Effects of Phosphogypsum Application in Topsoil on Amelioration of Subsoil Acidity of Nonallophanic Andosols

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Synopsis


Effects of phosphogypsum (PG) applied in topsoil on amelioration of subsoil acidity of nonallophanic Andosols were studied comparing with that of calcium carbonate (lime). Both barley (Hordeum Vulgare L.) and alfalfa (Medicago sativa L.) were grown on Kawatabi (thick high humic) and Kitakami (light colored) nonallophanic Andosols treated by different amounts of PG.

1. After 1012 mm of rain, 82% of Ca applied as lime to topsoil still remained in topsoil, whereas about 75% of Ca applied as PG moved toward subsoil reflecting their relatively high solubility.

2. Both pH (H₂O), intensity factor of soil acidity and exchangeable acidity y', capacity factor of it, were extremely lowered in Kitakami Andosol with phosphogypsum (10 g/kg soil) application, but not in Kawatabi Andosol attributing to high buffering and chelating ability of humus contained.

3. Root growth of both barley and alfalfa in Kitakami Andosol were extremely amended when increasing the application rate of phosphogypsum.

4. Possibility of amelioration of subsoil acidity by PG application to topsoil were strongly suggested in nonallophanic Andosols, especially in light colored nonallophanic Andosols.

Key words: Aluminum toxicity, Andosol, Exchangeable acidity, Phosphogypsum, Subsoil acidity.

Introduction

Crop productions in nonallophanic Andosols are often severely restricted by subsoil acidity which cause aluminum toxicity to crops. Subsoil, as well as topsoil, is very important for crops as a place of water and nutrient uptake. Therefore the amelioration of subsoil acidity is one of the most important problems for intensive agriculture. However, the solubility of commercial liming materials are very low and it is difficult to ameliorate subsoil acidity by the application of these materials in topsoil. Recently, gypsum or phosphogypsum...
(PG), which has a much higher solubility<sup>40</sup> than calcium carbonate (lime), was studied as an ameliorant for subsoil acidity in highly weathered soils and showed remarkable effects on improving the crop rooting toward subsoil by reducing the aluminum toxicity<sup>1-4,8</sup>.

Andosols are widely distributed in Japan and require extremely large amounts of phosphate fertilizer for crop productions. In Japan, large amounts of both phosphoric acid and PG, by-products of phosphoric acid production, are annually produced. Therefore, the utilization of PG in the agricultural field is under consideration. The objective of the present study is to determine the effects of phosphogypsum application in topsoil on amelioration of subsoil acidity of nonallophanic Andosols.

**Materials and Methods**

According to the amounts of humus in the soil, nonallophanic Andosols are divided into humus nonallophanic Andosols and light colored nonallophanic Andosols. Thus, we used the following two types of soils as test soils: Kawatabi soil (thick high humic Andosol, collected at Naruko, Miyagi prefecture), and Kitakami soil (light colored Andosol, collected at Kitakami, Iwate prefecture). The clay fractions of both Kawatabi and Kitakami Andosols were dominated by 2 : 1–2 : 1 minerals and both soil showed strong soil acidity as shown by low pH(H<sub>2</sub>O) and high values of y<sub>1</sub> (see Fig. 2<sup>9</sup>).

Vertical movements of PG and lime in the soil profiles were studied using open end columns (diameter 36 cm, length 90 cm). The test soils were packed in 5–90 cm of the columns and fine particles of PG or lime were mixed with each topsoil (0–15 cm) by the rate of 10 g or 5 g/kg soil respectively. This application rate is approximately equal to 1000 kg or 500 kg/10 a assuming the bulk density of Andosols is 0.7 and the depth of topsoil (plow layer) is 15 cm. The columns were placed in the field and the surface of each test soil was adjusted to the ground level. After 5 months (1012 mm of rain), soil samples were collected separately from the following soil segments: 0 to 15, 15 to 30, 30 to 45, 45 to 60, 60 to 75, and 75 to 85 cm. From the distribution pattern of Ca in the soil profiles, the movements of PG and lime were estimated.

Effects of PG on the root growth of barley (*Hordeum Vulgare* L. cv. Miyuki) were studied using 250 ml pots which were filled with Kawatabi or Kitakami soil. The application rates of PG or lime were at 10 g or 5 g/kg soil respectively. Pregerminated seeds were sown in the pot and were kept at 25°C. Root length, soil pH, and exchangeable acidity y<sub>1</sub> were measured on the 3rd day after sowing.

