Carbon mineralization potential and nutrient dynamics in soils under vegetation types and soil depths at Luot mountain

Nguyen Thi Bich Phuong[1*], Nguyen Thi Bich Hoa[1], Tran Thi Hang[1], Bui Manh Hung[1], Pervez Khan[2]
[1]*Vietnam National University of Forestry*
[2]*Shaheed Benazir Bhutto University Sheringal Dir Upper, Pakistan*

Khả năng khoáng hóa các-bon và biến động dinh dưỡng dễ tiêu trong đất dưới một số trạng thái thảm thực vật và độ sâu tầng đất tại núi Luốt

Nguyễn Thị Bích Phượng[1*], Nguyễn Thị Bích Hòa[1], Trần Thị Hằng[1], Bùi Mạnh Hưng[1], Pervez Khan[2]
[1]*Trường Đại học Lâm nghiệp*
[2]*Đại học Shaheed Benazir Bhutto Sheringal Dir Upper, Pakistan*
**Corresponding author: phuongntb@vnuf.edu.vn*

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ABSTRACT

Soil mineralization is a crucial soil process that improves soil physical properties, enhances carbon sequestration, and provides essential minerals and available nutrients for plant growth. This study was conducted at five vegetation types and soil depths at Luot mountain area, located in VNUF campus, Hanoi city. Samples were incubated in the dark at 25°C and measured at intervals of 1, 2, 5, 10, 15, 25, 35, and 40 days in the laboratory to determine C-CO_2 respiration from soils. The study showed that CO_2 emissions were highest in topsoils and decreased with deeper soil depths. Mineralized C-CO_2 decreased from Shrubs > Acacia + Native species (NS) > Pinus + NS > Native species > Control. CO_2 emissions peaked early in the incubation period and then stabilized in the 40-day incubation period. Larger aggregates (≥ 5mm) decreased significantly under most vegetation types, except for Shrubs, where the reduction was minimal. Aggregate size ≥3mm increased post-incubation, notably under Pinus + NS and Native species, with smaller aggregates also increasing slightly. Organic matter content was highest in the topsoil but decreased post-incubation due to microbial C mineralization. There was an increase in soil organic matter at 10-20 cm and 20-40 cm layers after incubation, especially under Shrubs. Available nitrogen slightly increased in soils post-incubation for most vegetation types. Phosphorus content increased post-incubation, peaking under Shrubs, while potassium levels were generally poor but increased during incubation. The study found that C-CO_2 mineralization was strongly associated with soil porosity and pH, suggesting that higher porosity and optimal pH enhance mineralization, with organic matter content being crucial for available nutrient cycles in soils.

TÓM TẮT

Quá trình khoáng hóa là một quá trình quan trọng của đất giúp cải thiện các tính chất vật lý của đất, tăng cường sự lưu giữ carbon, và cung cấp các khoáng chất thiết yếu cũng như các chất dinh dưỡng dễ tiêu cho sự phát triển của cây trồng. Nghiên cứu này được thực hiện dưới năm trạng thái thực vật và các độ sâu đất khác nhau tại núi Luốt, Trường Đại học Lâm nghiệp, Hà Nội. Các mẫu đất được ủ trong điều kiện tối ở 25°C và xác định lượng và tốc độ hô hấp C-CO_2 từ đất vào các khoảng thời gian 1, 2, 5, 10, 15, 25, 35 và 40 ngày trong phòng thí nghiệm. Kết quả cho thấy lượng phát thải CO_2 cao nhất ở lớp đất mặt và giảm dần ở các lớp đất sâu hơn. Lượng C-CO_2 khoáng hóa giảm dần từ trạng thái Cây bụi > Keo + CBĐ (Cây bản địa) > Thông + CBĐ > CBĐ > Đối chứng. Khả năng khoáng hóa C-CO_2 đạt cao nhất ở giai đoạn đầu ủ đất và sau đó ổn định trong suốt 40 ngày ủ. Đoàn lạp đất kích thước ≥ 5 mm giảm đáng kể dưới hầu hết các trạng thái thực vật, ngoại trừ trạng thái cây bụi. Kích thước đoàn lạp ≥ 3mm tăng lên sau quá trình ủ, đặc biệt là dưới rừng Thông + CBĐ và Cây bản địa, với các đoàn lạp đất nhỏ hơn cũng tăng nhẹ. Lượng chất hữu cơ cao nhất ở lớp đất mặt nhưng giảm sau quá trình ủ do khoáng hóa C do vi sinh vật. Chất hữu cơ trong đất tăng lên ở độ sâu 10-20 cm và 20-40 cm sau quá trình ủ.

Từ khóa:
Dinh dưỡng dễ tiêu, đoàn lạp đất, hô hấp C-CO_2, khoáng hóa đất, quá trình ủ đất.

