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Application of soil amendments: investigation of incubation time on some soil solution properties of Kien Giang, Vietnam

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ABSTRACT

Soil amendments can affect soil properties such as pH, EC, available phosphorus (P), and ammonium nitrogen (NH4+). The aim of this study was to determine the potential influence of submergence incubation time on some soil properties using soil amendments under controlled laboratory conditions suitable to the characteristics of rice-growing areas in Kien Giang, Vietnam. The experiment included treating soil supplemented with lime (at ratios of 0.0, 0.4, 0.6, and 1.0%) and soil supplemented with lime (0.4%) combined with alkalized biochar (at ratios 0.0, 0.2, 0.4, and 0.8%). The treatments were incubated in the laboratory under submerged conditions, and pH, EC, available phosphorus (P), and ammonium nitrogen (NH4+) parameters were measured at 7, 14, 21, 35, and 60 days. The results showed that soil supplemented with lime improved pH and EC, and maintained high phosphorus release for 21 days, but did not improve NH4+ release. In contrast, soil supplemented with lime (0.4%) combined with alkalized biochar improved pH and EC, maintained high levels of phosphorus and NH4+ content up to 35 days. The results showed that using lime combined with alkalized biochar to improve soil in rice-growing areas has many advantages compared to using lime alone. Therefore, understanding the contribution of soil incubation time with amendments to soil properties is an important prerequisite for developing a strategy to ensure crop productivity.

1. INTRODUCTION

According to the current trend of intensive agriculture, the possibility of nutrient depletion or imbalance has occurred regularly in cropping systems. Furthermore, the recent energy crisis has increased the price of inorganic fertilizers, which has contributed to pressure on soil nutrients and crop yields [1,2]. Modern agricultural practices emphasize integrated nutrient management practices that maintain soil fertility over longer periods and more stable crop yields. The application of organic and inorganic fertilizers alone gives lower performance than integrated nutrient management practices [2]. Especially when integrated with organic amendments, it has significantly improved soil quality and ecosystem sustainability as a buffering agent, source of plant nutrients, and enhanced soil microbial biomass [2].

Soil pH reflects the overall chemical state of the soil and affects the entire range of chemical and biological processes occurring in the soil [2]. Electrical conductivity (EC) of soil serves as an indirect measure of both total dissolved solids and the mineralization/decomposition of organic matter [3]. Phosphorus is an essential element for plant growth. Phosphorus (P) deficiency often occurs in rice fields due to low solubility and mobility in soil and high immobilization capacity [4,5]. Ammonium nitrogen, NH_4^+, is the main source of N nutrients for soil. NH_4^+ in each type of soil changes (fixed or released) differently depending on the type of amendment used, mineral composition, pH, and organic content [6].

The Veitnam Mekong Delta, including Kien Giang Province, is a high-yield rice-growing area, contributing significantly to Vietnam's rice output [7]. To maintain stable productivity, in addition to using inorganic fertilizers, it is necessary to combine with amendments (inorganic and organic) to maintain soil quality parameters in rice-growing areas in Giang Thanh District, Kien Province. Various studies have shown that the use of amendments has a significant effect on soil physicochemical indices such as pH, EC, available phosphorus, and ammonium nitrogen. These changes may be due to an increase in organic matter associated with proton consumption during neutralization, decarboxylation, decomposition, and adsorption of organic molecules [3]. One of the characteristics of the Mekong Delta soil is activated alum soil (acid sulfate soil–Orthi Thionic Fluvisols WRB), which has strong acidity, so the use of pH-improving substances is very frequent.

Using lime increases soil pH, soil available P content, cation exchange capacity (CEC) [8], and base saturation, and reduces mobile Al concentration [9]. However, using lime for sustainable agriculture

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is not economically and environmentally feasible due to costs and unrecoverable resource exploitation. Biochar produced from the low-temperature pyrolysis of organic material is a carbon-rich substance that has several important features that improve pH and alter the availability of nutrients such as phosphorus (e.g., available phosphorus is significantly increased by using biochar, whereas previously it was fixed by high levels of Al and Fe in the soil) [9]. Besides, biochar can regulate soil N dynamics by promoting nitrification, reducing denitrification, adsorbing NH_4^+, and reducing ammonia volatilization [10]. However, the use of biochar has also been reported to impair nutrient availability, with limited improvement in acidity, especially when soils have very low pH [11]. An alternative method to reduce biochar application rates could be to use a liquid biochar extract that can be sprayed, or irrigated [12]. Therefore, the use of alkalized biochar has been proposed. Dak Lak, Vietnam is the country's leading coffee-growing province with an area of more than 200,000 hectares, an annual output of about 550,000 tons of finished products [13], and about 300,000 tons of waste coffee husks, which is a rich source of raw materials for biochar production.

To improve understanding of crop nutrient requirements, knowledge of soil characteristics after the application of amendments is needed. Therefore, it is necessary to monitor changes in soil properties over time. The objective of the current study is to determine the potential effects of incubated time under submerged conditions when using integrated lime and alkaline biochar to improve some physicochemical properties of the soil sample.