Effects of PG on the root growth of barley and alfalfa (*Medicago sativa* L. cv. Dupui) toward subsoil were studied as follows. The upper 3 cm of the plastic pot (1.2 liter), topsoil, was filled with well-limed (pH 6.5) and fertilized test soil. The lower 7 cm of the pot, subsoil, was filled with test soil containing the following rate of gypsum (CaSO<sub>4</sub>·2H<sub>2</sub>O): 0, 0.86, 2.58, 4.30 g/kg soil. These amounts are 0, 10, 30, and 50% of PG applied at a rate of 10 g/kg soil. In this experiment, the reagent grade gypsum was used, because gypsum is a major component of PG which move from topsoil to subsoil with a surface application of it. The seedlings of barley or alfalfa grown for 10 or 20 days in a glass house respectively, were collected and their root lengths were measured.
The following chemical determinations were conducted using air-dried soil samples (<2 mm): pH (H₂O) measured potentiometrically in water (1:2.5). Exchangeable acidity ( AuthService was determined by the titration of 125 ml of KCl soil extracts (100:250) with 0.1 M NaOH (Phenolphthalein was used as an indicator). Calcium was extracted with M ammonium acetate and determined by atomic absorption spectroscopy.

Results and Discussions

1. Vertical movements of phosphogypsum in the soil profiles

Vertical distribution pattern of Ca applied as PG or lime in the topsoil are shown in Fig. 1. Seventy-five percent of applied PG moved into subsoil after 1012 mm of rain. At the depth of 15-30 cm, the level of PG was 14 percent, at 30-45 cm, it was 17 percent, at 45 to 60 cm, 27 percent, and at 60 to 75 cm, 14 percent of Ca from PG was found. Therefore, it suggests that relatively rapid movement of PG from topsoil to subsoil will occur by rainfall. On the other hand, about 82% of Ca applied as lime were still remained in the top 0-15 cm. To investigate the practical aspects of Ca leaching in the field, soil column experiments were conducted in Brazilian Savanna Oxisol by Richey et al. They reported that an addition of 1,200 mm of water to 2,000 kg/ha Ca added as CaCl₂, CaSO₄ and CaCO₃ caused Ca movement to 180, 75 and 25 cm respectively. These results mean that gypsum or phosphogypsum applied in topsoil may be useful to reclaim the subsoil acidity, whereas the movement of lime by rain is too slow to reclaim it.

![Fig. 1. Vertical distribution patterns of Ca applied as phosphogypsum or calcium carbonate in the soil profile. (after 1012 mm of rainfall)](image)
2. Effects of phosphogypsum on the root growth of barley

Effects of PG and lime on the soil acidity of Andosols and the root growth of barley are shown in Fig. 2. The pH(H$_2$O), intensity factor of acidity, of Kawatabi soil was lowered only

(a) Soil pH(H$_2$O)

![Graph showing soil pH(H$_2$O) for C, PG, and Lime]

(b) Exchangeable acidity y$_i$

![Graph showing exchangeable acidity for C, PG, and Lime]

(c) Root length

![Graph showing root length for C, PG, and Lime]

Kawatabi soil

**Fig. 2.** Effects of phosphogypsum and calcium carbonate on the soil acidity of Andosols and the root growth of barley.

C: Control, PG: Phosphogypsum, Lime: Calcium carbonate.
slightly by a PG application and that in Kitakami soil was extremely reduced from 5.3 to 4.5 (Fig. 2-a). The remarkable reduction of pH (H₂O) in alluvial soil was also reported by Tanaka and Hitsuda. This change of pH in Kitakami soil can be explained by the salt effect of PG resulting the increase of solution Al³⁺ while the little change of pH in Kawatabi soil can be explained by the strong buffering ability of humus. The pHs of soil treated by 5 g/kg soil of lime were raised to 6.0 in Kawatabi and 7.0 in Kitakami soil.

Effects of PG on the exchangeable acidity $y_t$, capacity factor of acidity and practical indicator of Al toxicity in Andosols, are shown in Fig. 2-b. With PG treatment, $y_t$ decreased from 9.8 to 7.7 in Kawatabi and from 28.1 to 19.9 in Kitakami soil. The small change of $y_t$ in Kawatabi soil can be attributed to the big pool of exchangeable Al which is combined with humus. With lime treatment, $y_t$ disappeared almost completely both in Kawatabi and Kitakami soil.

Effects of PG treatment on the root growth of barley are shown in Fig 2-C. The root length of barley increased 25% (from 33 to 41 mm) in Kawatabi soil and 150% (from 12 to 29 mm) in Kitakami soil reflecting the reduction of $y_t$ in each soil. From these results it is suggested that PG is more effective in nonallophanic Andosols with low humus content. On the other hand, the root length of barley grown in soil treated with lime increased about 100% (35 mm) in Kawatabi and 500% (57 mm) in Kitakami soil. This means that lime is much more effective in amelioration of the soil acidity than PG. However, the solubility of lime is much smaller than PG and it is extremely difficult to reclaim subsoil acidity with a lime application in topsoil as mentioned above. Therefore, we may use only PG as an ameliorant of subsoil acidity of Andosols by its application in topsoil.