Lượng N_{dt} tăng nhẹ trong đất sau ủ ở hầu hết các trạng thái thực vật. Lượng P_{dt} tăng sau quá trình ủ, trong khi mức K_{dt} thường thấp nhưng tăng lên trong quá trình ủ. Nghiên cứu cho thấy khoáng hóa C-CO_2 liên quan chặt chẽ đến độ xốp và pH của đất. Đồng thời, lượng chất hữu cơ đóng vai trò quan trọng trong chu trình chất dinh dưỡng dễ tiêu trong đất.

1. INTRODUCTION

Global warming currently caused by greenhouse gases is of particular concern due to its significant impact on human life and all living organisms on Earth. Among these, carbon dioxide (CO_2) is one of the most influential greenhouse gases contributing to global warming [1].

The biological systems on Earth, including forests, have the ability to store and release CO_2 into the atmosphere. The biological growth of plants is one of the primary and most important pathways for consuming CO_2 from the atmosphere. Notably, forests with their long lifespan and large biomass continuously store a significant amount of carbon, not only in the trees themselves but also in the forest soil. However, the decomposition of biological materials, such as organic residues from plants, animals, and microorganisms in the soil, through microbial activity, will release CO_2 back into the atmosphere [2]. Researchers at the University of Oregon, 2009 also suggested that "carbon accounting regulations for forests should prioritize protecting old-growth forest areas from external impacts. A large amount of carbon, including soil carbon, will return to the atmosphere if these forest areas are disturbed" such as by logging or wildfires. In such cases, when the soil has no or only young regenerating vegetation to absorb CO_2, the amount of CO_2 emissions from the soil will exceed the amount of CO_2 absorbed by plants from the atmosphere. At this point, soil respiration plays a vital role in the global carbon cycle, contributing significantly to the emission of carbon dioxide into the atmosphere. This process involves the breakdown of organic matter by microorganisms and the respiration of plant roots, both of which release CO_2 as a byproduct [3]. Besides, different plant species return diverse organic matter to the soil, which has varying decomposition potential, thus creating different levels of available nutrient and CO_2 emissions from the mineralization process that had not been previously studied.

The Luot mountain which is also the special-use forest has various models of planted forest tree species that are strictly protected. This area provides soils on the forest floor intact organic matter from different tree species, which helps clarify several issues: (i) The mineralization capacity of organic matter (OM) in different forest tree species and at various soil depths, (ii) Dynamics of available nutrients after soil incubation in the laboratory, (iii) The relationship between soil organic matter and soil physical and chemical properties. Therefore, the study results provide a foundation for studies on C-CO_2 mineralization, soil nutrient improvement, and the proposal of nutrient management measures for forest floor at the Luot mountain in the future.

2. RESEARCH METHODS

2.1. Study area

The study was conducted in the Luot mountain area, located in VNUF campus, Chuong My district, Hanoi city. This area is situated at coordinates 20°50' North và 105°30' East and has an average elevation of 54 – 113m above sea level. Luot mountain is characterized by a diverse range of vegetation types, including mixed plantations Acacia, Pinus and native species (NS), native specices, and shrubs. This area has an annual rainfall ranging from 1,300 to 2,300 mm, which is divided into two distinct seasons: the rainy season typically begins in April and lasts until October, while the dry season starts in

November and continues until March of the following year [4]. The average annual temperature and precipitation is 22.5°C and 1,700 mm, respectively. The soils in this region are predominantly Ferralsols on the neutral magma rock Poocfiarite rock.

The selection of Luot mountain as the study location is based on its ecological diversity and the distribution of different vegetation types, ensuring the representativeness and reliability of the research results on carbon mineralization potential and the dynamics of available nutrients in soil under these different vegetation types.

2.2. Data collection methods

2.2.1. Composite samples at different vegetation types and soil depths

Five plots with an area of 500 m^2 (20 m x 25 m) were established under forest and vegetation types: (1) Mixed forest of *Acacia mangium* and Native species (Acacia + NS), (2) Mixed forest of *Pinus merkusii* and Native species (Pinus + NS), (3) Mixed native species forest (Native species), (4) Shrubs, (5) Bare soil (Control).

In each plot, soil samples were collected at five random spots - four at the corners and one in the center. At each spot, samples were taken from three depths: 0-10 cm, 10-20 cm, and 20-40 cm because these layers encompass both the topsoil and subsoil, where significant organic matter decomposition and nutrient cycling occur [5]. Samples were taken from five random spots - four at the corners and one in the center - and then combined to create a composite sample from the same depth. The individual samples were thoroughly mixed, stored in plastic bags, and labeled for soil incubation and available nutrient content determination.

Soil samples for bulk density analysis were collected separately, stored in plastic bags, labeled, and analyzed immediately upon returning to the laboratory.

2.2.2. Control samples in the bare site

The bare site was characterized by the absence of forest trees and perennial grasses to ensure a comparison of soil properties under different forest plantation conditions. Soil samples were collected to determine bulk density, soil incubation, and other physical and chemical properties, similar to those in the studied plantation states mentioned above.

