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농학석사학위논문

**Effect of liming on chemical speciation of
phosphorus in a deforested soil**

석회 시용이 벌채지역 토양 내 인의
화학종 변화에 미치는 영향

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박지숙

A Thesis for the Degree of MASTER OF SCIENCE

**Effect of liming on chemical speciation of
phosphorus in a deforested soil**

Advisor: Hee-Myong Ro

**A Dissertation Submitted in Partial Fulfillment of the
Requirements for the Degree of**

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**to the Faculty of the school of Agricultural Biotechnology
at
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Seoul, Korea**

by

JI SUK PARK

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ABSTRACT

Effect of liming on chemical speciation of phosphorus in a deforested soil

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Phosphorus is necessary element in plant nutrient, and reacts sensitively to changing soil pH. Deforestation affected soil properties, particularly in soil pH. It is well known that soil pH is subject to change by liming and the changes in soil pH cause the changes in chemical phosphorus fractions. To investigate the liming effect on pH and phosphorus fraction on deforested soil, soil sample was each subjected to three treatments of control and limed. Limed soils were treated with CaCO_3 : 1 g $\text{CaCO}_3 \text{ kg}^{-1}$ (Low) and 4 g $\text{CaCO}_3 \text{ kg}^{-1}$ (High). Each limed soils were incubated at $25 \pm 2^\circ\text{C}$ during 50 days. Soil samples were analyzed for pH, total-P, organic-P, available-P, inorganic-P, exchangeable Ca. Inorganic P was partitioned into three following chemical form according to the fraction procedure reported by Chang and Jackson (1957): Fraction A (Soluble and loosely bound P + Al bound P +

Fe bound P), Fraction B (Reductant soluble P: redox sensitive P) and Fraction C (Ca bound P). During experimental periods, soil pH increased rate of calcium carbonate. Soil pH decreased with time in limed soils. Available-P began to decrease in limed soils at the first day of incubation (both soil 0.67 mg kg^{-1}). However, control soil pH and available-P was not change significantly ($P < 0.05$). During experimental period, total-P and organic-P were not changed in control and limed soils. Particularly, organic-P increased in limed soils at 50 day (increased approximately 20 mg kg^{-1}). Concentrations of exchangeable calcium were not changes significantly in control and limed soils ($P < 0.05$). Inorganic-P fraction changed in limed soils. Both limed soils decreased in Fraction A and Fraction C and increased in the Fraction B. Control was not change in all fractions during experimental periods. Most studies showed that concentration of calcium bound phosphate increased with liming. However in this study, concentrations of Fraction C in limed soils were lower than those in control soil.

Key words: Deforestation, Liming, Phosphorus, Chemical speciation, pH

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I . INTRODUCTION

Deforestation is the clear-cut of forest trees where the land is converted to a non-forest. The removal of trees without sufficient reforestation has led to unfavorable ecological consequences including habitat, biodiversity and soil quality (Hossain *et al.*, 2011). A number of studies reported that changes in soil chemical properties due to deforestation decreased the level of soil nutrients, pH, cation exchange capacity (CEC) and available phosphorus (Zaman *et al.*, 2010; Hajabbasi *et al.*, 1997). Hossain *et al.* (2011) found that deforestation significantly lowered soil pH. Changing soil pH is an important chemical practice because it affects the availability of nutrients to plants and the activity of soil microorganisms. Soil pH affects plants grow and some plants may have difficult in absorbing nutrients in highly acidic soils.

In acidic soils, liming (such as CaCO_3 and CaSO_4) is a very effective practice to raise soil pH. Liming has two major implications to chemistry in soil; since it increases pH value and adds large amount of calcium ion (Fransson *et al.*, 1999). Application of lime to acid soil can increase mineralization rates due to a higher microbial activity and plant nutrient uptake and elimination Al and Mn toxicities (Haynes, 1984; Trasar-Cepeda *et al.*, 1991; Curtin & Syers, 2001). However, phosphorus availability is known to be affected by calcium carbonate and to react on its surfaces (Fixen & Ludwick, 1982; Freeman & Rowell, 1981; Griffin & Jurinak, 1973; Holford & Mattingly, 1975). Changing soil pH will change adsorption reaction that is speciation of phosphate and electrostatic potential of the adsorbing surfaces (Barrow, 1984; Curtin & Syers, 2001).

Generally, phosphorus reacts sensitively to change of soil pH. Phosphorus is the most limiting nutrient for primary productivity in plants and soil microorganisms. In the pedosphere, almost phosphorus occurs as phosphate that is in oxidized form as orthophosphate and the phosphorus ions are complexes with calcium, iron, aluminum and silicate mineral. The form of phosphate ion is pH-dependent. The influence of pH on distribution of orthophosphate ions are described in Figure 1. As seen in Figure 1, in pH range of most soils (5 to 8), H_2PO_4^- and HPO_4^{2-} are the predominant species. H_3PO_4 and PO_4^{3-} are predominant from soil pH extremes. Phosphorus is limited use in acid soils. The variation of available phosphorus in acidic soil mainly depends on the composition of particles that bind phosphorus. P sorption is positively correlated with the amount of free metal ions oxide in acid sulfate soil (Jugsujinda *et al.*, 1995). In low pH value, aluminum and iron may gradually react with phosphate to form insoluble aluminum and iron phosphate compounds (Verma *et al.*, 2005). For this reason phosphorus reduced its bioavailability (Jones *et al.*, 1993). Phosphorus also has a less availability in alkaline soil because calcium carbonate has a high affinity for phosphate adsorption (de Kanel & Morse, 1978). Ionic composition affected by changes in pH can lead to a shift in nutrient availability such as increasing of dissolved calcium concentration, hydrolytic iron and aluminum species can decrease availability of phosphorus (House, 1999; Ro & Cho, 2000). These reactions are P-forms binding to metals and free cation, measured by different sequential extraction schemes, so-called P-fractionations (Aiserli *et al.*, 2002). Most of these P-forms are very low solubility and difficulty used for plant uptake (Brady & Weil, 1999).