2. MATERIALS AND METHODS

2.1. Sample Collection

The soil sample was taken from Vinh Phu, Giang Thanh District, Kien Giang, Vietnam, located at 10°24′34.7″N 104°45′34.0″E. The sampling area selected was the largest rice-growing area in the region, with stable productivity. Five sub-samples were collected from a 10-m diameter sampling area at a depth of 0–10 cm. These sub-samples included four from each corner and one from the central diagonal position. The sub-samples were then thoroughly mixed to create a composite sample for further analysis. Soil samples should be stored in plastic bags or PE bottles at a temperature of 4°C, with the labels stating the full location, sample collection date of July 28, 2022, and sample collection time of 10:07 a.m. Soil samples were transported to the laboratory, air-dried, ground, and sieved through a 2-mm sieve. Later, the samples were analyzed to determine particle density, bulk density, total carbon (TOC), pH, EC, soil structure, ammonium, and available P in soil. Coffee husks were obtained in January 2019 from a farm located at 12°34′43.8″N, 108°01′39.3″E in Pong Drang, Krong Buk Town, Dak Lak Province, Vietnam.

2.2. Analytical Method

Bulk density, particle density, porosity, and CEC [8] of soil were determined [14]; soil texture was determined by the hydrometer method [14]; soil pH (with H_2O ratio 1:5) was determined by Hanna–HI 8314 pH meter; TOC of soil was determined by Walkley–Black method [14]; available phosphorus was determined according to Olsen method; and NH_4^+ was extracted according to ISO 14225:1998 [14].

A total of 1 g of air-dried soil was weighed and digested in a muffle furnace at 550°C for 1 h to convert organically bound P to inorganic forms. The digest was then extracted with 25 mL of 1 N HCl using a reflux condenser for 1 h to solubilize inorganic P. After cooling, the extracts were diluted to volume in 100 mL volumetric flasks, and the total P concentration was determined colorimetrically [15].

2.3. Experimental Setup

2.3.1. Tools: chemicals and equipment

Laboratory apparatus must be cleaned before use by filling it with 1 M nitric acid for at least 24 h and then rinsing it with demineralized water. Distilled water was used, which was filtered by an ultra-clean water purifier Model: EASYpure II RF from Thermo Scientific, USA. The chemicals used in the experiment were of analytical purity grade from Merck ($K_2Cr_2O_7$, NaOH, $(NH_4)_2Fe(SO_4)_2$, NH_4Cl, HNO_3) and from China (KCl, HCl, NaH_2PO_4, H_2O_2).

2.3.2. Preparation of biochar

Coffee husk biochar was prepared following a modified version of the method described by Yoo et al. [16]. In this adaptation, coffee husks were oven-dried at 60°C and crushed to a particle size below 5 mm. Then, it was pyrolyzed under anaerobic conditions in Nabertherm Furnace, Germany at a temperature of 300°C, with a heating rate programmed at 10°C/min, and stored for 2 h. The samples were then cooled naturally in the furnace overnight. The pyrolysis product was crushed through a 1-mm sieve and stored in a sealed PE bag at 4°C [16]. Biochar samples were then used to determine recovery efficiency (%H), pH, TOC, number of H^+/OH^- groups, and CEC. The results have been presented in detail in previous research [17] [Table 1].

2.3.3. Preparation of alkalized biochar

Accurately 30 g of biochar was weighed into a 500-mL beaker containing 200 mL of distilled water. The mixture was homogenized on the IKA T25 digital–Germany machine for 1 h at a speed of 6000 rpm. Small amounts of 85% CaO were added to the mixture to maintain pH 9–10. The samples were ground for another hour and pH was adjusted with H_2SO_4 and water so that the mixture weighed 300 g at pH 8. The samples were then transferred to plastic bottles, sealed tightly, and used for incubation experiments.

2.3.4. Incubation experiment

The soil incubation process under submerged conditions was simulated according to Maranguit et al. [18]. There are eight treatments as listed in Table 2.

Table 1: Recovery efficiency and some surface physicochemical components of biochar.

t °C	%H	pH	mmolH⁺ g⁻¹	mmolOH⁻ g⁻¹	%TOC	CEC, cmol kg⁻¹
300	51.4	7.59	1.73	11.17	25.5	30.9
SD	0.8	0.16	0.11	0.15	1.0	11

% H: Recovery efficiency. pzc: Point of zero charge. SD: Standard deviation.

Table 2: Treatments used in the experiment.