The basic physical and chemical properties of soil samples at the study sites before soil incubation were summarized in Table 1.

Table 1. Soil physical and chemical properties of soils before incubation

Positions	Depth	D (g/cm^3)	d (g/cm^3)	P (%)	pH_{KCl}	OM (%)	NH_4^+ (mg/100gsoil)	P_2O_5 (mg/100gsoil)	K_2O (mg/100gsoil)
Pinus + NS	0-10	1.28	2.7	52.59	5.28 ± 0.01	4.19 ± 0.12	1.09	0.54	8.14
	10-20	1.37	2.77	50.54	4.9 ± 0.01	2.8 ± 0.11	0.81	0.54	6.50
	20-40	1.47	2.82	47.87	4.83 ± 0.00	2.78 ± 0.05	0.73	0.47	5.38
Acacia + NS	0-10	1.3	2.63	50.57	5.9 ± 0.08	4.27 ± 0.16	1.07	0.67	8.02
	10-20	1.36	2.74	50.36	4.83 ± 0.01	3.06 ± 0.05	0.77	0.66	6.89
	20-40	1.4	2.73	48.72	4.67 ± 0.00	2.4 ± 0.10	0.69	0.53	5.28
Native species	0-10	1.3	2.71	52.03	5.52 ± 0.11	4.5 ± 0.12	1.09	0.68	8.17
	10-20	1.37	2.84	51.76	5.08 ± 0.01	3.82 ± 0.11	0.98	0.68	6.53
	20-40	1.51	2.88	47.57	4.76 ± 0.00	3.57 ± 0.05	0.89	0.54	5.41
Shrubs	0-10	1.17	2.8	58.21	5.5 ± 0.03	4.9 ± 0.16	1.18	0.77	10.77
	10-20	1.23	2.81	56.23	5.18 ± 0.04	4.33 ± 0.16	1.02	0.71	8.06
	20-40	1.28	2.82	54.61	5.1 ± 0.03	3.99 ± 0.16	0.96	0.67	6.43
Control	0-10	1.4	2.72	48.53	4.91 ± 0.00	2.34 ± 0.16	0.43	0.43	5.39
	10-20	1.47	2.74	46.35	4.83 ± 0.02	1.77 ± 0.11	0.38	0.40	4.30
	20-40	1.5	2.77	45.85	4.84 ± 0.00	1.76 ± 0.16	0.37	0.40	4.27

2.3. Soil sample analysis methods in the laboratory

2.3.1. Soil physico-chemical characteristics analysis

The composite soil samples from 5 vegetation types and 3 different depths were divided into two parts. One part was prepared for soil incubation immediately to maintain the soil's natural condition from the field. The process and analytical parameters for this soil amount were described in detail in Section.

The remaining soil was air-dried and removed stones and litters larger than 2 mm. Then, the soil samples were ground and sieved through a 2 mm sieve. This portion was analyzed for physicochemical properties, including moisture content, bulk density, proportion, aggregate distribution sizes, pH_{KCl}, organic matter content, available nitrogen, phosphorus, and potassium.

Aggregate distribution sizes were determined by the shaker machine with the intensity of 200 rpm in one minute duration.

pH_{KCl} were determined by automatic pH machine. The determination of soil organic matter (OM) was applied by Tiurin method. Available nitrogen (mg/100 g soil) was determined by applying modified Kjeldahl method (TCVN 6498:1999). Available phosphorus (mg/100g soil) was determined by colorimetric method (TCVN 8940:2011). Available potassium (mg/100 g soil) was analyzed by the emission spectroscopic method (TCVN 8662:2011).

There were 3 replicates for analyzing C-CO_2 mineralization, pH, organic matter content parameters were repeated three times. The total samples for these parameter were 45. The rest parameters were analyzed with 15 samples in total for each.

All soil characteristics were analyzed at the Soil Analysis Laboratory, Center for Forestry Research and Climate Change, Vietnam National University of Forestry.

2.3.2. Soil incubation experiments in the laboratory

1.6-liter capacity jars with tightly sealed lids were used for soil incubation experiments. Each jar contains 250g of soil at field moisture content, 20 ml of NaOH 0.1N solution in a 50 ml glass beaker placed inside the jar alongside the soil. The soil incubation process was carried out under dark conditions with a black cloth cover to optimize microbial activity [6]. Soil incubation samples from control and 4 experimental sites were replicated three times. At intervals of 1, 2, 5, 10, 15, 25, 30 and 40 days, NaOH samples were extracted for titration to determine soil CO_2 emissions using HCl solution and phenolphthalein indicator. At each titration point, jars were opened for 10 minutes to allow microbial respiration with access to oxygen. Additionally, distilled water was supplied to maintain soil moisture content similar to the initial conditions during each lid opening which helped to maintain microbial activity.

Blank samples consisted of jars containing 20 ml of NaOH solution without soil, used to quantify CO_2 gas levels present in jars without soil incubation during each titration.

