotation), 67 mm (the fifth rotation).

The stable infiltration rate, observed near the end of the measurement period, also showed a declining trend: 54 mm/5 min in the first rotation, 27 mm in the second rotation, 20 mm in the third rotation, 21 mm in the fourth rotation, and 27 mm in the fifth rotation (Figure 3.5). All values of both initial and stable infiltration rates in Eucalyptus plantations were significantly lower than those observed in natural forest controls. Cumulative infiltration after 120 minutes, was highest in the first rotation at 1808 mm and declined in subsequent cycles (Figure 5). Specifically, the cumulative values were 1020 mm (the second rotation), 961 mm (the third rotation), 877 mm (the fourth rotation), and 812 mm (the fifth rotation). The relative reduction ranged from 5.82% (the second to third rotation) to 43.56% (the first to second rotation), with an average reduction of 16.38% between each cycle. When compared to the natural forest control, which

recorded 2065 mm of cumulative infiltration, the Eucalyptus plantation soils showed significantly lower infiltration capacity, only 39.32% (the fifth rotation) to 87.54% (the first rotation) of the natural forest value.

Infiltration rates declined across successive Eucalyptus rotations due to cumulative soil degradation from repeated short-rotation harvesting. Each cycle disturbs the soil, removes organic matter, and causes compaction, progressively reducing its ability to absorb and retain water. Compared to natural forests, Eucalyptus plantations have significantly lower infiltration capacity. This is largely because natural forests maintain continuous litter, diverse root systems, and minimal disturbance. In contrast, Eucalyptus stands often lack understory, have poorer litter quality (frequently removed during harvest), and develop shallow or dense roots, all of which slow organic matter recovery and hinder water movement.

3.2.3. Comparison of Total Infiltration in one hour at different land-use types from other studies

The total one-hour infiltration across a variety of land-use types, including Eucalyptus plantations, Acacia, mixed species, natural forest, and bare land has shown (Figure 6). Among all land uses, the natural forest reached the highest infiltration capacity at 1,174 mm/hour, serving as the baseline. The first rotation of Eucalyptus plantations recorded a comparably high infiltration rate of 1,089 mm/hour, ranked second only to the natural forest. However, infiltration decreased notably across successive Eucalyptus rotations: 653 mm/hour in the third rotation, 552 mm/hour in the fourth, and 448 mm/hour in the fifth, demonstrating a clear trend of declining infiltration capacity with continued plantation cycling.

In comparison, Acacia auriculiformis reached a peak infiltration of 809 mm/hour, while infiltration rates in Acacia mangium ranged from 310 mm/hour (5-year-old stands) to as low as 59 mm/hour in earlier cycles. Mixed stands such as Pinus-Acacia mangium and Acacia-Eucalyptus recorded intermediate values (434 mm/hour and 360 mm/hour, respectively). Bare land and grass plots had notably lower infiltration, with bare land after burning and bare land 2017 registering 212 mm/hour and 204 mm/hour, respectively.