Treatments	Combined Materials	Treatments	Combined Materials
V 0.00%	Soil + 0.0% lime (control sample)	VB 0.0%	Soil + lime 0.40% + 0.0% alkaline biochar
V 0.40%	Soil + 0.4% lime	VB 0.2%	Soil + lime 0.40% + 0.2% alkaline biochar
V 0.60%	Soil + 0.6% lime	VB 0.4%	Soil + lime 0.40% + 0.4% alkaline biochar
V 1.00%	Soil + 1.0% lime	VB 0.8%	Soil + lime 0.40% + 0.8% alkaline biochar

Specifically, 10 g of each soil sample according to the presented treatments was taken in a 60-mL polypropylene tube. A volume of 24 mL of pure distilled water was added to each tube (ensuring that there was always a layer of water on the surface), and the air was expelled by N_2 degassing. Then, the suspension is covered with a rubber stopper to prevent O_2 diffusion or loss due to evaporation and ensure anaerobic conditions. Three replicates for each determination were incubated at room temperature in the dark at 28 ± 1°C. After adding water, the samples were collected on days 7, 14, 21, 35, and 60 of submergence. The samples were shaken, filtered (filter with a pore size of 0.45 µm), and determined to identify pH, EC, available phosphorus, and NH_4^+ in the filtrate solution. The filtrate used to determine soluble P and NH_4^+ was immediately acidified with 1 mL of 0.1 M HCl to prevent microbiological processes.

2.4. Processing Experimental Data

Following data collection, all statistical analyses were performed using the Microsoft Excel software. To minimize bias, replicate samples were incorporated into the analyses, allowing for the evaluation of both precision and potential systematic errors. All experiments and subsequent analyses were repeated in triplicate for increased reliability. Homogeneity of variance was assessed using the SPSS 23.0 software. Subsequently, differences in mean values between experiments were determined (p-value < 0.05). For experiments with non-significant variance (Sig > 0.05), Tukey's post-hoc test was used for multiple comparisons. Conversely, Tamhane's T2 test was employed when significant variance was observed (Sig < 0.05).

3. RESULTS AND DISCUSSION

3.1. Determine the Physicochemical Composition of the Soil

The results of determining some physicochemical properties of soil samples collected in Giang Thanh, Kien Giang, Vietnam are presented in detail in Table 3. The soil sample obtained is of the loam clay type according to the soil texture triangle with clay, silt, and sand being 64%, 34%, and 2% of the Orthi Thionic Fluvisols soil type, mainly heavy sulfate alum soils. The results obtained are similar to the research of Ly et al. [19], also on soil in the Mekong Delta rice-growing area in terms of soil structure. The TOC content of 5.4% is similar to the research results of Khuong and colleagues stating that acid sulfate soil in the Mekong Delta ranges from 4.10% to 6.16% [20] or as studied by Ly et al. [19] from 1.4% to 6.1%.

The bulk density value is 1.12 g cm^{-3}, lower than that obtained by Ly et al. [19] (1.25 g cm^{-3}), possibly due to the higher organic content of the research sample. The CEC of the Giang Thanh soil sample was 28.6 cmol kg^{-1}, showing research results that were higher than pineapple soil in Hau Giang ranging from 9.5 to 15.0 cmol kg^{-1} [20].

Table 3: Physical and chemical parameters of the soil sample.

Parameters	Value	SD
pH	3.61	0.02
EC (mS cm^{-1})	0.57	0.02
Bulk density, g cm^{-3}	1.12	0.02
Particle density, g cm^{-3}	2.49	0.16
TOC, %	5.4	0.1
Cation exchange capacity (CEC), cmol kg^{-1}	28.6	0.6
Available phosphorus content, mg P_2O_5 kg^{-1}	118	18
NH_4^+ content, mg kg^{-1}	10.0	0.2
Clay, %	64	Loam clay
Silt, %	34	
Sand, %	2	

Assessed according to the London 1984 scale from the report of Chiem et al. [21], the CEC value in the study was high (15.1–30.0 cmol kg^{-1}). CEC is an important soil property because it affects the assimilation of nutrients and the acid-buffering capacity of the soil. Determination results [Table 3] show that pH 3.61 belongs to the group of strongly acidic soils, and only the most acid-tolerant plants can grow in this pH [22]. Similar results were also found with some acid sulfate soil compared to pineapple soil in Vi Thanh, Hau Giang, with pH ranging from 3.10 to 4.49 [20]. The EC value of the soil sample is 0.57 mS cm^{-1}, which is also equivalent to pineapple soil in Hau Giang with EC ranging from 0.19 to 1.99 mS cm^{-1} [20] or as in the study on rice soil by Ly and colleagues, it was 0.56 mS cm^{-1} [19].

3.2. Effect of Lime on pH, EC, Releasing Phosphorus, and Ammonium Nitrogen

3.2.1. pH of soil solution

Research results on the influence of soil incubation time when adding lime at ratios of 0.0, 0.4, 0.6, and 1.0% to soil solution pH are presented in Figure 1. The results showed that pH increased rapidly in the first week for lime-added treatments. Specifically, pH increased from 3.6 to 6.9, 6.5, and 7.3 correspond to the amount of lime added increasing from 0.0, 0.4, 0.6, and 1.0%, respectively. In the following weeks, the pH fluctuated from 6.6 to 5.7 for a lime ratio of 0.4%, ranging from 6.1 to 7.0 when the rate is 0.6%, ranging from 7.3 to 7.4 with a rate of 1.0%. In particular, at the lime ratio of 0.4%, the pH showed signs of decreasing slightly over incubation time, while at dosages of 0.6 and 1.0%, the change is not statistically significant according to one-way ANOVA on SPSS 23.