Figure 1. Set up samples for soil incubation experiments in the laboratory

Incubational soil samples were air-dried, sieved, and analyzed for aggregation size distribution, pH_{KCl}, organic matter content, and available nitrogen, phosphorus, and potassium contents using the methods described in section 2.3.1.

2.4. Data processing methods

Parameters of soil physical and chemical parameters include bulk density, specific gravity, porosity, moisture content, concentrations of available nitrogen, phosphorus, potassium, organic matter content were calculated by formula [7]. The amount of releasing CO_2 released is calculated according to Isermeyer's method, 1952 [8].

SPSS software version 20 was used to analyze collected data. Examination of differences in C-CO_2 mineralization, organic matter content between five vegetation types, three different soil depths as well as between two different times: before soil incubation and after soil incubation using linear mixed effect model and Kruskal – Wallis test. The correlation between the studied parameters was analyzed by Principle Component Analysis (PCA) [9].

The graphs were used to present the differences of studied parameters between five vegetation types, different soil depths as well as between two different times: before soil incubation and after soil incubation.

3. RESULTS AND DISCUSSIONS

3.1. The mineralization capacity (C-CO_2 respiration) of soils at the studied sites

Organic matter mineralization in soil releases carbon dioxide to the atmosphere as a result of microbial decomposition of organic matter in soil. This process is a key component of the carbon cycle, contributing to the breakdown of organic materials, which in turn enhances nutrient availability and soil fertility [10].

Besides facilitating nutrient recycling within the soil, it also contributes significantly to the atmospheric CO_2 levels [11]. The rate of soil respiration is influenced by various factors such as the light intensity, temperature, moisture, and organic matter content [12].

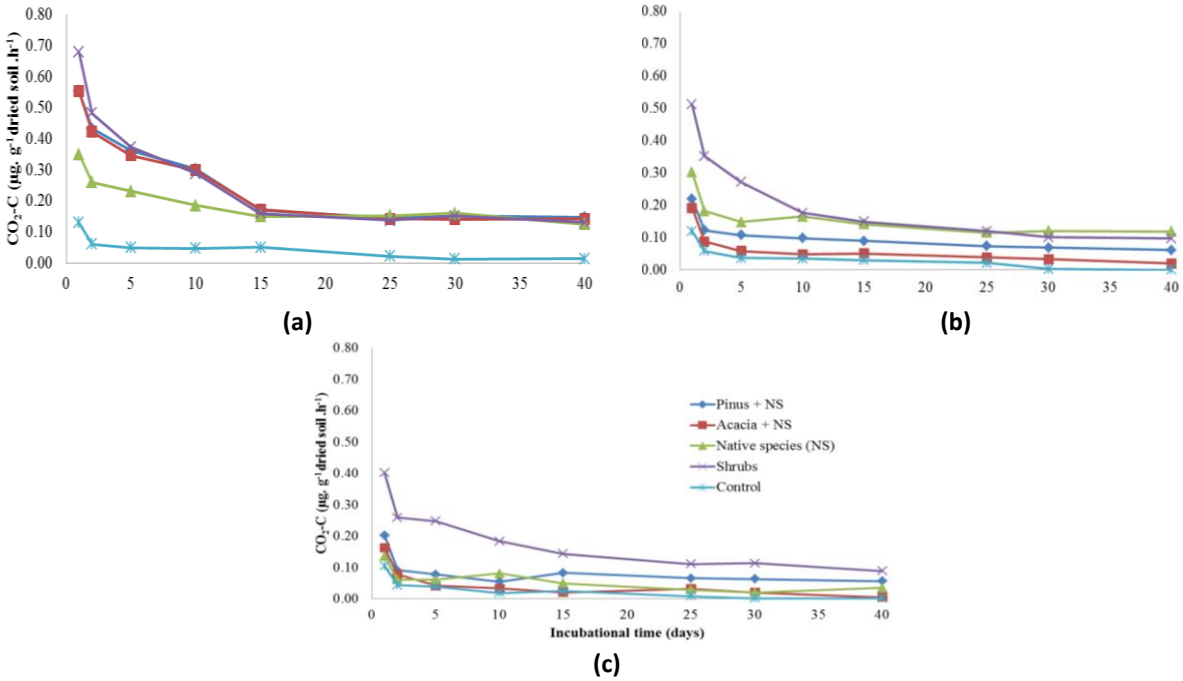


Figure 2. Soil carbon mineralization dynamics at depths under different vegetation types (a) 0–10 cm, (b) 10–20 cm, (c) 20–40 cm

The research results indicated that the highest amount of C-CO_2 emissions occurred in the surface soil layer (0-10 cm), was lower in the 10-20 cm layer, and lowest in the 20-40

cm layer. This was distinctly observed for the three states of Fresh Shrub Groundcover, Pinus, and Acacia with Sig. values < 0.05. In the native tree state, there was little change between the surface soil layer and the 10-20 cm layer, while the 20-40 cm layer showed the greatest reduction throughout the soil incubation process. Meanwhile, in the control state, there was little difference in C-CO_2 amounts between the three soil layers at most incubation time points.