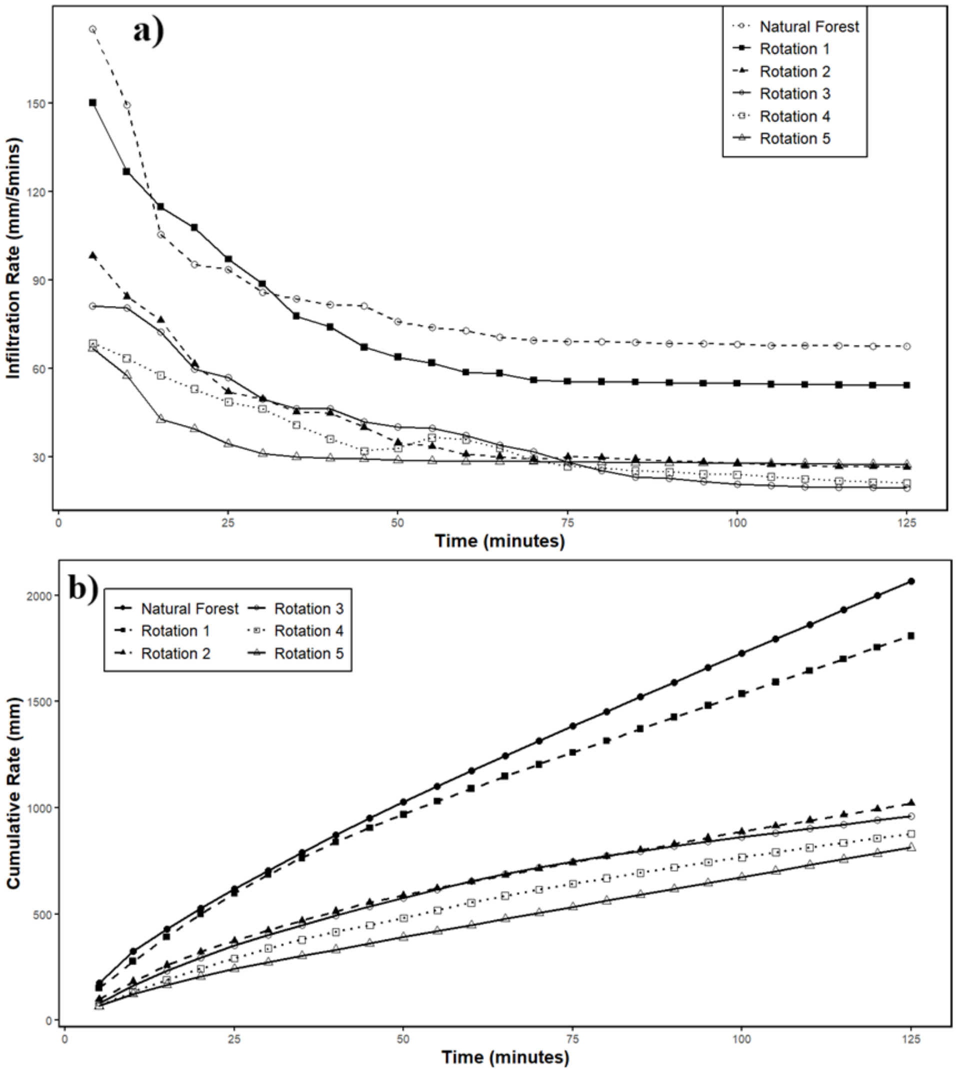

Figure 5. Response of (a) Infiltration Over Time and (b) Cumulative Infiltration to Eucalyptus Plantation Rotations

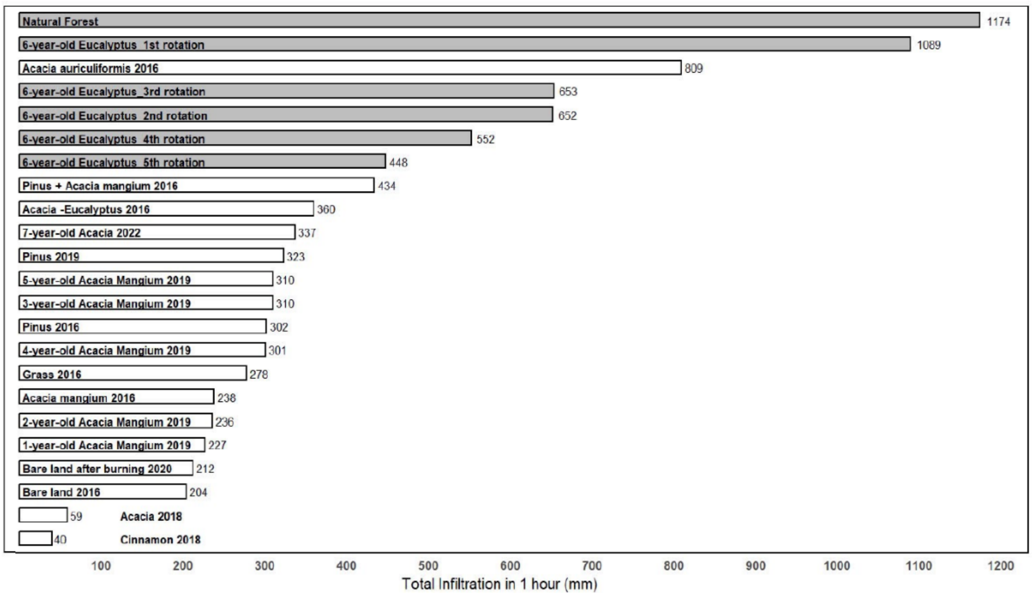

Figure 6. Comparing total infiltration in 1 hour of soil under different ages of Acacia plantation with those from other previous studies [4, 5] & [12-16]

