Agricultural utilization of the apatite-phosphorus in pyroclastic flow deposits

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Abstract
In Abashiri District of eastern Hokkaido, Japan, much arable land leveled for agricultural use has subsoil layers that consist of Kutcharo pyroclastic flow deposits. These deposits in subsoil are generally firm and they inhibit the root development of arable crops. However, their available phosphorus (Truog-P) content is high (70-170 mg P_2O_5 /kg). Sources of phosphorus (P) in the pyroclastic flow deposits were previously evaluated as apatite. In 2007 and 2008, the utilization of the apatite-P in pyroclastic flow deposits in the subsoil was tried in a field cultivation experiment with sugar beet. Before the experiment, trenchers were used to thoroughly mix the pyroclastic flow subsoil with topsoil in a part of the field to promote root development (subsoil mixed plot) and the rest of the field was used as a control plot. During the cultivation, the changes of the soil available P and P uptake of sugar beet were measured. Subsoil mixing clearly improved root development. For the subsoil mixed plot, the yield of sugar was 30% higher, and the phosphorus uptake was 50% higher than the control plot in 2007. In 2008, also the increase of phosphorus uptake was observed for subsoil mixed plot although the yield was not improved. Under cultivation, it was observed that the soil Truog-P was increased and the pH was decreased in the subsoil mixed plot. These results suggested that the weathering of apatite-P in the pyroclastic flow deposits was enhanced in the subsoil mixed plot by the reaction with soil reactive Al and/or Fe and low pH condition. The weathering of apatite-P should increase the P uptake of the sugar beet. Thus the apatite-P should be an important P resource for agriculture.

Key Words
Apatite, phosphorus, pyroclastic flow deposits, sugar beet, utilization.

Introduction

In the Hokkaido region of northern Japan, much arable land has been leveled with backslope cutting and foreslope filling for large scale agriculture. This includes i) removing and storing the A horizon layer, ii) cutting and filling to create wide and gently sloping fields by grading, and iii) replacing the stored topsoil evenly to create an Ap horizon. Such procedures have made soil profiles irregular. In the Abashiri district of Hokkaido, Kutcharo pyroclastic flow deposits are widely distributed as parent material; the deposits are present at about a 40-50 cm depth from the soil surface as subsoil (Figure 1). The pyroclastic flow deposits are generally sandy and firm, so the development of crop roots in the subsoil has been inhibited (Nakamaru *et al.* 2008). Therefore pyroclastic flow deposits in the subsoil layer have been regarded as an inhibitor to agricultural production. However, it is also known that some volcanic materials such as tephras or pyroclastic flow deposits contain a significant amount of apatite phosphorus (apatite-P) (Nanzyo and Yamasaki 1998, Nanzyo 2002). Although its solubility is low (Engelstad *et al.* 1974), the existence of apatite has been reported for Pinatubo pyroclastic flow deposits in the Philippines (Nanzyo 2002), and for Unsen pyroclastic flow deposits in Japan (Nanzyo *et al.* 2003), and also for Kutcharo pyroclastic flow deposits in Abashiri area. The deposits contain 300-800 mg P_2O_5/kg of apatite-P, and 70-140 mg P_2O_5/kg has been evaluated as plant available (Nakamaru *et al.* 2008). The apatite-P is untouched phosphorus (P) resource and its utilization is important because recently the price of phosphate rock is soaring (Steven *et al.* 2008).

Apatite is ranked as an easily weathered mineral. We are trying to utilize the apatite in Kutcharo pyroclastic flow deposits in the Abashiri area. While apatite is considerably soluble in acid extracting solutions, the plant availability of apatite-P depends on many factors, such as soil conditions, types of plants and the properties of apatite (Rajan *et al.* 1996). In a previous study, it was reported that pigeon pea and chickpea could utilize apatite-P in Pinatubo pyroclastic flow deposits by releasing organic acids from their roots (Nakamaru *et al.* 2000). In our current study, we examined the apatite-P utilization of sugar beet while improving the physical properties of the pyroclastic flow deposit layer in the subsoil. Sugar beet was used as a test crop because it was one of the most important crops around Abashiri.

As the subsoil improvement method, we used a trencher to mix the pyroclastic flow deposit layer in the subsoil and topsoil layer (A horizon). Generally the trencher is used for the cultivation of Chinese yam (Dioscorea opposita naga imo strain) and edible burdock (Arctium lappa L. var. edule), and it can cultivate up to one meter depths. With the mixing of pyroclastic flow deposits and A horizon, we considered that the apatite weathering in the deposits could be enhanced by the reaction with active Al and Fe in the A horizon of Andisol. From the viewpoint of soil genesis, Walker and Syers (1976) reported that with time the apatite in the parent rocks was gradually converted into occluded, non-occluded and organic P. Because Andisol commonly contains a large amount of active Al and Fe (Shoji *et al.* 1993), the P released with apatite weathering should react with active Al and Fe in a manner similar to that described by Walker and Syers. It has also been reported that the reaction of apatite-P and active Al and Fe was promoted by an acidic condition (Nanzyo *et al.* 1997). Therefore, we investigated the weathering of apatite-P under cultivation with the changes of soil pH.