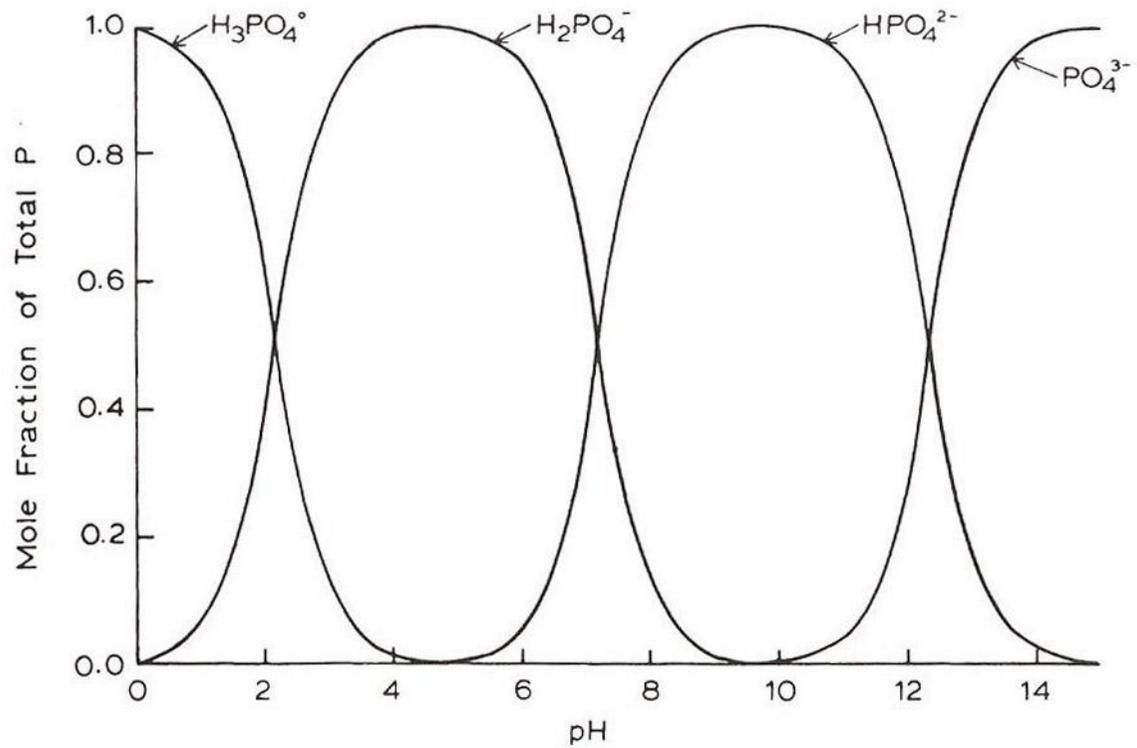


Figure 1. Effect of pH on the distribution of orthophosphate ions in solution (Willard L. Lindsay, 1979).

Because of inorganic phosphorus are likely to be strongly adsorbed onto the mineral surfaces, the different fractions such as labile P, reductant P, metal bound P by using various chemical extractants (Chang & Jackson, 1957; Williams *et al.*, 1976). Several studies have shown that Fe, Al oxides and Ca compounds are the primary affecting P sorption by soil (Froelich, 1988; Syers, Evans *et al.*, 1971) and how phosphate availability responds to lime addition (Mansell *et al.*, 1984; Naidu *et al.*, 1990; Curtin *et al.*, 1993). Liming has been reported to increase, decrease or not affect the phosphate that can be extracted from such soils. Quantification of the phosphorus fraction is necessary for the better understanding of phosphorus chemical speciation under particular environment in soil. Nevertheless, liming is not clearly investigated influence in phosphorus speciation change. The objective was, therefore, to understanding liming effect on phosphorus speciation in deforestation soil. The study hypothesized that liming increased in soil pH and affected the various changes in phosphorus chemical fractions such as calcium, aluminum and iron bound P at the same time. To do so, this study conducted a batch incubation study has been made under laboratory conditions to investigate the influence of lime on soil pH and phosphorus speciation.

II. MATERIALS AND METHODS

1. Sampling sites and soil preparation

The sampling site is located in Seoul National University Forest Mt. Backwoon, Jeollanam-do (35°2'N, 127°35'E). Deforestation site has been clear cut 5 years ago, mostly for cultivation of pitch pine (*Pinus rigida* Mill.). Soil samples (0-30 cm in depth) were taken in February 2012. Immediately after sampling, soil sample was air-dried at room temperature and passed through a 2-mm sieve and mixed thoroughly. Soil sample was analyzed for soil texture, bulk density, pH, organic matter, total-P, available-P and CEC (Cation Exchange Capacity). Physical and chemical properties of the soil were shown in Table 1.

Table 1. Chemical and physical properties of soil.

Parameters	Soil
Texture*	Loam
sand (g kg ⁻¹)	500.3
clay (g kg ⁻¹)	199.5
silt (g kg ⁻¹)	303.8
Bulk density (Mg m ⁻³)	1.1
pH (1:5)	5.43
Organic matter (g kg ⁻¹)	44.5
Total P (g kg ⁻¹)	0.26
Available P (mg kg ⁻¹)	0.78
CEC (cmol kg ⁻¹)	20.1

* USDA scheme: sand (2-0.05 mm), silt (0.05-0.002 mm), clay (<0.002 mm).

2. Lime Requirement

Lime requirement was determined by incubation pH buffer curve method (NIAST, 1998). 100 g of air-dried soil sample was individually placed into each 250 mL Erlenmeyer flask and mixed with calcium carbonate (0, 0.1, 0.2, 0.3, 0.5, 0.7 and 0.9 g). The mixture was sealed with parafilm[®] and shaken 120 rpm at 25 ± 2 °C in 5 day and this soil was dried on room temperature. Soil pH was determined in a 1:5 air-dried soil to water ratio using a pH meter (Thermo, Orion 3 Star, US). From the pH data can draw pH buffer curve and obtained lime requirement values for desired target pH of from Figure 2.

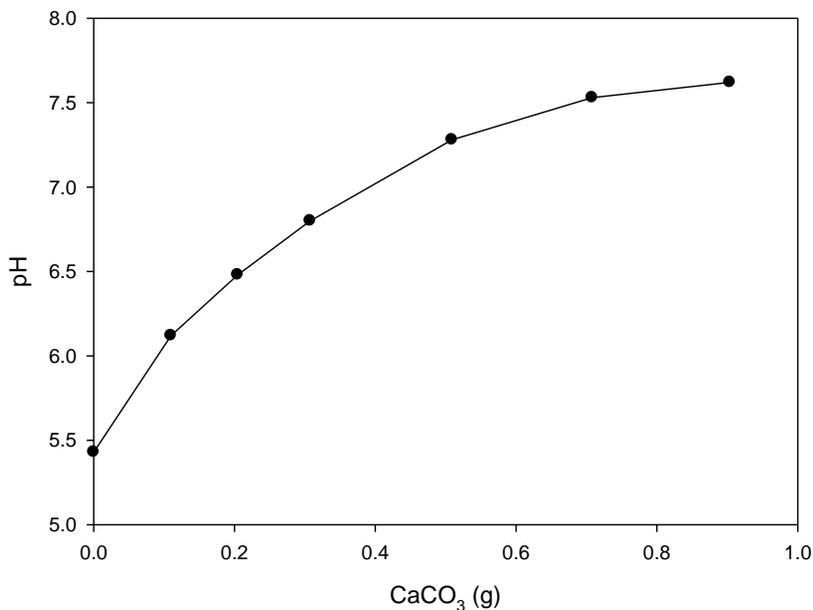


Figure 2. Lime requirement curves of used soil.