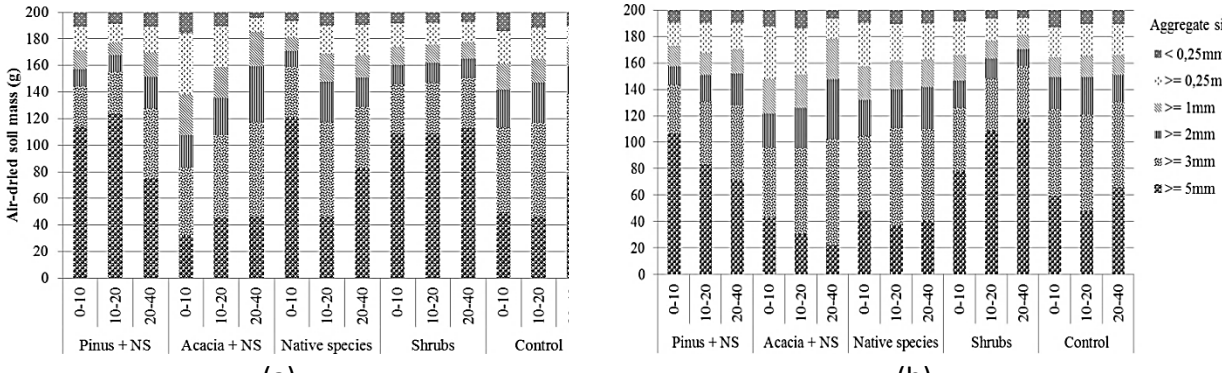
In the surface soil layer, C mineralization decreased progressively from SH > P+NS > A+NS > NS > C. In contrast, in the 10-20 cm and 20-40 cm soil layers, the highest C-CO_2 emissions were observed in the Shrubs state, followed by a gradual decrease from NS > P+NS > A+NS > Control with Sig. < 0.05.

The study by Guo et al. (2023) also demonstrated that different vegetation types affected the accumulation of organic matter, thereby influencing the rate of SOC mineralization [13]. Additionally, the greater amount of organic matter originating from litter and tree roots, along with the diverse microbial community in the surface soil layer, was the main reason for the higher accumulation of C-CO_2 in the surface soil layer [14].

Overall, the amount of mineralized carbon was observed to decrease sharply on the first and second days of soil incubation across all soil depths under all studied vegetation types. After that, it gradually decreased from day 2 to day 15. Then, this amount remained relatively stable until day 40. In the control position, this amount was always the lowest, and there was almost no CO_2 emission from soil mineralization because the organic matter content in this position was very poor (before cultivation, the OM content only reached 2.34% in the topsoil, and 1.77% and 1.76% at the 10-20 cm and 20-40 cm layers, respectively. This is consistent with the study by Guo et al., 2023. This study concluded that the available organic carbon substrates become depleted over time. As the incubation progresses, the remaining carbon compounds are more resistant to decomposition, requiring more energy and specialized microbial activity, which slows down the overall mineralization rate. Additionally, microbial activity may decline as a result of reduced nutrient availability and changes in soil conditions, further contributing to the decrease in C-CO_2 emission.

3.2. The comparison of soil aggregates before and after soil incubation

Soil aggregation plays a crucial role in maintaining soil health by influencing its physical structure such as porosity, water retention, and root growth, which also aids in erosion control [15]. Chemically, well-aggregated soils enhance nutrient cycling and availability by protecting organic matter and supporting microbial activity. This directly impacts the availability of essential nutrients including nitrogen, phosphorus, and potassium, making them more accessible for plant uptake while reducing nutrient loss through leaching [16]. The changes in soil aggregate size distribution were shown in the figure below.



(a) (b)

Figure 3. Changes in soil aggregate sizes before (a) and after soil incubation (b)

The largest soil aggregates (≥ 5mm) tended to decrease significantly at all studied depths under the Pinus + NS, Acacia + NS, and Native species. In the Shrubs, this trend only occurred in the topsoil, with little to no change observed at the 10-20 cm and 20-40 cm layers. The distribution of aggregates ≥5mm in the control position also showed no difference between before and after soil incubation. Meanwhile, aggregate size ≥ 3mm tended to increase at various depths after soil incubation, particularly under the Pinus + NS and Native species conditions. The distribution of the remaining smaller size classes also showed an increasing trend after incubation across all depths under all conditions, although the differences were not substantial.

Papadopoulos, 2011 demonstrated that soil aggregates were clusters of soil particles that bind together, often held by organic matter such as decomposing plant residues, roots, and microbial exudates [15]. During the mineralization process, microorganisms decompose organic matter within these aggregates, leading to the breakdown of soil structure. As the organic binders are consumed, soil aggregates disintegrate into smaller particles, releasing nutrients and contributing to changes in soil texture and fertility.