The decline in both initial and cumulative infiltration rates across successive Eucalyptus rotations in Phu Tho aligns with trends in previous studies, for instance, study by [7], who reported that repeated plantation cycles reduced capillary porosity, increased soil bulk density, and impaired saturated hydraulic conductivity. These findings correspond quite closely with the results, especially the sharp drop in infiltration between the first and second rotation (43.56%), followed by a more gradual decline thereafter. This similarity is likely due to soil compaction from machinery use, decreased organic matter inputs, and disruption of soil that lead to the reduction of formation and stability of macropores. In addition, the results from [7] strengthens the conclusion that soil physical degradation is a dominant driver of hydrological decline.

However, [11] present a partial contrast, observing that infiltration can improve with stand age due to increased fine roots and organic matter. Their study, focused on stand age within a single rotation, differs from this study's design, which compares different sites across multiple rotations. This may explain the apparent contradiction: infiltration may improve early in a cycle, but cumulative degradation dominates over successive rotations. In our study, initial infiltration in the first rotation reached 1,089 mm/h, indicating good early performance - but declined to 448 mm/h by the fifth rotation. Differences in site management likely account for this: [11]'s sites retained more understory and had longer cycles, while Phu Tho plantations experienced frequent disturbance and minimal residue return.

Compared to Acacia and mixed-species plantations, Eucalyptus in later rotations performed worse. Acacia showed one-hour infiltration of up to 809 mm/h, exceeding fifth-rotation Eucalyptus by over 80%. This may reflect differences in litter quality and rooting. Acacia fixes nitrogen and produces nutrient-rich litter, supporting better soil structure and microbial activity. Eucalyptus litter, by contrast, decomposes slowly and contributes less organic matter. Acacia roots may also enhance porosity more effectively than Eucalyptus's finer, denser roots. However, even Acacia can show low infiltration under poor conditions. For example, [13] reported much lower rates (22.8–238.9 mm/h for Acacia; 14.9–66.9 mm/h for Cinnamon) on steep slopes with sparse understory and moderate compaction. Cinnamon's hydrophobic litter further reduced infiltration.

4. CONCLUSION

Successive short-rotation Eucalyptus plantations in Phu Tho's headwater catchments have significantly degraded soil and water environments compared to adjacent native forests. Over five rotations, bulk density increased, porosity declined from 38.1% to 28.9%, and compaction limited root growth and water infiltration. Soil fertility also deteriorated: TOC fell by 39%, TN by 33%, P by 45%, K by 62%, and pH dropped from 3.61 to 3.26. In contrast, natural forest soils maintained higher porosity (46.7%), nutrient levels, and a more stable pH (3.71), reflecting their ecological resilience.

Hydrological function declined in parallel. Initial infiltration rates dropped from 150 to 67 mm/5 min across rotations, and cumulative infiltration after 120 minutes fell from 1,808 mm to 812 mm, just 39% of natural forest capacity. These declines are closely tied to the deterioration of soil structure and nutrient status. To mitigate these declines, management practices such as retaining logging residues, applying organic matters, extending rotation lengths, and reducing pre-burning should be considered. These measures can help restore soil structure, improve nutrient cycling, and enhance long-term hydrological function.

While the study applied methods suited to available time and funding, it faced limitations. Spatial substitution across rotation cycles may have introduced variability in site conditions, and sampling was limited to the 0 - 30 cm topsoil layer with few composite samples. Future research should adopt time controlled designs and deeper, more intensive sampling to improve accuracy. Despite these constraints, the study clearly shows that without restorative measures, repeated short-rotation Eucalyptus plantations undermine soil health and watershed services. A shift toward more ecologically resilient forestry models is essential to protect soil, water, and long-term landscape sustainability in tropical uplands.

REFERENCES

[1]. Bargali S.S., Singh R.P. & Joshi M. (1993). Changes in soil characteristics in eucalypt plantations replacing natural broad-leaved forests. Journal of Vegetation Science. 4(1): 25–28. DOI: 10.2307/3235730.