3. Adsorption Isotherm

One hundred gram of air-dried soil samples were individually placed into each 250 mL Erlenmeyer flask and mixed with calcium carbonate (1, 2, 3, 5, 7 and 9 g L⁻¹ in deionized water). The mixture was sealed with parafilm[®] and shaken at 25±2°C, 120 rpm in 5 day and this suspension was filtered through Whatman No. 42 paper. Concentrations of calcium in the filtrate were measured by ICP (Inductively Coupled Plasma) Optical Emission Spectrometer (ICPS-1000IV, Shimadzu, Japan). Adsorption isotherms were constructed using best-fit regression equations. Freundlich constants K and $1/n$ were also calculated from the equation

$$\log X = 1/n \log C + \log k$$

where

X = the amount of calcium absorbed (mg kg⁻¹)

C = calcium concentration of the equilibrium solution (g L⁻¹)

k = Freundlich adsorption constant

$1/n$ = represents the slope of the curve

4. Batch incubation experiment

To investigate the liming effect of pH and phosphorus fraction on deforestation soil, soils (100 g) were individually transferred into 250 mL plastic bottles and total of 63 bottles were prepared for three treatment (control and adjusted soil pH 6 and 7) x triplicate x 7 destructive samplings. The soil sample was split into three treat: control and lime treat (adjusted soil pH 6 and 7), and groups were pre-incubated at $25 \pm 2^\circ\text{C}$ in the dark. The deforestation soil was limed to target pH adding laboratory grade, powdered calcium carbonate (CaCO_3). Soil water content was adjusted to 0.31 kg kg^{-1} for soil (field capacity). After pre-incubation, limed soils were added $1 \text{ g CaCO}_3 \text{ kg}^{-1}$ (Low CaCO_3) and $0.4 \text{ g CaCO}_3 \text{ kg}^{-1}$ (High CaCO_3) (adjusted pH 6 and 7, respectively) to each bottle. The bottles were incubated at $25 \pm 2^\circ\text{C}$ in 50 days. Soil water content was adjusted to field moisture capacity during the 50 day batch experiment by adding deionized water to bottles every other day as necessary to maintain their initial condition.

5. Sampling and analyses

Triplicate soil samples for each treatment were prepared for analysis of chemical properties at interval of 0 (5 h after application), 1, 5, 10, 25, 40 and 50 days after the application of calcium carbonate. Soil samples were air-dried at room temperature and passed through a 2-mm sieve and mixed thoroughly and analyzed for pH, total-P, organic-P, available-P, inorganic-P and exchangeable Ca. Soil pH was determined in a 1:5 air-dried soil to water ratio using a pH meter (Thermo, Orion 3 Star, US). Total P was determined by the ammonium paramolybdate-vanadate colorimetric method after a perchloric acid digestion (Kuo, 1996) using UV-visible spectrophotometer (UV-1601, Shimadzu, Japan). Organic P was determined by the ignition method (Saunders & Williams, 1955) and available P by Bray-1 method (Bray *et al.*, 1945) using the spectrophotometer. Inorganic P of calcareous and non-calcareous soils was partitioned into three following chemical form according to the fraction procedure (Fig. 3) reported by Change and Jackson (1957): (i) Fraction A (Soluble and loosely bound P +Al bound P + Fe bound P) obtained by soil extracts with various extractor (Calcareous soil : 0.1 M NaOH + 1 M NaCl, Non-calcareous soil : 1 M NH₄Cl extraction + 0.5 M NH₄F + 0.1 M NaOH), (ii) Fraction B (Reductant soluble P; redox sensitive P) obtained by 0.3 M Na₃C₆H₅O₇ + 1 M NaHCO₃ to the residue and heat the suspension in a water bath at 85°C and after adding 1 g Na₂S₂O₄, and (iii) Fraction C (Ca bound P) obtained by adding acid solution (Calcareous soil : 0.5 M HCl, Non-calcareous soil : 0.25 M H₂SO₄), shaking for 1 h. Saturated NaCl was used to wash twice the residue after each extraction step. Determine the P various fraction concentrations were

determined by the ascorbic acid method (Murphy & Riley, 1962). Exchangeable calcium was determined by the ammonium acetate (pH 7) method (Sumner & Miller, 1996) using ICP (Inductively Coupled Plasma) Optical Emission Spectrometer (ICPS-1000IV, Shimadzu, Japan).

6. Statistical analysis

Data were statistically analyzed using General Linear Model procedures (SAS Institute, Version 9.3, Cary, USA). Analysis of variance (ANOVA) was used to evaluate the effect of calcium carbonate treatment on the pH and phosphorus in soil. The least significant difference (LSD) test at a confidence level of 95% was used to separate means.

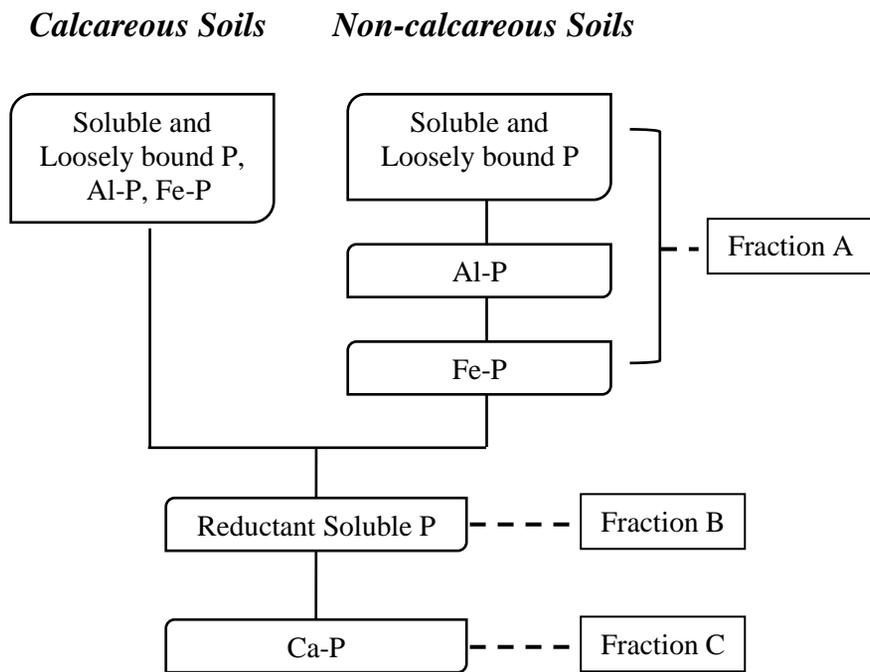


Figure 3. Fractionation scheme for inorganic P (Chang & Jackson, 1957).

III. RESULTS

1. Freundlich Adsorption Isotherm

Figure 4 shows the correlation between calcium adsorptions efficiency and calcium carbonate of soil. Sorption of calcium by this soil used in the present study was best explained by the Freundlich equation. Freundlich equation was used to illustrate the relationship between the amount of calcium adsorbed by soil and its equilibrium concentration in solutions. The amount of calcium adsorbed by the deforestation soil increased with rate of calcium carbonate concentration in equilibrium solution. Higher added calcium carbonate content of soil seems to be responsible for greater adsorption of calcium as compared to other added soil. The slopes and intercept values are 0.7379 and 4.1645, respectively.