3.3. The nutrient content dynamics in soil before and after soil incubation

The process of mineralization in the soil contributes to the concentration of available nutrients that plants can absorb [17]. The nutrient dynamics are influenced by factors such as organic matter contents, soil texture, moisture, temperature, and microbial activity. The rate of nutrient release and subsequent availability for plant uptake is critical for maintaining soil fertility and the plant growth [18].

3.3.1. Soil organic matter content (OM%)

The research results indicated that the organic matter content at the topsoil was highest and decreased at the 10-20 cm and 20-40 cm layers in both before and after incubation. However, in all studied positions, the values at the depth of 10-20 cm and 20-40 cm did not show significant differences, with Sig. > 0.05.

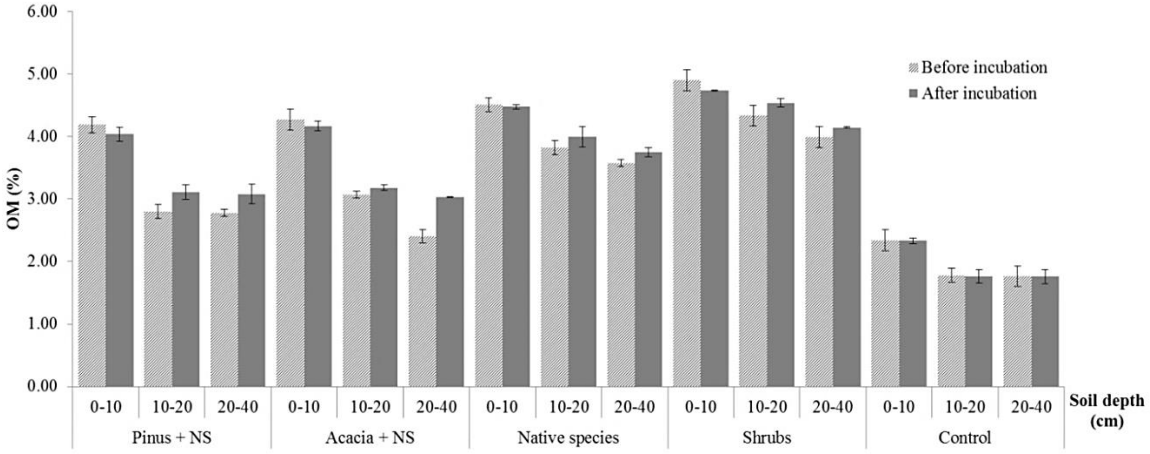


Figure 4. Comparison of organic matter content in soil before and after soil incubation

After the soil incubation process, the research results showed that the organic matter content in the topsoil at the study sites reached an average level (ranging from 3% to 5%) [19]. This content tended to decrease compared to before the soil was composted at the topsoil. This is because a portion of the carbon within the organic matter is released as CO_2 by microorganisms, leading to a decrease in the overall organic content of the soil. This reduction is particularly noticeable in the topsoil, where

organic matter is most concentrated and where microbial activity is typically highest. As a result, the topsoil becomes less rich in organic material over time [17].

On the other hand, at the 10-20 cm and 20-40 cm layers, the organic matter content increased after soil incubation compared to before soil incubation. The highest organic matter content after composting was found in the Shrubs, followed by Native species, Acacia + NS, Pinus + NS, control. In the Native species and Shrubs conditions, the organic matter content in the two lower layers was the highest and showed less variation. These two vegetation types recorded a thick soil layer, less variation in soil porosity between layers, and an increased 1 to 3 mm aggregates sizes after soil incubation period. This also enhanced the release of organic matter available for the mineralization process. Additionally, litters from species *Eupatorium odoratum* and *Mimosa pudica* in Shrubs was easily decomposed by microbial activities.

3.3.2. Available nitrogen content in soil (NH_4^+)

The available nitrogen content at all soil depths after soil incubation at the study sites was consistently at a poor level. This is because nitrogen is stored in organic matter, which is slowly released through mineralization processes specially in forest soil [18].

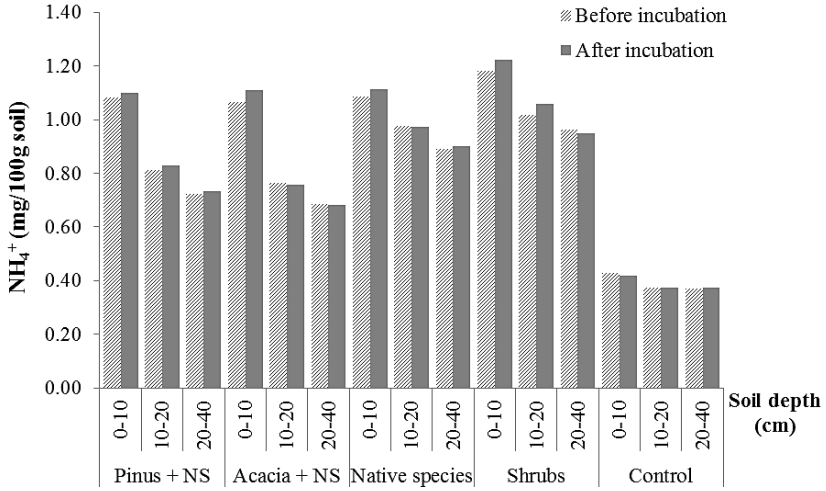


Figure 5. Comparison of available nitrogen content in soil before and after soil incubation