Research results showed that pH decreased significantly on day 14 with lime rates of 0.4 and 0.6%. This can be explained by the possibility of reactions occurring between lime and protons that are inside the soil particles. The results are similar to the research of Mkhonza et al. and Thite et al. [1,23]. The decreased pH may be due to nitrification or decomposition of organic complexes Al and Fe in the soil [23]. Research results have shown that soil incubation time changed pH in case of increasing the addition of lime but in general, the change is insignificant

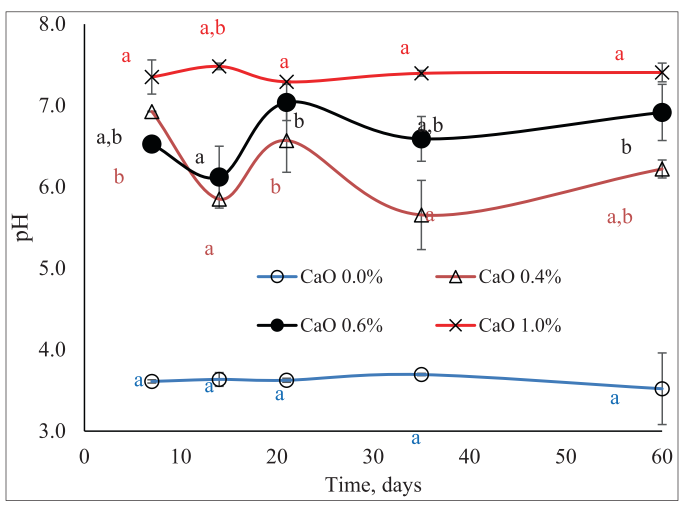

Figure 1: Effect of soil incubation time on soil solution pH when using lime, the different letters of the same color in the graph indicate meaningful differences.

for the soil sample. The results of the study are similar to the study of Mosharrof et al. [9] that lime addition increased soil solution pH.

3.2.2. EC of soil solution

Research results on the influence of soil incubation time when adding lime at ratios of 0.0, 0.4, 0.6, and 1.0% to EC soil solution were presented in Figure 2. Research results showed that EC did not change significantly from day 7 to day 21 for treatments adding lime at a rate of 0.0, 0.4, and 1.0% according to one-way ANOVA analysis on SPSS 23. Specifically, EC fluctuated from 0.62 to 0.63, 0.74 to 0.71, and 0.59 to 0.63 mS cm^{-1} corresponding to the proportions of lime added. With a lime ratio of 0.6%, the EC changed insignificantly on days 7 to 14, but on day 21, the change was statistically significant, specifically, EC was 0.57, 0.59, and 0.68 mS cm^{-1}, respectively. Thereafter, there was a statistically significant increasing trend up to day 35 for all treatments, corresponding to EC values of 0.69, 0.88; 0.73, and 0.75 mS cm^{-1}. The increase in EC can be explained by mineralization and decomposition of organic fertilizers, which release ions into the soil solution and cause EC to increase [2]. When incubation continued until day 60, the trend decreased slowly for all treatments, but the decrease was not significant, corresponding to EC values of 0.68, 0.82, 0.710, and 0.715 mS cm^{-1}. The reduction process can be explained by the precipitation of dissolved P minerals in the form of Al and Fe bonds [23]. This explanation is also completely consistent with the results of the study showing that the amount of P in the soil solution decreased sharply at day 60 [Figure 3]. The results of the study are contrary to the results of the study by Thite et al. [1], which showed an increase in EC values at day 60. This can be explained by the soil characteristics in the study being acidic soil with a pH (of 3.6) and high TOC content (5.4%) compared to the soil in Thite et al.'s [1] study, which had high pH (8.1) and low TOC (0.57%). When organic content is decomposed, Al and Fe ions will be released in acidic soils, which will fix a large amount of P in the soil solution in the form of precipitation or surface adsorption.

3.2.3. Release of phosphorus

Results of surveying the effect of soil incubation time on the P release process in the soil at lime addition ratios of 0.0, 0.4, 0.6, and 1.0% were presented in Figure 3. The results showed that the P release content on day 7 of the control soil sample was at the lowest level of 17.8 mg kg^{-1} compared to 58.5, 71.6, and 79.1 mg kg^{-1} corresponding to a lime ratio of 0.4, 0.6, and 1.0%. After that, it continued to maintain a stable high level until day 35, specifically the amount of P released was 80.6 and 72.2 mg kg^{-1} corresponding to lime ratios of 0.4 and 0.6%. While at lime ratios of 1.0%, phosphorus release decreased insignificantly on days 7 and 14; but significantly decreased sharply on days 14 and 21. Specifically, the amount of phosphorus released was 79.1, 74.2 to 57.0 mg kg^{-1}. After day 35, the process continued to decrease until day 60, with a significant decrease for treatments with a dose of 0.0, 0.4, and 0.6% lime. However, 1.0% lime treatment had a significant decrease on day 35, and the decrease was insignificant compared to day 60. The increase in P content in the soil solution with lime additions in acidic soils can be explained by the fact that lime increases the pH of the soil solution, seriously weakening the activity of Al oxide, reducing the ability to retain P of the oxide surface, and thus increasing P availability. A similar explanation was also found in the study of Mosharrof et al. [9]. However, using high amounts of lime (in the case of adding 1.0% lime) will precipitate P with Ca in the form of calcium phosphate [24]. Similar results were revealed by Nishida et al. [25].