2. Changes in soil pH

The initial pH values of the soil used in this study was 5.49. The pH values of soils incubated with CaCO_3 were close to the target values. At the highest rate of limed soils (Low CaCO_3 and High CaCO_3) were 6.25 and 6.93, respectively and control was 5.57 (Fig. 5). The soils had differing curves relating pH to amount of added CaCO_3 . The pH declined approximately linearly with time after the first day on limed soils, but control decreased in 10 day and there was no change after 10 day.

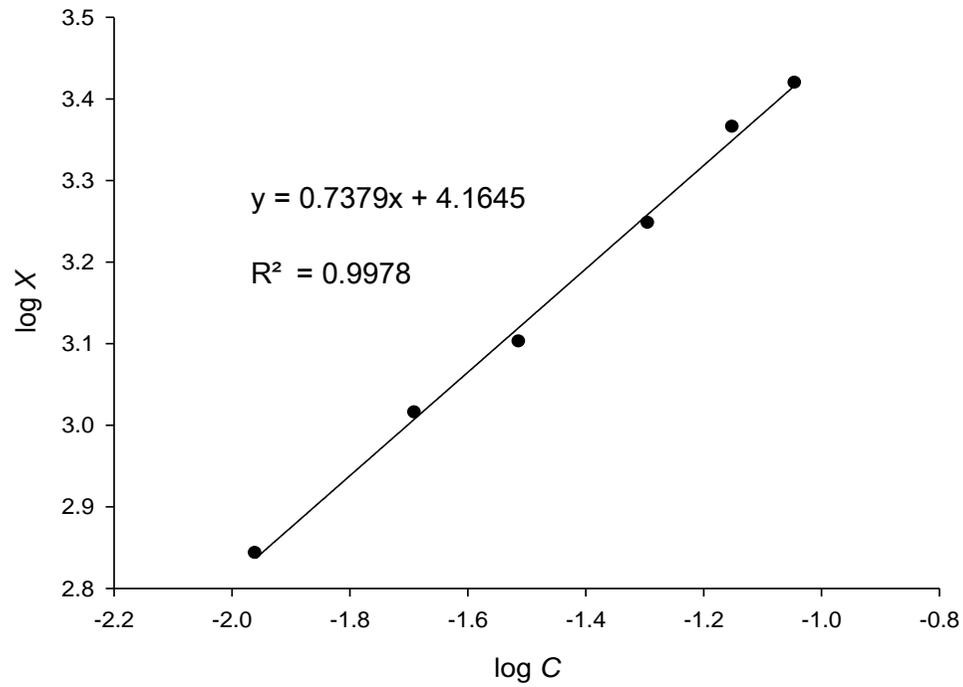


Figure 4. Freundlich isotherm for calcium adsorption.

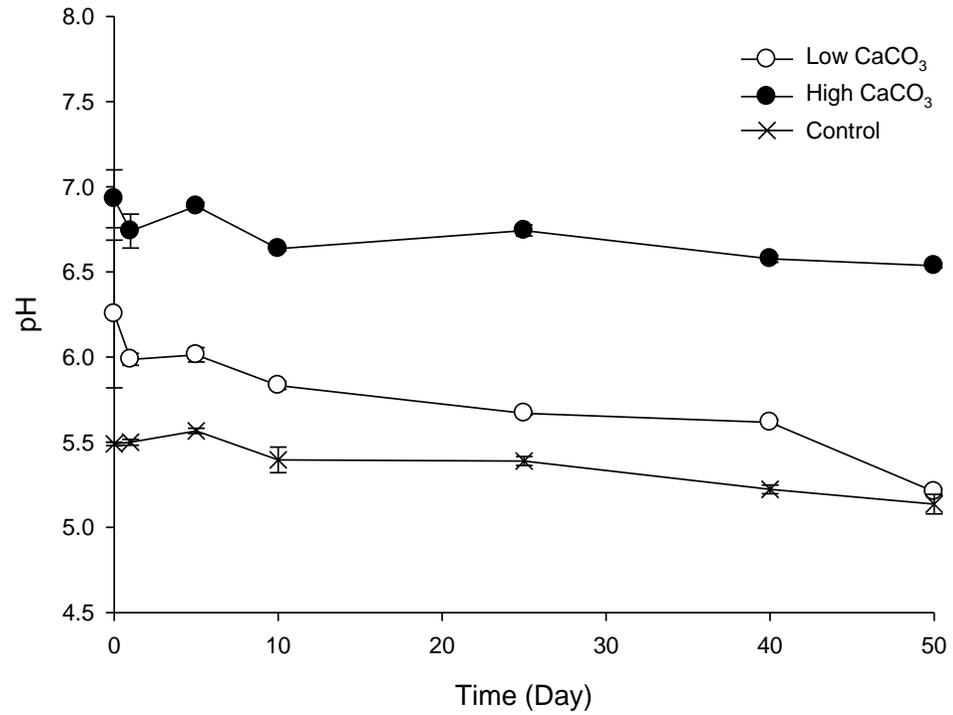


Figure 5. Changes in Soil pH during 50 days. Error bars indicate standard deviation of triplicate.

3. Changes in soil Phosphorus

Figure 6 shows the concentration of total-P during experimental periods. Total-P of the each soil with an initial concentration was range from 222.8 to 224.4 mg kg⁻¹ and the final concentration were range from 260.0 to 278.8 mg kg⁻¹. The total-P of soils incubated were not changes in control and both limed soils. Concentration of total-P was not changes significantly ($P < 0.05$) in experimental periods.

Concentration of organic-P were not changes in control and both limed soils (initial concentration range from 106.7 to 122.8 mg kg⁻¹, final concentration range from 124.5 to 146.5 mg kg⁻¹) (Fig. 7). Particularly, organic-P was increased in Low CaCO₃ at 50 day (increase approximately 20 mg kg⁻¹). There was not change significantly ($P < 0.05$) of organic-P during the experimental periods (except for Low CaCO₃).

Concentration of available-P in limed soils decreased in first day. Control was not change during experimental periods. However at 50 day, limed soils increased in up to concentration of control. Addition CaCO₃ was negative correlations with concentration of available-P in this study. Between Low CaCO₃ and High CaCO₃ were not significantly ($P < 0.05$) different in concentration of available-P (Fig. 8).