Methods

Cultivation experiment of sugar beet

A field cultivation experiment of sugar beet (Beta vulgaris ssp. vulgaris) was done in 2007 and 2008. Abashiri Experimental Farm of Tokyo University of Agriculture was used. The soil of this farm is classified as Typic Fulbudand. The experimental field had been leveled and the soil has an irregular profile. Surface soil is the A horizon of Andisol, but the soil profile has a pyroclastic flow deposit layer beginning at 40 cm from soil surface. This pyroclastic flow deposit is so firm that the fibrous root distribution of arable crops is generally limited in this layer. In 2005, trenchers were used to thoroughly mix pyroclastic flow subsoil with topsoil in a part of the field for Chinese yam cultivation, this area was used as the subsoil mixed plot and the rest of the field has been used as a control plot for the present study. Sugar beet plants were cultivated from May to October in 2007 and 2008. Before transplanting of Sugar beet the soil was fertilized using chemical fertilizer by conventional fertilization method in Abashiri area. In 2007, 17.5 kg of N, 40 kg of P_2O_5 and 11 kg of K_2O was applied, also, in 2008, 18.5 kg of N, 40 kg of P_2O_5 and 24 kg of K_2O was applied. At the harvest stage (October), sugar beet yield, the fibrous root development and the phosphate uptake were measured. The root distribution in the soil profile was determined by tracing the root in the profile onto a transparent plastic film. During the cultivation period, an auger was used to take soil samples from the field every month by dividing the soil layer into 10 cm intervals up to a depth of 90 cm. At the soil sampling, soil was sampled from three different places as replication.

For the soils sampled in May to October (the beginning of cultivation to the harvest period), pH (H_2O), acid oxalate extractable-Al, Fe (Alo, Feo) were measured. Acid oxalate extractable-Al and -Fe contents refer to the amount of Al/Fe-(hydr) oxides and Al/Fe-humus complex. They are regarded as active Al and Fe which are reactive components for phosphate adsorption (Parfitt 1978). Alo and Feo were measured by the method of Blakemore *et al.* (1981). The content of each chemical form of soil P was determined by the following methods. The soil available P amount was measured by the Truog method (Blakemore *et al.* 1981). Each chemical form of soil P (Al bound-P, Fe bound-P and Ca bound-P)was determined separately with the method of Chang and Jackson (1957).

Results

The yield and P uptake of sugar beet

The yield, plant dry weight, and P uptake of sugar beet are shown in Table 1 and 2. In 2007, the yield of sugar was 30% higher for the subsoil mixed plot than for the control plot (Table 1). Also, the P uptake of sugar beet was 50% higher for the subsoil mixed plot than the control plot (Table 2). However, in 2008, the tap root weight and the yield of sugar was lower in the subsoil mixed plot than the control plot (Table 1). This decrease of yield was possibly due to the Cercospora leaf spot (Cercospora beticola Saccardo) because the symptoms of this disease was commonly observed in the subsoil mixed plot from August to October in 2008. Also the increase of plant dry weight was smaller for the subsoil mixed plot than for the control plot from August in 2008 (Table 2). Although the yield was small, the P uptake from June to August was higher for subsoil mixed plot than the control plot in 2008 (Table 3). These results showed that the trenching procedure increased the P uptake of sugar beet by promoting the fibrous root development. Also, it was possible that the apatite-P in the pyroclastic flow deposits contributed to the increase of P uptake by sugar beet.

Table 1. The yield of sugar beet cultivated in 2007 and 2008. The values are the average of three replicated values and the standard deviation.

		Fresh tap root weight † (Mg/ha)	Sugar content† (%)	Sugar yield† (Mg/ha)
	Control	61.5±4.4	15.7±0.6	9.6±1.0
2007	Subsoil mixed	82.6±1.6	15.9±0.4	13.2±0.1
	Control	80.7±3.3	15.9±0.4	12.8±0.5
2008	Subsoil mixed	63.4±3.3	17.0±0.2	10.8±0.5

Table 2. Plant P uptake of sugar beet cultivated in 2007 and 2008. The values are the average of three replicated values and the standard deviation.

P-uptake (P_2O_5 g/plant)					
2007	2007.6.26	2007.7.24	2007.8.7	2007.9.4	2007.10.2
control	0.05±0.01	0.56±0.22	1.03±0.08	0.90±0.03	1.00±0.18
subsoil-mixed.	0.06±0.003	0.66±0.04	1.38±0.20	1.73±0.25	1.45±0.24
2008	2008.6.19	2008.7.17	2008.8.22	2008.9.24	2008.10.22
control	0.07±0.02	0.29±0.07	0.46±0.07	0.72±0.28	1.03±0.04
subsoil-mixed.	0.05±0.01	0.38±0.09	0.47±0.06	0.57±0.03	0.82±0.11

Changes of soil pH and available P during cultivation

The changes of the distribution of soil pH and available P (Truog-P) in the soil profile in later growth period are shown in Figure 1. The soil pH was changed by the trenching procedure. Although no big change was observed for the pH in the control plot, subsoil pH tended to be lower in the subsoil mixed plot than in the control plot (Figure 2).