In the case of a sharp decrease in the amount of P released at days 35 and 60, it can be explained by the fact that the addition of lime

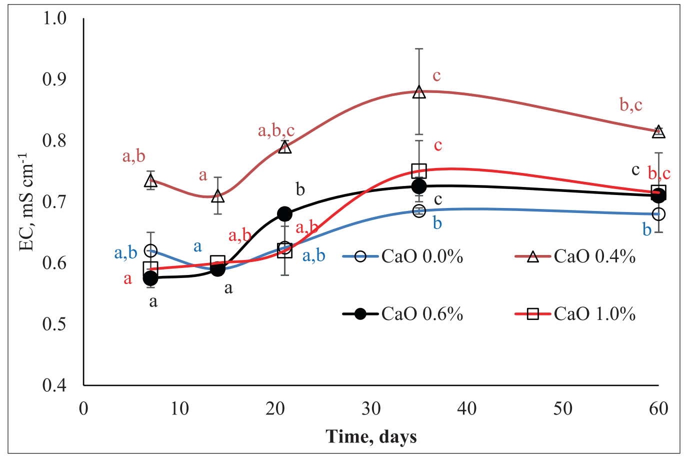

Figure 2: Effect of soil incubation time on soil solution EC when using lime, the different letters of the same color in the graph differ significantly.

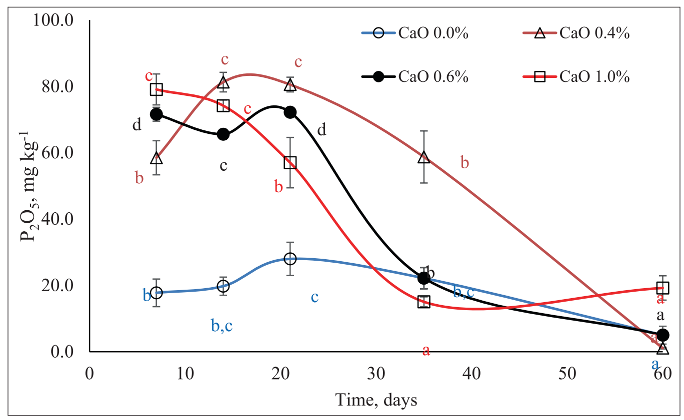

Figure 3: Effect of soil incubation time on released P when using lime, the different letters of the same color in the graph differ significantly.

increases the microbial community, thus increasing the decomposition of organic matter and the release of Fe and Al. At that time, the lowest P content is due to the strongest bond between P and Al and Fe. The research results are similar to the study of Mkhonza et al. [23].

3.2.4. Release of NH_4^+

Results of surveying the effect of soil incubation time on the release of NH_4^+ in soil with lime addition ratios of 0.0, 0.4, 0.6, and 1.0% are presented in Figure 4. The results showed that NH_4^+ release increased on days 7 and 14 but was not statistically significant in treatments with lime ratio 0.0, 0.6, and 1.0%, specifically the amount of NH_4^+ on days 7 and 14 ranged from 0.9 to 1.2, 1.3 to 1.2, and 0.3 to 0.4 mg kg^{-1}, respectively. Meanwhile, at a lime ratio of 0.4%, the amount of NH_4^+ released increased significantly, specifically from 0.3 to 1.8 mg kg^{-1} on days 7 and 14, respectively. The amount of NH_4^+ continued to increase on day 21, and the increase was statistically significant in all experimental treatments. Then, it decreased on day 35, and the decrease was significant with treatments using lime ratios of 0.0, 0.4, and 0.6%, while with the 1.0% lime treatment, there was no significant decrease. Next was the increase again on day 60, the increase was statistically significant for all experimental treatments. This can be explained because the increased amount of lime added increased pH, which increased microbial activity, leading to increased ability to decompose SOM. Then, it is possible to increase the amount of mineral N [23]. In case the amount of NH_4^+ released decreases, it may be due to an increase in nitrification from microbial activity. The increase or decrease in the amount of NH_4^+ released does not follow a clear trend, possibly because the activity of microorganisms in the soil depends on many factors such as pH, organic matter content, and soil type [23]. Therefore, specific research is needed.

In general, the use of lime in improving acidic soil samples has improved pH and EC and improved the maintenance of released phosphorus until day 21 ranging from 57.0 to 80.6 mg kg^{-1} but did not improve the amount of NH_4^+ released, only ranging from 0.4 to 3.0 mg kg^{-1}.