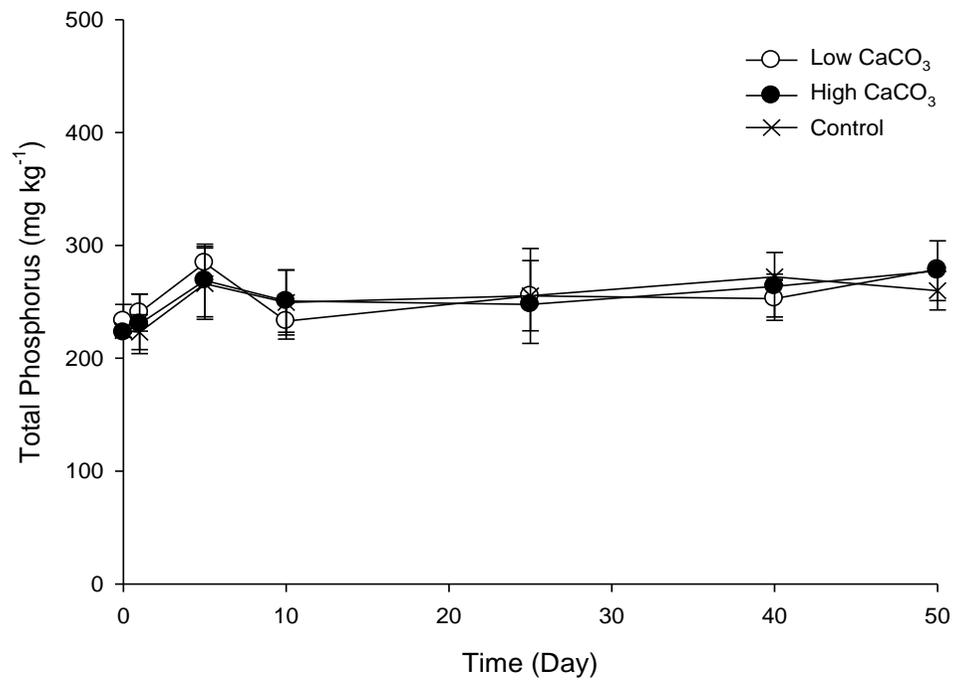


Figure 6. Changes in concentrations of total-P during 50 days. Error bars indicate standard deviation of triplicate.

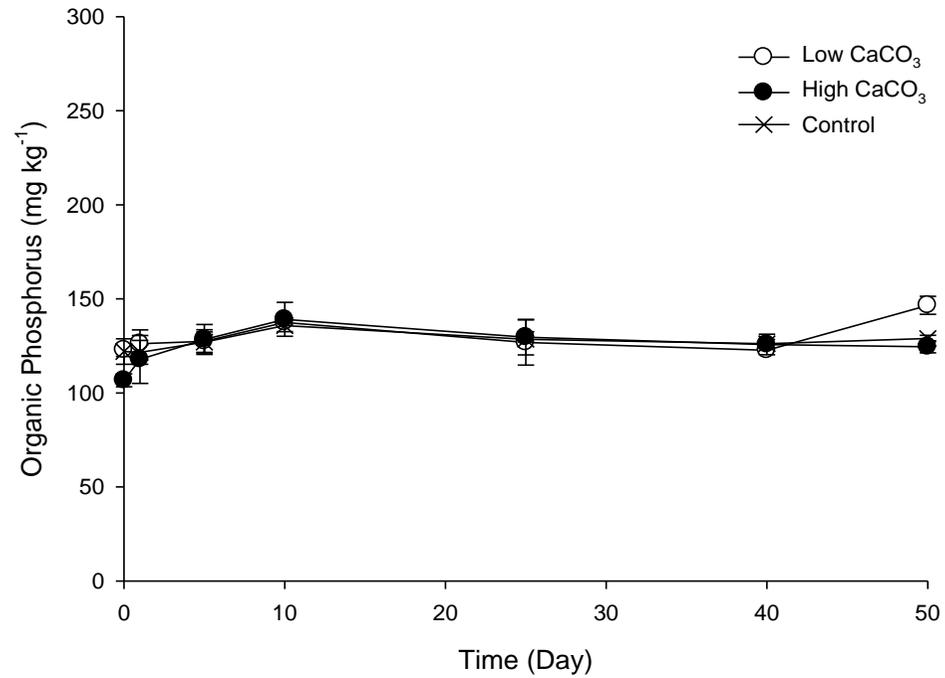


Figure 7. Changes in concentrations of organic-P during 50 days. Error bars indicate standard deviation of triplicate.

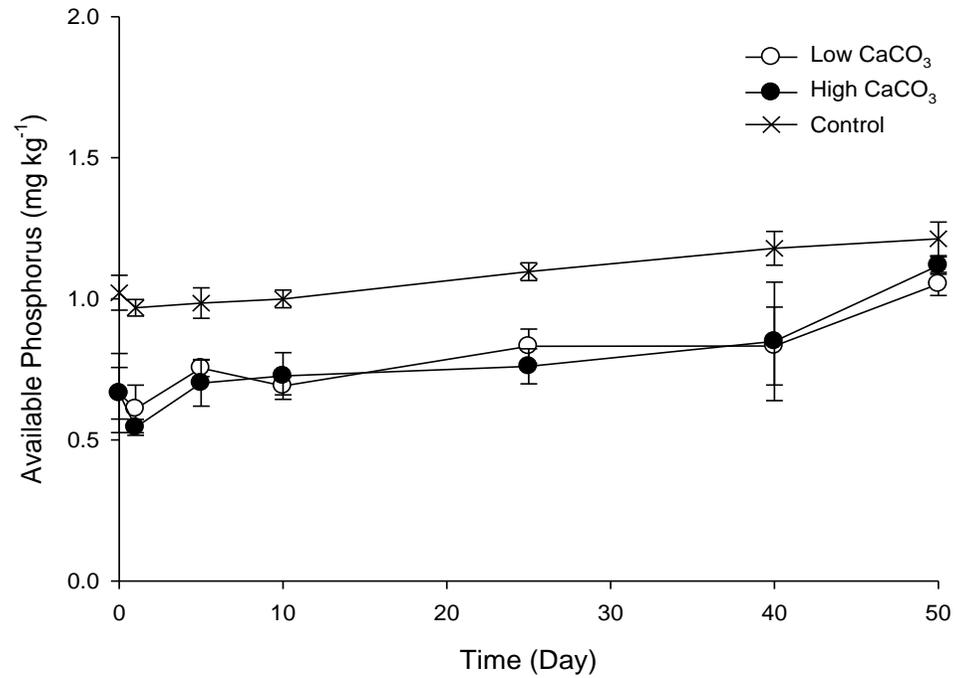


Figure 8. Changes in concentrations of available-P during 50 days. Error bars indicate standard deviation of triplicate.

In this study, inorganic P was partitioned into three following chemical form. Concentration of each fraction had changes significantly ($P < 0.05$) during experimental periods. Fraction A means for concentrations of soluble-, loosely-, aluminum- and iron phosphate (Fig. 9). The concentration of Fraction A in control was not changes significantly ($P < 0.05$) in this study. At the 10 day, limed soils were increased. However, the concentration in limed soils sharply decreased in 25 day and then increased in 50 day. Concentration of limed soils had the significantly ($P < 0.05$) difference during experimental periods.

Concentration of fraction B mean for concentrations of reductant soluble phosphate (Fig. 10). The concentration of Fraction B in control was not change significantly ($P < 0.05$) and limed soils were changes significantly ($P < 0.05$) each group and day. The concentration of control was 0 mg kg^{-1} from beginning to end. Concentrations of limed soils (Low CaCO_3 and High CaCO_3) were 12.13 mg kg^{-1} and 18.30 mg kg^{-1} in first day, respectively. Concentrations of limed soils were changes in experimental periods.

Concentration of Fraction C mean for concentration of calcium bound phosphate (Fig. 11). The concentration of Fraction C in control was not change in this study. However, concentrations of Fraction C in both limed soils were changes significantly ($P < 0.05$) during experimental periods. Overall, concentrations of limed soils were lower than control except for 5day. At 5 day, limed soils increased higher than control.