The research results revealed that the highest available nitrogen content was at the topsoil at all study sites. There was little difference in the nutrient content between the 10-20 cm and 20-40 cm soil layers. In the topsoil, the nitrogen content after soil incubation was highest under Shrubs (1.22 mg/100 g soil), ranging from 1.10 to 1.11 mg/100 g soil under Acacia + NS, Native species, and Pinus + NS, and lowest in the control (0.42 mg/100 g soil). Compared to before soil incubation, the available nitrogen content tended to increase slightly in most vegetation types, except for Shrubs. In this type, the cycle of returning organic matter from plants might be faster and also more quickly decomposed so that nutrient content returned effectively. This led to the humus and available nitrogen content in this type being generally higher than in other vegetation types.

3.3.3. Available phosphorus content in soil (P_2O_5)

The available phosphorus content in the soil after soil incubation at the research sites reached a poor level. This is also a common

assessment found in forest soils [19]. The research results indicated that, at all vegetation types and depths studied, the phosphorus content after soil incubation tended to increase compared to these values before incubation, except at the control site. After soil incubation, the trend of available phosphorus typically shows an initial increase due to the mineralization of organic phosphorus compounds [17].

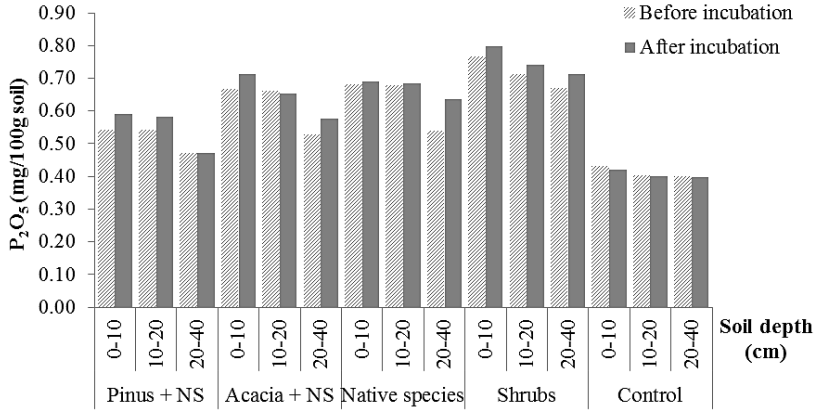


Figure 6. Comparison of available phosphorus content in soil before and after soil incubation

The available phosphorus content in the soil was highest in Shrubs after soil incubation, followed by Native Trees, Acacia + NS, Pinus + NS, and finally the control. The difference in available phosphorus content between the topsoil and the 10-20 cm soil layer was not significant. In the 20-40 cm layer, this nutrient content tended to decrease. In many forest areas, phosphorus availability is generally low due to high rates of phosphorus fixation and low soil pH (about 4.6 to 5.2) in study sites.

3.3.4. Available potassium content in soil (K_2O)

The available potassium content in the soil after incubation at the study sites was at a poor level (< 10 mg/100 g soil), except for the topsoil layer under Shrubs, which reached a medium level (10.91 mg/100 g soil) [19]. In all vegetation types, the available potassium content in the soil tended to decrease with increasing soil depth. This trend normally occurs in forest soil because potassium is more concentrated in the upper layers due to the accumulation of organic matter, root activity, and nutrient cycling processes. In the deeper layer of the soil profile, potassium levels often diminish due to reduced organic matter and less root activity [18].

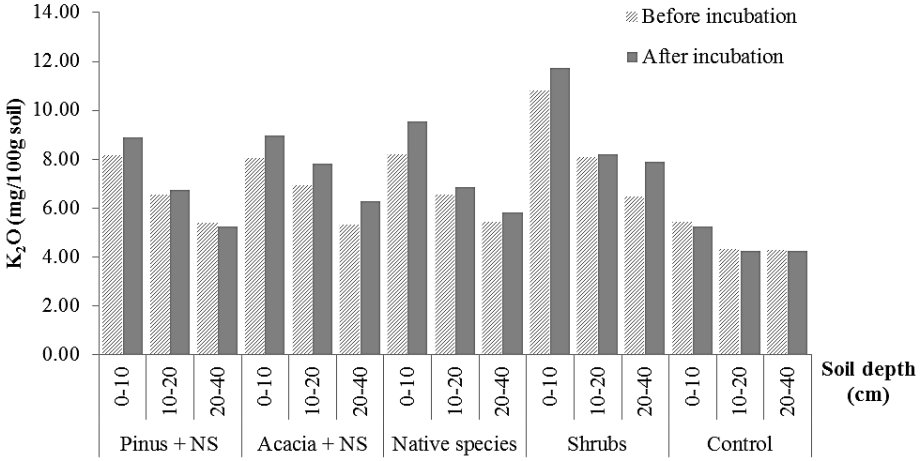


Figure 7. Comparison of available potassium content in soil before and after soil incubation