3.3. Effect of Combined Addition of Lime and Alkalinized Biochar on pH, EC, Releasing Phosphorus, and Ammonium Nitrogen

3.3.1. pH of soil solution

Research results on the influence of soil incubation time when adding lime (ratio 0.4%) combined with alkalized biochar at 0.0, 0.2, 0.4, and 0.8% ratios on the pH of the soil solution were presented in Figure 5. The results show that the samples supplemented with alkaline biochar all had pH values greater than the control sample (no alkalized biochar added) during incubation. The pH trend decreased on day 7, the decrease ranged from 6.9 to 6.2, 7.7 to 6.5, 7.9 to 7.5, and 7.7 to 6.4, corresponding to alkalinized biochar ratios of 0.0, 0.2, 0.4, and 0.8%. The decrease in pH levels on days 7 and 21 was statistically significant for all treatments supplemented with alkalinized biochar. The decrease in pH level on days 21 and 60 was statistically significant with the treatment adding 0.2 and 0.8% alkalinized biochar, while the 0.4% rate was not significant, according to the results of one-way ANOVA analysis on SPSS 23.

The decrease in pH may be due to the release of organic acids such as humic acid, carbonic acid, and other organic acids during the mineralization of organic matter [2]. The research results are also similar to the study of Thite et al. [1], which suggested that organic matter caused the pH decrease during incubation. Furthermore, the prolonged decrease in pH over time can also be explained by the release of aluminum from the organic Al complex during the decomposition of organic matter of biochar. Similar explanations were also found in the study by Mkhonza et al. [23].

3.3.2. EC of soil solution

Research results on the effects of soil incubation time when adding lime (0.4%) combined with alkalized biochar at ratios of 0.0, 0.2, 0.4, and 0.8% on soil solution EC were presented in Figure 6. Research results showed that the EC values of the treatments supplemented with alkalized biochar were all smaller than the control samples on day 7. When increasing the biochar ratio, the EC value increases. Specifically, the EC value increased by 0.55, 0.62, and 0.69 dS m^{-1}, respectively [Figure 6]. This can be explained by the increase in soluble salts that are present in alkalinized biochar. The EC value increased rapidly and significantly from day 7 to day 14 for the treatment adding 0.2 and 0.4% alkalinized biochar and maintained a non-significant change until day 35. Then, there was a significant decrease at day 60. Meanwhile, the EC value of the VB 0.0 treatment did not change significantly on days 7, 14, and 21 and only increased significantly at day 35 and no significant change at day 60. With the VB 0.8% treatment, the EC value fluctuated the least (0.69–0.73 dS m^{-1}), not meaningful, according to one-way ANOVA analysis on SPSS 23.

The increase in EC can be explained by the mineralization and decomposition of organic matter, which releases ions into the soil solution, leading to an increase in soil EC. Similar explanations were also found in the study by Patra et al. [2]. Furthermore, Ca ions can

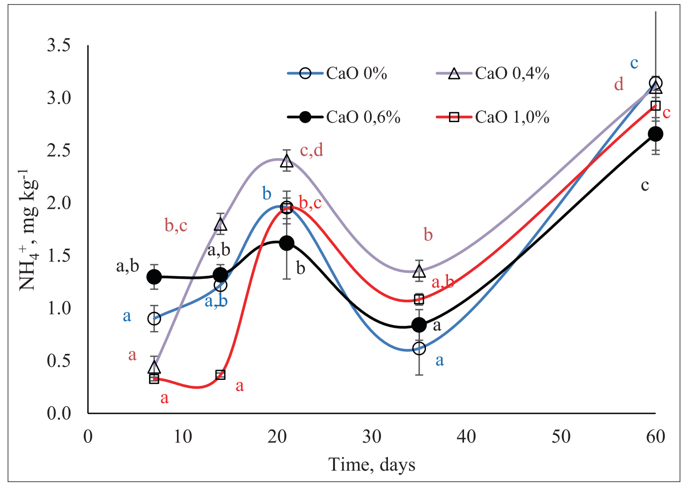

Figure 4: Effect of soil incubation time on released NH_4^+ when using lime, the different letters of the same color in the graph differ significantly.

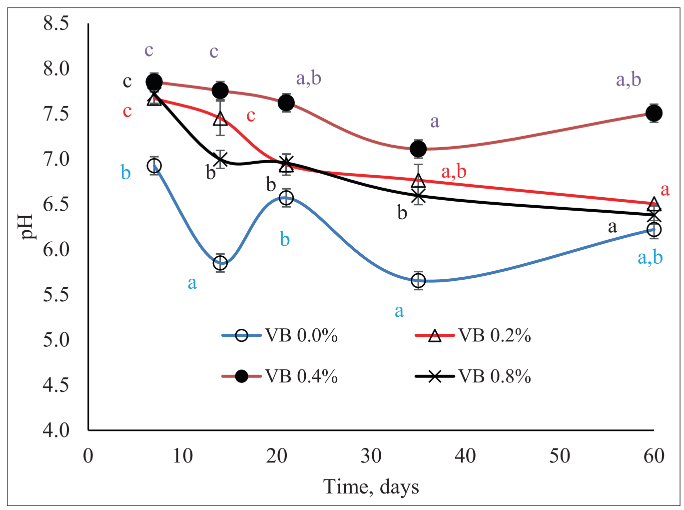

Figure 5: Effect of soil incubation time on pH when using lime (0.4%) combined with alkalized biochar, the different letters of the same color in the graph differ significantly.