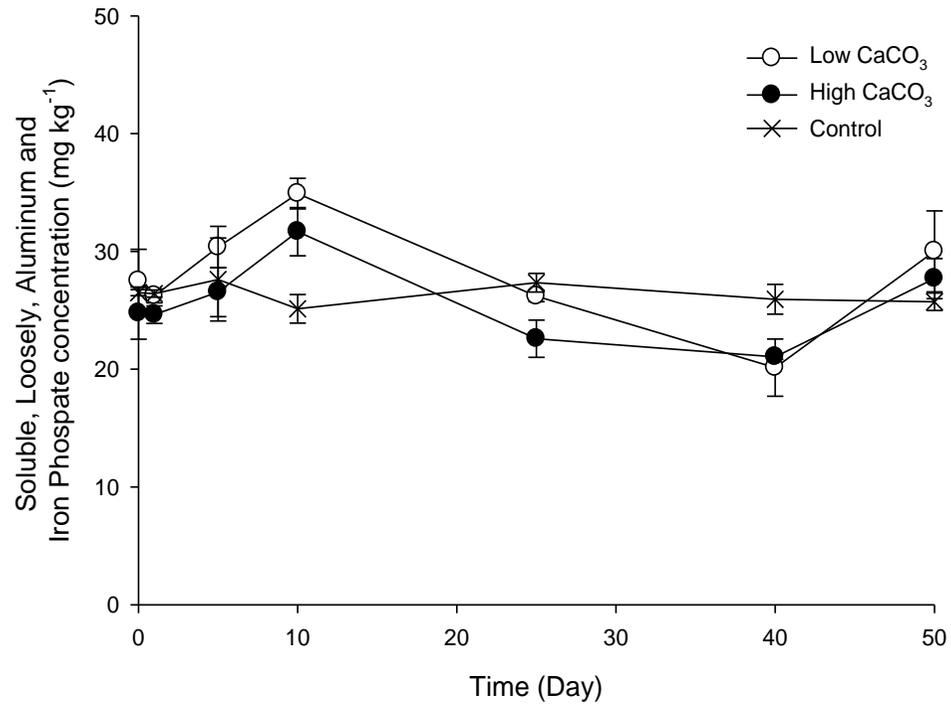


Figure 9. Changes in concentrations of soluble-, loosely-, aluminum- and iron-P during 50 days. Error bars indicate standard deviation of triplicate.

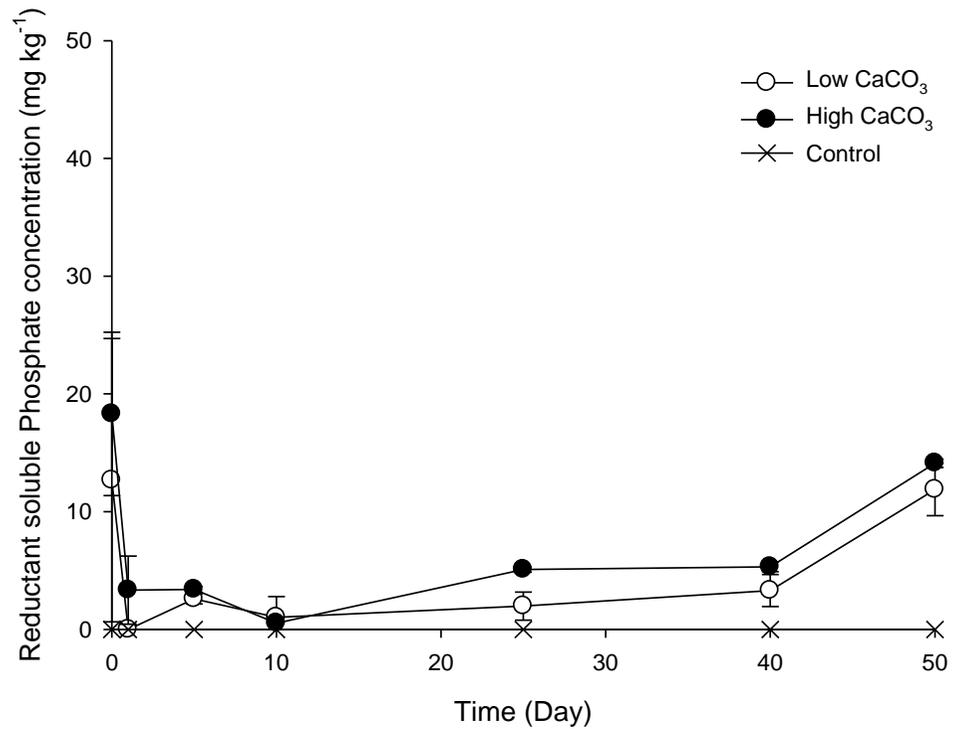


Figure 10. Changes in concentrations of reductant soluble-P during 50 days.

Error bars indicate standard deviation of triplicate.

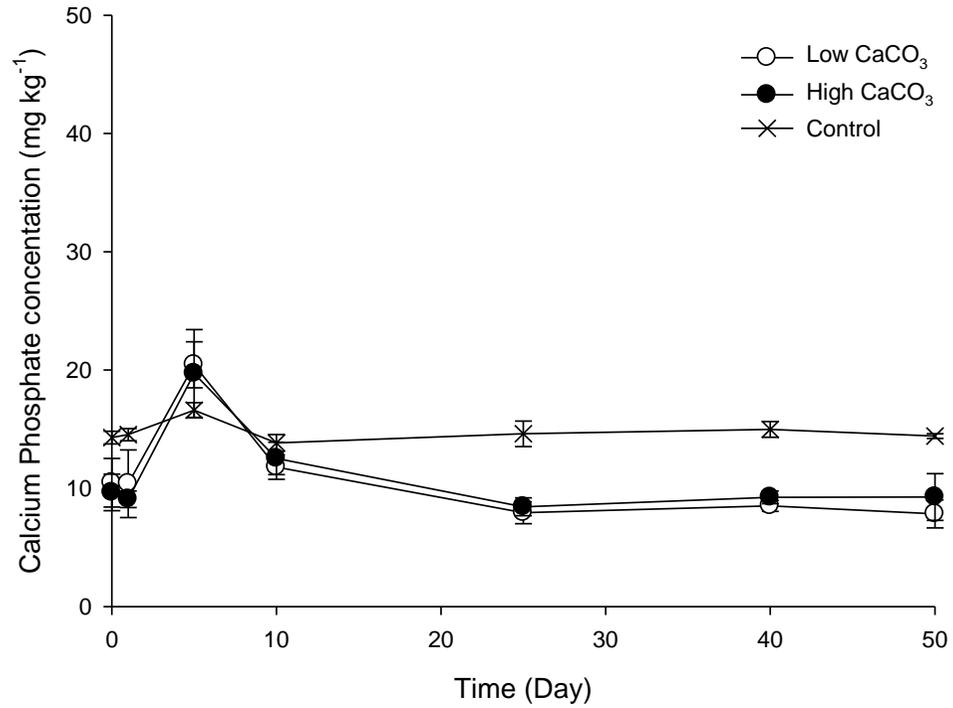


Figure 11. Changes in concentrations of calcium-P during 50 days. Error bars indicate standard deviation of triplicate.

