PROBLEMS AND IMPROVEMENT OF VOLCANIC ASH SOILS IN JAPAN WITH REFERENCE TO THE WEATHERING SEQUENCE

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Characteristics of volcanic ash soils, obviously, closely relate to the rock types of parent ash. However, they are also strongly correlated with the weathering sequence of volcanic ash soils.

Under the Japanese climatic conditions, as a small amount of humus accumulates on the top surface layer, layer differentiation thus becomes clear and fairly good farming can be anticipated about 150 years after the eruption of a volcano. Soil texture consists mostly of sand of primary minerals and a very small amount of clay exists at this first stage of weathering.

After approximately 3,000 years of weathering, humus as well as clay contents increase. This clay part of soils consists mostly of allophane and free hydrous sesquioxides. Therefore, the highest phosphate fixation capacity of soils appears at this second stage.

The third stage of the weathering sequence is essentially a process of crystallization of these allophane and free hydrous sesquioxides to 2 : 1 or 1 : 1 type minerals. Soil humus content again decreases along with the high phosphate fixation capacity.

In the present paper, problems and improvement methods are discussed mainly along with these three stages of the weathering sequence of volcanic ash soils in Japan.

Occurrence of cobalt deficiency in ruminants in the grasslands of volcanic ash soils. Presentation of an example illustrating the first stage of the weathering sequence

1 Cobalt contents of herbage and soils of volcanic ash origin throughout Japan

In Japan the granitic soils found in some areas of Chugoku district, the western part of Honshu Island, have been considered to be the only cobalt deficient soils, on which the endemic nutritional disorder called Kuwazu (local Japanese name) occurs. The Kuwazu syndrome had already been studied and found to be due to cobalt deficiency in ruminants (Uesaka and Chang, 1953).

On the other hand, a nation-wide survey on the mineral composition of herbage and grassland soils was carried out in 1971–74 with the cooperation of soil scientists from 6 national research institutes (Research Council MAFF, 1978).

The results of the survey indicated that cobalt deficient areas were more numerous than formerly thought. In this survey, 35% of grasslands had herbage cobalt contents lower than 0.1 ppm and 20% lower than 0.07 ppm with a 8 : 2 grass-legume mixture condition. The areas considered as cobalt deficient by the above standards were concentrated on soil of volcanic ash origin where no cobalt deficiency was ever suspected because parent minerals of these soils are not rhyolitic but mostly andesitic. It is well known that there is a correlation between soil total cobalt and herbage cobalt and usually soil total cobalt contents of less than 5 ppm are insufficient to secure normal growth of ruminants (Kubota, 1964). Occurrence of cobalt deficiency in ruminants on rhyolitic volcanic ash soils in New Zealand and granitic soils in the United States and Japan was considered to result from low soil total cobalt contents. The survey showed that the suspected

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areas have soils mostly of andesitic volcanic ash origin and thus they have total cobalt contents higher than 5 ppm, the threshold value for the deficiency.

As mentioned before, although total-Co had been used as a parameter of occurrence of cobalt deficiency, the results of $HClO_4$-Co in Table 1 cast some doubt about this assumption.

HNO_3-$HClO_4$ digestion of soils does not destroy most of the primary minerals of the sand fraction of soils. This is the reason why $HClO_4$-Co is always lower than total-Co. Cobalt in crystalline structure of primary minerals is so tightly combined that it has no opportunity to become available to herbage. As shown in Table 1, the ratios of $HClO_4$-Co to total-Co ranged from 94.5 to 18.3%. The ratio, however, is negatively correlated with the sand fraction of soils (Fig. 1) and the larger the sand fraction, the lower the ratio.