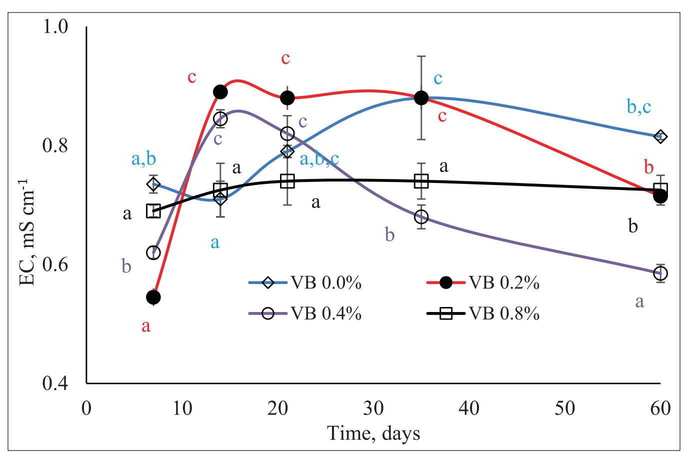

Figure 6: Effect of soil incubation time on EC when using lime (0.4%) combined with alkalized biochar, the different letters of the same color in the graph differ significantly.

replace monovalent cations on the soil surface and also contribute to increasing EC in the soil solution. Similar explanations were found in the study by Nigussie et al. [26]. The decrease in EC at day 60 may be due to a decrease in the solubility of Al and Fe in the soil when binding with available P to form precipitation. A similar explanation is also found in the report by Nigussie et al. [26].

3.3.3. Release of phosphorus

Results of surveying the effect of soil incubation time on the P release process in soil supplemented with lime (0.4%) combined with alkaline biochar at ratios of 0.0, 0.2, 0.4, and 0.8 % were presented in Figure 7. The released P content remained high during the first 3 weeks (up to day 21), for treatments supplemented with alkaline biochar. Specifically, for treatment VB 0.2%, the amount of P released fluctuated from 62.4 to 62.4 mg kg^{-1}, for treatment VB 0.4%, the level fluctuated from 76.6 to 64.6, and for treatment VB 0.8% levels ranged from 68.8 to 80.3 mg kg^{-1}.

This can be explained by the fact that organic acid salts in biochar may compete for P adsorption sites or, if previously adsorbed, P may be ejected. Similar explanations were also found in the study by Fink et al. [27]. The organic salts present in biochar have a high affinity for Al and Fe, and this affinity allows for the removal of Al and Fe, leading to the release of free P from these bonds [24].

Then, the amount of released P decreased significantly at day 35 in the case of treatments VB 0.4 and VB 0.8%, corresponding to the amount of P released as 21.2 and 16.0 mg kg^{-1}. Only in the case of the VB 0.2% treatment was maintained until day 35, the change was not significant with a released p-value of 70.5 mg kg^{-1}. The amount of released P decreased sharply at day 60, the decrease was significant with the VB 0.2% treatment and insignificant with the VB 0.4 and VB 0.8% treatments. This can be explained by resorption or precipitation on the soil surface and by precipitation of Al and Fe with P from the decomposition of organic matter of Al and Fe complexes [28]. Furthermore, it can also be attributed to the fixation of P in the form of tricalcium phosphate. Similar results were found by Nishida et al. [25].

3.3.4. Release of NH_4^+

Results of surveying the effect of soil incubation time on the release of NH_4^+ in soil supplemented with lime (0.4%) combined with alkalized biochar at ratios of 0.0, 0.2, 0.4, and 0.8% were presented in Figure 8. The released NH_4^+ content remained at a higher level than the control treatment VB 0, at most soil incubation times. The amount of NH_4^+released increased on day 7 of incubation and remained high until day 21, ranging from 19.3 to 23.2, 20.7 to 22.4, and 20.1 to 22.7 mg kg^{-1} correspond to treatments of VB 0.2, VB 0.4, and VB 0.8. Then it decreased sharply with a significant decrease at day 35, respectively, 7.0, 11.5, and 13.3 mg kg^{-1}. Then it decreased slowly at day 60, fluctuating around a value of 8.0 mg kg^{-1}.

Increased available NH_4^+ content in the soil solution may be due to increased microbial communities leading to the mineralization of organically bound N. This can also be attributed to the decrease in soil pH increasing NH_4^+ in the soil [25]. Furthermore, Ca cations contained in alkaline biochar also contribute to removing NH_4^+ from adsorption sites in the soil. In addition, dissolved or colloidal organic anions in alkaline biochar also contribute to attracting NH_4^+ in the soil. The results obtained were similar to the study of Liyanage et al. [29] when investigating the NH_4^+ mineralization process using green manure, which occurred within about 7–20 days of incubation and was higher than using biochar directly.