4. Changes in soil exchangeable calcium

Figure 12 shows the concentration of exchangeable calcium during experimental periods. Exchangeable calcium increased in limed soils. Concentration of control was not change during experiment periods. The initial concentration of exchange calcium used in this study was 178.0 mg kg^{-1} . The initial exchangeable calcium concentrations of limed soils (Low CaCO_3 and High CaCO_3) were 711.1 mg kg^{-1} and $1939.2 \text{ mg kg}^{-1}$, respectively. At the highest rates of limed soils were in first day and control was 185.5 mg kg^{-1} . The concentration of exchangeable calcium declined with time after the first day on limed soils. However, concentration of exchangeable calcium was not changes significantly ($P < 0.05$) during the experimental periods.

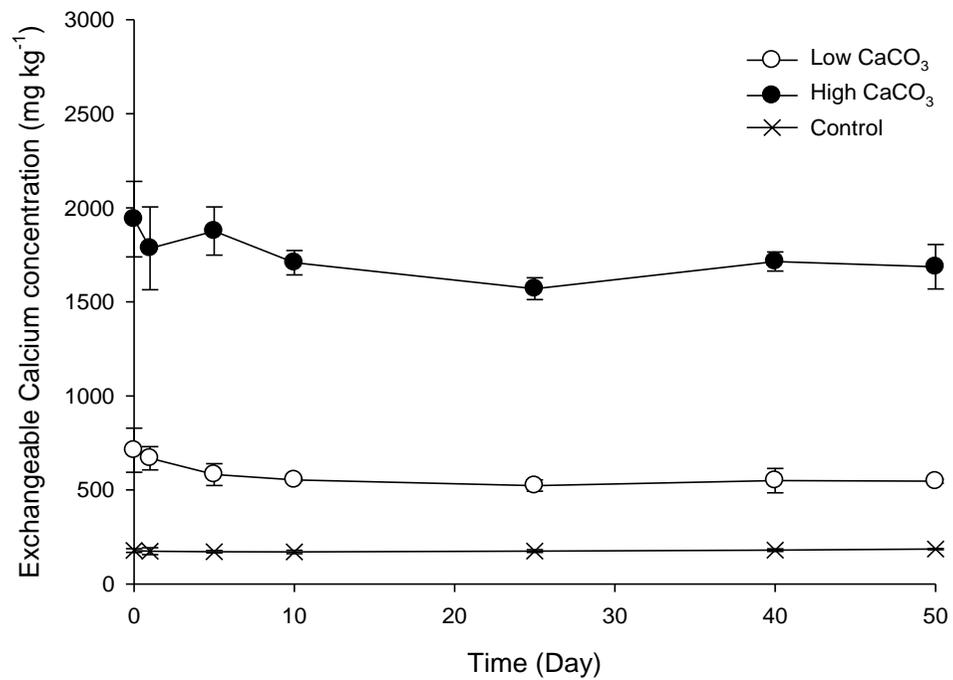


Figure 12. Changes in concentrations of exchangeable calcium during 50 days.

Error bars indicate standard deviation of triplicate.

IV. DISCUSSION

In this study, soil pH increased with increasing calcium carbonate. However, pH declined with time at limed soils. It was probably caused by relatively exchangeable ions such as aluminum and iron, and equilibrium reaction of inorganic P fraction. Chaplain *et al.* (2011) demonstrated that the decrease in soil pH due to charged hydroxyl-Al polymers. To understanding the interaction of the lime and pH, the equilibrium reaction of exchangeable cation and CEC need to be considered.

Liming increases litter, humus decomposition and mineralization rates due to a higher microbial activity with a rise in pH (Fransson *et al.*, 1999; Haynes, 1984; Trasar-Cepeda *et al.*, 1991). Mckenzie (1992) found that an increase in microbial activity could have increased mineralization of organic-P. In this study, concentrations of organic-P were not changes in control and limed soils (Fig. 7). Particularly, the organic-P has increased in Low CaCO₃ (50 day). The organic-P increase in Low CaCO₃ at 50 day is thought to be the result of the release of organically bound P from decomposed litter and humus, as Verma *et al.* (2005) said. Generally, organic P mineralization and immobilization were affected by microbial activity, temperature, humidity, aeration, soil pH and plant. However, there is not clearly defined whether such environmental effects on organic phosphorus. For the better understanding about these mechanisms, further studies about the organic phosphorus mineralization/immobilization mechanisms are necessary.

Concentration of available-P decrease in limed soils during experimental periods (Fig. 8). Pailles & Moody (1995) demonstrated that between available-P

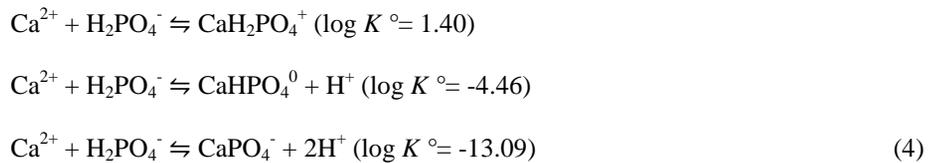
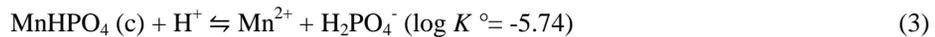
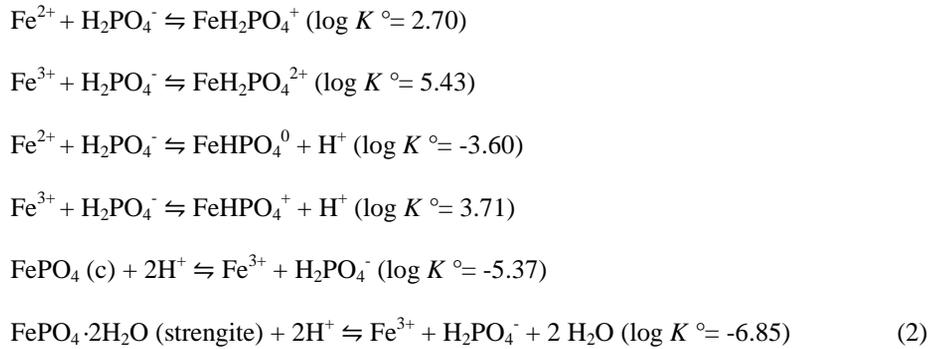
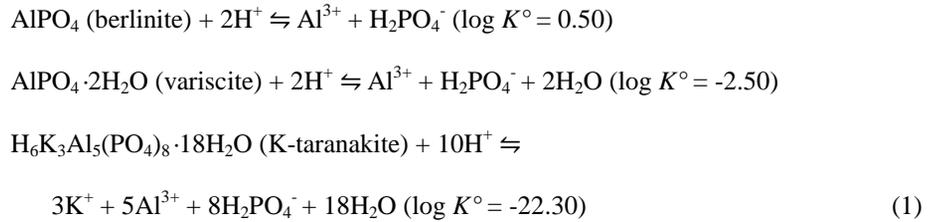
and calcium carbonate content has a strong negative relationship. In this study, available-P was significantly ($P < 0.05$) decreased by liming. As the calcium carbonate decomposes, relatively free cation such as calcium, aluminum and iron ions which are combined with phosphorus decrease the concentration of available-P.