The alleviation of aluminum toxicity by gypsum or phosphogypsum seems to be attributed to many factors. The mechanisms proposed include a “self-liming” due to ligand exchange of OH⁻ on oxide surfaces by SO₄²⁻, decrease of aluminum ion activity in soil solution or increase of calcium ion activity, precipitation of aluminum sulfate minerals by increasing in SO₄²⁻ concentration, formation of the AlSO₄⁺ ion-pair which is less toxic to plants, displacement and leaching of soluble aluminum, etc. However, remarkable reduction in exchangeable acidity $y_t$ which is the most useful indicator of aluminum toxicity in Andosols, was found in this experiment. The mechanism of alleviation of aluminum toxicity of Andosols by PG is in need of further investigation.

3. Effects of phosphogypsum on rooting of barley and alfalfa toward subsoil

Effects of the application rate of PG on the root growth of barley and alfalfa toward subsoil were studied by applying gypsum into subsoil, because it is the major component of PG that moves from topsoil to subsoil by rain. The results obtained in Kawatabi soil and Kitakami soil are shown in Figs. 3 and 4, respectively. In Kawatabi soil, as expected from foregoing results, there were no significant effects of gypsum on the root length of both barley and alfalfa toward subsoil. On the other hand, in Kitakami soil, with increasing application rates of PG from 0 to 0.86, 2.58, and 4.3 g/kg soil, the root length of barley increased from 60 to 66, 79, and 101 mm respectively. Likewise, the root length of alfalfa increased from 34 to 43, 49, and 59 mm. At the application rate of 0.86 g gypsum/kg soil, the elongation of roots toward subsoil increased 15% in barley and 65% in alfalfa. This application rate is equal to 10% of PG...
applied in topsoil at a rate of 10 g/kg soil. The movement of this level of gypsum from topsoil to subsoil by rain and the decrement of $y_1$ of subsoil by this gypsum are fully expected from the results shown in Figs. 1 and 2.

With the foregoing results, it may be concluded that amelioration of subsoil acidity of Andosols by PG application in the topsoil is highly possible in nonallophanic Andosols, especially in light colored nonallophanic Andosols. Similar observations were also reported in some weathered soils\(^{1-4}\). The practical method of subsoil amelioration of nonallophanic Andosols by PG application in topsoil and the mechanism of the reduction of exchangeable acidity $y_1$ (exchangeable Al) by PG will be discussed in a forthcoming paper.

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References

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非アロフェン質黒ボク土の下層土酸性改良に対する
リン酸石膏の作土施用効果

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要約

強酸性下層土、非アロフェン質黒ボク土では、アルミニウムの過剰障害により下層土への根張りが制限され作物の生育・収量が著しく低下する。この下層土のアルミニウムの過剰障害をリン酸石膏の作土施用によって軽減することを試みた。供試土壌としては強酸性で腐植含量を異にする多腐植質黒ボク土（川渡）と淡色黒ボク土（北上）を用い、1）圃場に埋設した円筒試験でリン酸石膏と炭カルの降雨による移動速度の検討、2）オオムギとアルファルファの幅試験によるリン酸石膏と炭カルの酸性改良効果（アルミニウムの過剰障害軽減）を検討した。

川渡黒ボク土の作土（0−15 cm）に施用したリン酸石膏（1000 g/m²）は、5月（降雨 1012 mm）後下層土（15−75 cm）に約75%が移動したのに対し、炭カル（0.5 kg/m²）は約82%が作土に残留した。

強酸性非アロフェン質黒ボク土に対するリン酸石膏と炭カルの施用効果を検討したところ、腐植に富む川渡黒ボク土ではリン酸石膏施用によって pH (H₂O), 交換酸度 y₁ とも顕著な変化は見られなかったが、腐植の少ない北上土壌では pH は低下し、交換酸度 y₁ も著しく減少した。オオムギの伸長に対する施用効果は交換酸度 y₁ を反映し、北上土壌で顕著であった。また、炭カルの施用効果はリン酸石膏よりさらに大きかった。

リン酸石膏の作土施用による下層土酸性改良を想定し、主たる移動体質である石膏の下層土施用効果を検討したところ、リン酸石膏の実用的施用量（1000 g/m²）の10%程度からオオムギ根とアルファルファ根の下層土への伸長改善効果が見られた。この効果は腐植の少ない淡色黒ボク土で顕著であった。

リン酸石膏の作土施用による黒ボク下層土酸性改良の可能性が示唆され、その効果は腐植の少ない黒ボク土で特に顕著であると推定された。

キーワード：アルミニウム過剰障害、黒ボク土、交換酸度、リン酸石膏、下層土酸性。