Table 1 Cobalt content of volcanic ash soils from different volcanoes

	Origin	Total-Co		$HClO_4$-Co		$HClO_4$-Co*/Total-Co
		Range	Average	Range	Average	
		ppm	ppm	ppm	ppm	%
1	Meakan-Mashu	5.0 – 7.0	6.1	2.0 – 3.9	3.0	47.8
2	Tokachi		10.5		5.2	49.5
3	Usu	13.8 – 19.9	16.9	6.5 – 13.2	9.8	56.2
4	Tarumae		24.5		5.0	20.4
5	Shimokita**	10.3 – 11.1	10.7	8.1 – 7.9	8.0	74.9
6	Towada-Hakkoda	4.3 – 9.3	6.8	1.3 – 4.2	2.8	37.7
7	Chokai		7.5		6.7	89.3
8	Iwate	21.2 – 42.3	29.8	8.9 – 24.3	16.0	52.8
9	Zao	20.2 – 21.3	20.8	3.2 – 4.4	3.8	18.3
10	Nasu**	16.9 – 26.3	20.3	5.3 – 17.4	9.8	47.3
11	Fuji	19.9 – 29.5	24.7	19.1 – 27.4	23.3	94.5
12	Haruna	21.4 – 24.8	23.1	7.8 – 8.3	7.9	34.3
13	Asama		19.1		5.4	28.3
14	Daisen-Sanbe	6.9 – 8.8	7.9	3.7 – 6.3	4.9	62.6
15	Yufu		12.6		6.6	52.4
16	Kujyu		18.3		12.4	67.8
17	Unzen		11.7		7.0	59.8
18	Aso	17.3 – 25.4	22.3	11.3 – 16.0	14.9	68.0
19	Kirishima	10.3 – 24.7	16.1	5.0 – 9.1	6.6	42.7
20	Sakurajima	9.8 – 14.1	12.0	3.7 – 4.0	3.9	33.1
21	Kaimon		18.2		12.3	67.6

Note: * average $HClO_4$-Co/average Total-Co x 100
** The origin is unknown.

As mentioned previously, in soils at the early stage of weathering, sand/clay ratio of soil is high, whereas the ratio decreases in soils at the advanced stage of weathering. Thus the ratio of $HClO_4$-Co to total-Co is a reflection of the weathering sequence of soils (Kobayashi *et al.*, 1964).

As far as the volcanic ash soils are concerned, soil total-Co might hardly be a reliable parameter for estimating the availability of Co because of the wide variation in the weathering sequence.

An example of the relationship between soil cobalt and herbage cobalt is shown in Table 2. As the soil total-Co contents exceeded 5 ppm, orchardgrass showed cobalt contents lower than 0.07 ppm, the minimum value for ruminant needs. $HClO_4$-Co of these two soils is much lower than 5 ppm, the maximum value commonly associated with cobalt deficient soils. The level of herbage cobalt is considered to be in accordance with $HClO_4$-Co but not with total-Co.

Based on these results, the volcanic ash soils which cause cobalt deficiency are roughly divided into three groups;

Group A: total-Co 5 ppm

Group B: total-Co 5 – 10 ppm, $HClO_4$-Co 5 ppm

Group C: total-Co 10 ppm, $HClO_4$-CO 5 ppm

Group A soils have rhyolite as their parent rock and are deficient soils irrespective of the weathering sequence. But very few cases are actually recorded in Japanese grassland farming. Group B and C soils have andesite to basalt as their parent rocks and correspond to the intermediate to early stage of the weathering sequence.

Group B soils are most important in relation to cobalt deficiency in Japanese grassland farming. Soils derived from the volcanoes Meakan-Mashu, Towada-Hokkoda and Daisen-Sanbe belong to this group.

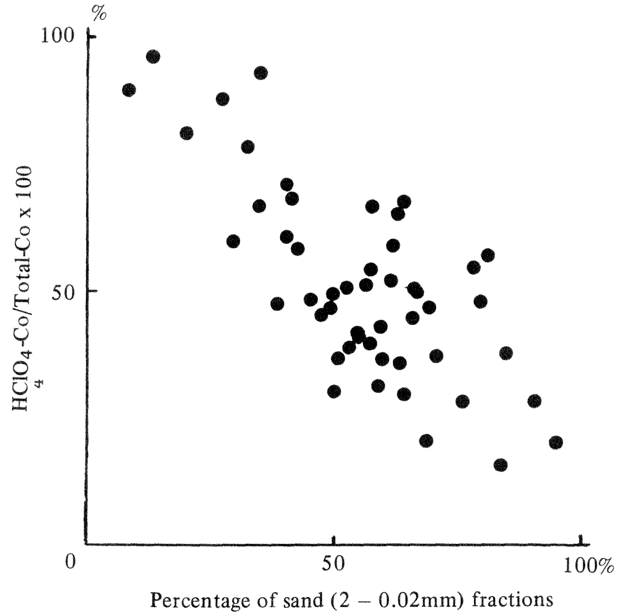


Fig. 1 Relationship between soil sand fraction and $HClO_4$-Co/Total-Co ratio.