The decrease in NH_4^+ content may be due to NH_4^+ fixation in wetland soil. Microbial Fe^{3+} reduction, followed by the dissolution of Fe oxides

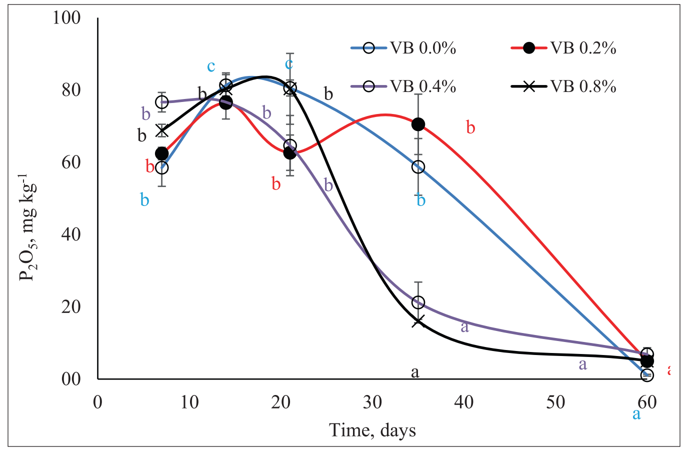

Figure 7: Effect of soil incubation time on released P when using lime (0.4%) combined with alkalized biochar, the different letters of the same color in the graph differ significantly.

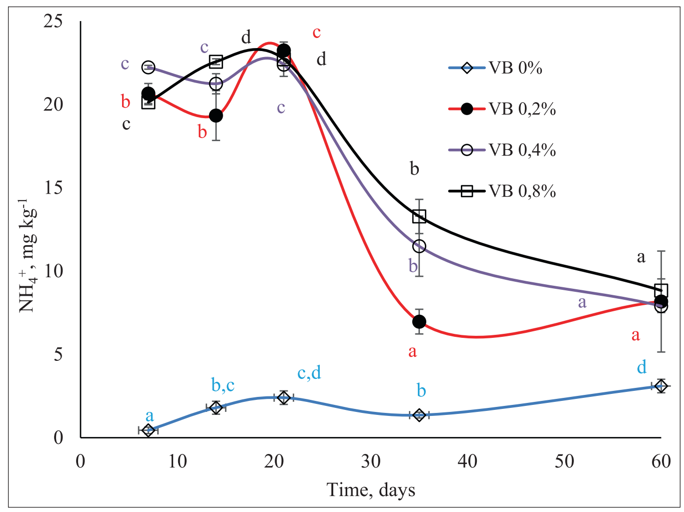

Figure 8: Effect of soil incubation time on released NH_4^+ when using lime (0.4%) combined with alkalized biochar, the different letters of the same color in the graph differ significantly.

coating the clay mineral surface, promotes the diffusion of NH_4^+ ions into the interlayers of the clay mineral. A similar explanation is also found in the report of Nieder et al. [6]. On the other hand, after 30 days the nitrification process also increased rapidly, with the amount of NH_4^+ converted to NO_3– reducing the NH_4^+ content, the results are similar to the study by Liyanage et al. [29].

The use of lime combined with alkalinized biochar as an acidic soil amendment on the collected sample in Vietnam has improved pH and EC, and maintained high phosphorus release until day 35, fluctuating at 59.0–80.0 mg kg^{-1} and maintained high NH_4^+ release ranging from 19 to 23 mg kg^{-1} until day 21.

4. CONCLUSION

From the above research results, it allows us to draw some conclusions as follows:

Soil samples at geographical coordinates 10°24′34.7″N 104°45′34.0″E in Vinh Phu, Giang Thanh, Kien Giang, Vietnam were collected and submerged under controlled conditions in the laboratory. The results showed that the incubation time did not affect pH and EC but affected available phosphorus (released phosphorus remains at a high level for a period of 7–21 days with samples V 0.4% and V 0.6%), while NH_4^+ release increased on day 21 and decreased on day 35 in the case of incubation with lime. While the solution of using lime (0.4%) combined with alkaline biochar not only maintains pH and EC, it also increases available phosphorus and NH_4^+ in the soil solution for a longer period (35 days). Research results showed that incubation time changed pH, EC, available phosphorus, and ammonium nitrogen in the soil sample but did not follow a clear trend. The study results also provide valuable insights into soil incubation times for developing strategies for using biochar-based products.

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6. AUTHOR CONTRIBUTIONS

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agree to be accountable for all aspects of the work. All the authors are eligible to be an author as per the international committee of medical journal editors (ICMJE) requirements/guidelines.

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8. CONFLICT OF INTEREST

The authors report no financial or any other conflicts of interest in this work.

9. ETHICAL APPROVALS

This study does not involve experiments on animals or human subjects.

10. DATA AVAILABILITY

All the data is available with the authors and shall be provided upon request.

11. USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

12. PUBLISHER'S NOTE

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