[2]. Huang Y., Xiong T., Zhao M., Deng Y., Yang G., Ban Y., Lei T., Yu X. & Huang Y. (2024). Influence of soil properties and near-surface roots on soil infiltration process in short-rotation eucalyptus plantations in southern subtropical China. Catena. 234: 107606. DOI: 10.1016/j.catena.2023.107606.

[3]. Ministry of Agriculture and Rural Development (2025). National Forest Status Report 2024.

[4]. Dung B.X. (2016). Soil infiltration characteristics of different land-use types at Luot Mountain, Xuan Mai, Ha Noi. Journal of Forestry Science and Technology. 4: 47–58.

[5]. My T.T.T., Dung B.X., Quynh K.T., Tu T.T., Tri T.D. & Sandar K. (2022). Pre-harvesting of acacia plantation and environmental impacts: A case study in Luong Son, Hoa Binh. Journal of Forestry Science and Technology. 3: 102–113. DOI: 10.55250/jo.vnuf.2022.3.102-113

[6]. Wang J., Deng Y., Li D., Liu Z., Wen L., Huang Z., Jiang D. & Lu Y. (2022). Soil aggregate stability and its response to overland flow in successive Eucalyptus plantations in subtropical China. The Science of the Total Environment. 807: 151000. DOI: 10.1016/j.scitotenv.2021.151000.

[7]. Tan Y., Yang K., Qin J., Ni L., Liao S., Zeng D., Pan H. & Gu D. (2024). Soil hydrology characteristics among forest type, stand age and successive rotation in Eucalyptus plantations in Southern China. Forests. 15(3): 423. DOI: 10.3390/f15030423.

[8]. Zhou X., Zhu H., Wen Y., (2020). Intensive management and declines in soil nutrients lead to serious exotic plant invasion in Eucalyptus plantations under successive short-rotation regimes. Land Degradation & Development. 31: 297–310. DOI: 10.1002/ldr.3449.

[9]. Soares E.M.B., Ferreira G.W.D., Oliveira F.C.C., Teixeira R.S. & Silva I.R. (2019). The influence of the rotation length of eucalypt plantations on soil organic matter dynamics in southern Brazil. Soil Science Society of America Journal. DOI: 10.2136/sssaj2018.12.0459.

[10]. Dai Q., Wang T., Wei P. & Fu Y. (2023). Effects of Successive Planting of Eucalyptus Plantations on Tree Growth and Soil Quality. Sustainability. 15(8): 6746. DOI: 10.3390/su15086746.

[11]. Medeiros P.L.D., Pimenta A.S., Miranda N.D.O., Melo R.R.D., Amorim J.D.S. & Azevedo T.K.B.D. (2025). The myth that Eucalyptus trees deplete soil water — a review. Forests. 16(3): 423. DOI: 10.3390/f16030423.

[12]. Dung B.X., Linh N.T.M., Thuy T.T., Kha L.N., Linh P.T. & Trang P.T.T. (2016). Infiltration characteristics of soil under Eucalyptus plantation forest in headwater of Vietnam. Journal of Forest Science and Technology. 2: 63–74.

[13]. Linh P.T., Dung B.X. & Bao T.Q. (2018). Infiltration characteristics of soil under cinnamon and Acacia plantation forest in headwater of Viet Nam. Vietnam Journal of Forest Science. 4: 64–74.

[14]. Dung B.X., Thu V.T.H., Linh N.T.M. & Gomi T. (2019). Temporal and spatial infiltration characteristics of soil under Acacia and pine plantations in the mountainous area of Van Don, Quang Ninh, Vietnam. Journal of Vietnam Environment. 11(2): 51–64. DOI: 10.13121/jve.vol11.no2.pp51-64.

[15]. Dung B.X., Trang P.Q., Linh N.T.M., Hoa D.T.T. & Gomi T. (2019). Soil erosion and overland flow from Acacia plantation forest in headwater catchment of Vietnam. IOP Conference Series: Earth and Environmental Science. 266: 012012. DOI: 10.1088/1755-1315/266/1/012012.

[16]. Thi Thanh Hoa D. & Dung B.X (2020). Temporal infiltration characteristics of soil under different ages of Acacia plantation in Luong Son headwater, Hoa Binh, Vietnam. Journal of Forestry Science and Technology. 10: 038–047.