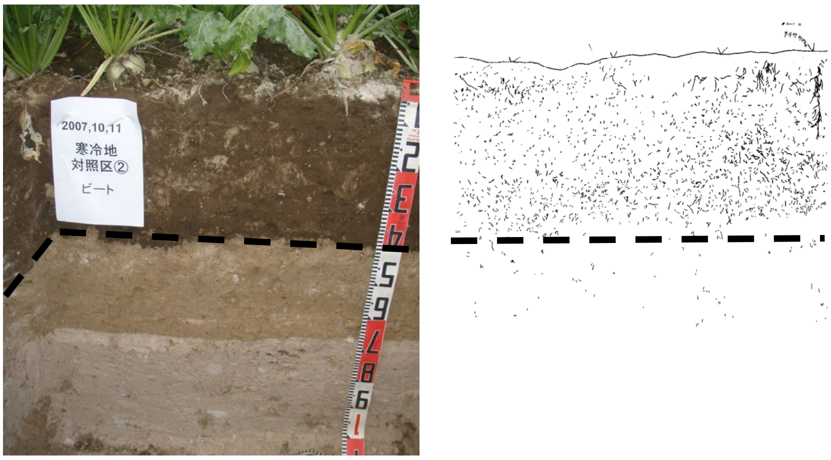

Figure 1. The soil profile morphology and the distribution of sugar beet fibrous roots. Dotted lines indicate the border of the A horizon and pyroclastic flow deposit layer (August 2007).

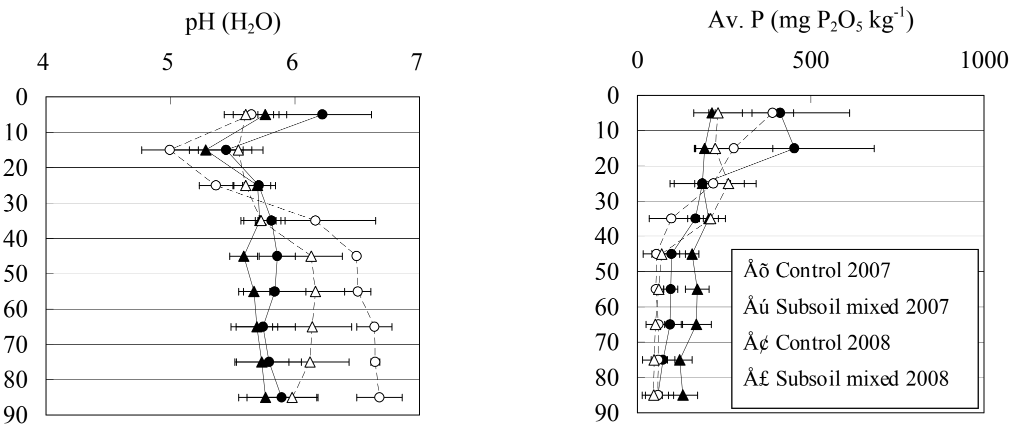

Figure 2. Changes of soil pH and available P distribution in soil profile in later growth period of sugar beet (October 17, 2007 and October 30, 2008). Horizontal and vertical axes indicate soil pH or available P and depth (cm). The values are the average of three replicated values and the error bars indicate the standard deviation.

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This tendency was observed more clearly in 2008. The trenching procedure should decrease the subsoil pH by the mixing with low pH topsoil. Soil available P tended to be high in the surface soil for both plots due to the usual P fertilization. For the control plot, no obvious change was observed for Truog-P content during cultivation. However, in 2007, for the subsoil mixed plot, Truog-P content was low in the subsoil (40-90 cm) in June but increased later in the growth period. From July to October, the Truog-P content of subsoil was higher for the subsoil mixed plot than for the control plot. In 2008, Truog-P content was higher for subsoil mixed plot during the plant growth period. These tendencies were correlated to the pH change shown in Figure 1; soil Truog-P content tended to be high for the low pH condition. It is known that low pH increases the dissolution of apatite-P (Nanzyo *et al.* 1997), therefore, it was considered that the weathering of the apatite-P in the pyroclastic flow deposits was enhanced by the mixing with low pH topsoil.

Conclusion

From the results of our field experiment, we showed that using a trencher before planting increased the P uptake of sugar beet by promoting root development and apatite weathering. The apatite weathering should be enhanced by the contact of apatite mineral to topsoil with low pH and high active Al and Fe contents. We considered that the reaction with apatite-P and active Al and/or Fe should enhance apatite dissolution by reducing P concentration in soil solution. The contribution of apatite-P for increase of soil available P was shown by two years of field experiment. The apatite-P should be important P resource for agriculture. More detailed information about the changes of soil P forms will be discussed in the conference.

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