The available potassium content in the soil after soil incubation at the research sites tended to increase during the 40-day incubation period. This was most evident in the topsoil of vegetated areas, with the highest increase observed in Shrubs, followed by Native species, Acacia + NS, Pinus + NS, and lastly, the control. The nutrient content also increased after incubation at depths of 10-20 cm and 20-40 cm in all vegetation types, except at the control position. There was no significant difference in available potassium content at the deeper layers. This was due to potassium being primarily derived from the mineral components of the maternal rock Poocfiarite rock that forms the soil in Luot mountain.

3.4. The relationship between C-CO_2 mineralization capacity and soil physicochemical properties

Soil mineralization capacity is closely linked to soil physical properties, such as texture and structure, which influence aeration and moisture levels, as well as chemical properties like pH and OM content. These factors, in turn, might determine the availability and mobility of essential nutrients like nitrogen, phosphorus, and potassium [3].

The results from Principal Component Analysis (PCA) biplot showed that: the soil respiration have a notable association with soil porosity, as higher porosity can enhance aeration, which is crucial for microbial activity involved in the mineralization process. Conversely, soil density and the proportion of certain soil components appear to have a weak or negligible direct relationship with C-CO_2 mineralization, indicating that these physical properties may not significantly influence the rate at which C-CO_2 is released during mineralization.

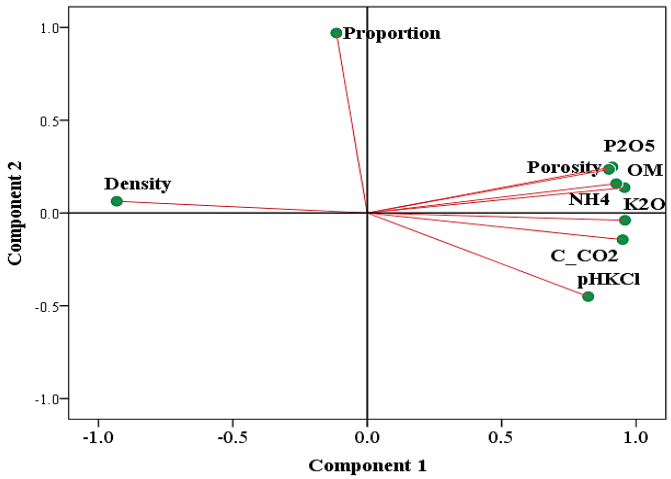


Figure 8. The relationship between C-CO_2 mineralization capacity and physicochemical properties

Besides, C-CO_2 mineralization capacity is strongly influenced by soil chemical properties, particularly pH. A close relationship with pH suggests that optimal pH levels are critical for efficient mineralization. Organic matter content also plays an essential role in providing the necessary substrate for the mineralization process to release available nitrogen, phosphorus and potassium in soils.

4. CONCLUSIONS

The highest C-CO_2 mineralization were observed in the topsoil layer (0-10 cm), particularly under Shrubs, followed by Pinus+NS, Acacia+NS and Native species. The control site, with minimal organic matter, exhibited the lowest CO_2 emissions. The amount of CO_2 emiss from soils decreased in deeper soil depths: 10-20 cm and 20-40 cm. This underscores the critical role of vegetation in influencing soil CO_2 release and highlights the varying decomposition rates of organic matter across different vegetation types.

Larger soil aggregates decreased after incubation under Pinus+NS, Acacia+NS and Native species conditions. In contrast, Shrubs showed minimal change in aggregate size distribution at deeper layers. Organic matter content decreased in the topsoil post-incubation, while the available nitrogen, phosphorus, and potassium contents varied by vegetation type and soil depth. Notably, Shrubs demonstrated higher available nitrogen and phosphorus levels, while potassium levels increased in vegetated areas over time, highlighting the complex interplay between organic matter decomposition and nutrient release.

The Principal Component Analysis revealed that soil respiration was closely associated with soil porosity and pH, suggesting that these factors are crucial for efficient mineralization. Organic matter content was identified as a significant driver of nutrient availability, influencing the release of available nitrogen, phosphorus, and potassium in soils. Future studies might consider extending the soil incubation period to better assess nutrient dynamics in the soil. Additionally, litter should be collected to observe differences in the decomposition of organic carbon on the surface among different vegetation types.

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