Concentration of exchangeable calcium increased in limed soils and control was not change. The additional CaCO_3 improves concentration of exchangeable calcium. Low CaCO_3 and High CaCO_3 were not significantly different during experimental periods. Reason that not changes in limed soils, calcium was not adsorbed with phosphorus. Generally, concentration of exchangeable calcium can increase or decrease depending on Ca bound phosphate (Bolton, 1977).

Lime addition affected the inorganic-P fraction. Following lime addition, decreased in soil acidity has been shown to change soil solution ionic composition. In acid condition, they have a weak electronegative charge, and in alkaline condition, they have an electropositive charge. A number of study reported that change in soil pH induced the adsorption reaction, speciation of phosphate and electrostatic potential of the adsorbing surface (Barrow, 1984; Curtin & Syers, 2001). The surface potential affected by pH is sensitive to exchangeable cation composition and ionic strength of the soil solution (Barrow, 1984; Curtin *et al.*, 1993). When pH is increased, the proportion of the divalent phosphate ion (HPO_4^{2-}) adsorption also increased (Barrow, 1984) and changes in pH affect the adsorption or desorption processes in solubility of Al-P, Fe-P and Ca-P (Larsen & Widdowson, 1970; LeMare, 1982; Syers *et al.*, 1971; Sharpley, 1991). The results for each soil inorganic P fraction may relative changes to soil pH and lime application.

In this study, the proportion of concentration of Fraction A (Fig. 9) was little varied during experimental periods. Concentration of Fraction A increased in 5 and

10 day limed soils. Increase in the free calcium ions adsorption was probably due to the relative adsorption of the free cation such as aluminum and iron with phosphorus, while CaCO_3 was decomposed (Reaction 1, 2)(Lindsay, 1979).



For these reasons, the concentrations of Fraction A were increased while the acidity of the soil was decreased. Reason that decreased in 25 day, according as exchangeable aluminum become more stable, reaction 1 was more promoted in soil.

Fraction B (Fig. 10) represents the redox-sensitive P forms (Kozerski & Kleeberg, 1998). Jin *et al.* (2001) demonstrated that usually dominant in concentrations of Fraction B in strongly acid soil. Haynes (1982; 1984) found that the effect of pH on phosphate retention by soil is not simple because of a variety of mechanisms. In this study concentration of limed soils Fraction B increased in first day, such increase may be due to reactions 2 and 3. A decrease in concentration of Fraction B was due to increased concentration of H^+ which returns Fe-P and Mn compound into Fe and Mn ion, respectively.

Fraction C (Fig. 11) mean for concentration of calcium bound phosphate. In general, concentration of calcium bound phosphate increased with liming (Evensen *et al.*, 2000; Adhami *et al.*, 2006). When calcium supplied at adequate rates, the aluminum replaced with calcium. However in this study, increased (5 day) for the moment, concentrations of limed soils Fraction C were decreased than control. Decrease in Fraction C might be related with the increase in Fraction B and reaction 4. For the better understanding about this result, further studies about the activity of phosphorus (such as adsorption strength of the cations with phosphorus), positive ions in soil surface, exchangeable form Al, Fe and Mn are necessary.

V. CONCLUSIONS

The results of this study give new insights in the influence of lime (CaCO_3) on soil phosphorus chemical speciation. Application of lime was effective in alleviating soil acidity. This study suggested that liming would be affected in soil phosphorus. The pH values of soils limed with calcium carbonate were close to the target values in limed soils. However, soil pH decreased with time after in Low CaCO_3 and High CaCO_3 . In limed soils, decreased available-P was due to CaCO_3 decomposition. In addition, changes in chemical speciation of inorganic-P were greater from limed soils, compared with control. An increase in soil pH increased the Fraction B (Reductant soluble P: redox sensitive P), but decrease the Fraction C (Ca bound P) and Fraction A (Soluble and loosely bound P + Al bound P + Fe bound P). Concentration of inorganic P in control was not change significantly ($P < 0.05$) during experimental periods. In general concentration of calcium bound phosphate increased with liming. However, this work confirms the interest results as increased in Fraction C. This result suggests that if concentration of exchangeable calcium ion was increases, Fraction C does not always increase. Furthermore, a further study studies about adsorption strength of the cations with phosphorus and field-based experiment are necessary.

VI. REFERENCES

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SUMMARY (In Korean)

인은 토양 산도에 영향을 받아 다양한 인산염을 생성하는데, 본 연구는, 산림벌채로 인해 산도가 증가한 토양에 석회를 사용하여 토양 pH를 교정하였을 때, 석회와 토양 내 인의 상호작용과 인의 화학종 형태에 미치는 영향을 구명하였다. 이를 위하여 전라남도 광양에 있는 서울대학교 남부 학술림 벌채지역에서 토양 시료 (0-30 cm)를 채취하였다. 시간에 따른 토양 내 pH와 인의 화학종 형태 변화를 구명하고자 항온실험을 진행하였다. 토양 수분은 포장 용수량 (0.31 kg kg^{-1})으로 유지하였고, 석회를 처리하여 $25 \pm 2^\circ\text{C}$ 에서 50일간 진행하였다. 석회처리는 pH 완충곡선법으로 교정량을 구하여 무처리구, 처리구 2수준 (pH 6.0 교정, pH 7.0 교정)으로 나누어 CaCO_3 (pH 6.0 교정: $1 \text{ g CaCO}_3 \text{ kg}^{-1}$; pH 7.0 교정: $4 \text{ g CaCO}_3 \text{ kg}^{-1}$)를 처리하였다. 항온실험결과 실험 처리구 모두에서 pH의 변화가 뚜렷하였다. Organic P의 경우 산도에 영향을 받는 토양 미생물에 의해 mineralization이 활성화되어 함량이 줄어들 것이라 예상했던 것과 달리, 처리구 pH 6.0교정 50일에 약간 증가하였으며, 이를 제외한 나머지 처리구에서는 실험기간 동안에 유의적인 변화가 없었다. Available P의 경우 처리구 모두에게서 Available P의 감소가 나타났다. 인의 화학종 변화를 알아보기 위해 수행한 Inorganic P 각각의 Fraction은 Al-P, Fe-P의 감소와 Ca-P가 증가되었을 것이라는 예상과 다르게 Al-P, Fe-P의 함량이 초기 증가했다 감소하는 경향을 나타냈으며, Ca-P 에서는 control 보다 감소하였다. 본 연구를 통하여 산도 교정을 위해 사용하는 석회에 의한 인의 화학종의 변화를 알 수 있었다.

Keywords : 산림벌채, 인, 석회사용, 화학종 변화

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