Table 2 Cobalt content of herbage and soils in pastures of Meakan-Mashu volcanic ash soil

Location	Orchardgrass-Co		Soil-Co	
	Range	Average	Total-Co	$HClO_4$-Co
	ppm	ppm	ppm	ppm
Nemuro	0.03 – 0.05	0.04	6.4	3.9
Teshikaga	0.03 – 0.06	0.05	6.0	2.6

2 Cobalt deficiency of ruminants observed on Meakan-Mashu volcanic ash soil (Kobayashi *et al.*, 1980).

The Stock Farm of Tamagawa University is situated at Teshikaga, Konsen district, Hokkaido where the soil belongs to the Meakan-Mashu series which was classified as one of the cobalt deficient soils. A feeding experiment was carried out at the Stock Farm to determine whether cobalt deficiency occurs in ruminants fed on herbage grown there. On June 21, 1978, 11 Suffolk X Corriedale cross-bred lambs were divided into two groups on the basis of body weight. The two groups were fed only grasses grown there. The grasses showed 0.065 ppm or less Co contents on an oven-dry basis. Deionized water was available *ad libitum.* A group of 7 lambs was given commercial mineral mixture without cobalt addition and the other group (control) was given the same commercial mineral mixture but containing about 0.01% Co for free consumption. Each lamb was weighed and blood tests were performed every two weeks. The experiment was run for 52 weeks. The results are shown in Fig. 2.

Between the 20th and 22nd week the animals to which Co had not been administered began to show a gradual decrease in weight as shown in Fig. 2. Because of extreme emaciation, 3 out of the 7 animals which had not received Co were slaughtered to perform an autopsy during the course of this experiment. The control animals gained an average of 17.7 kg in 44 weeks, whereas the remaining 4 animals which had not received Co in the diet lost 0.5 kg/head. Clinical, pathological and biochemical findings in the animals which did not receive Co showed ruminant Co deficiency.

The above results indicated that serious cobalt deficiency developed in all the animals whose diet was devoid of Co. Although such cobalt deficiency had not yet been reported in the district, the result of this experiment suggests that such deficiencies might have remained undetected.

After the results of these experiments, cobalt content of mineral mixtures sold in Japan was raised up to 100 ppm instead of the former 10 ppm Co-mineral mixtures. Farmers' complaints about low milk production and low body weight gains in this district eventually ceased. No cobalt deficiency of ruminants is believed to exist in Japan at present.

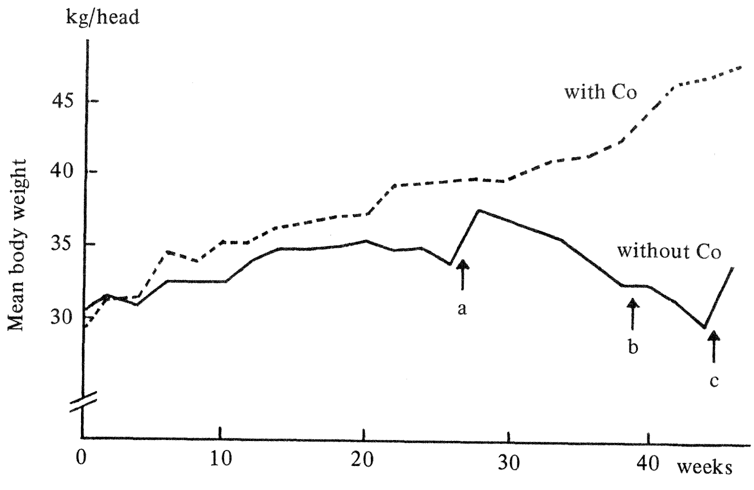


Fig. 2 Growth of lambs with and without Co administration by mineral mixtures.

Note: a; lamb slaughtered on Dec. 26.
b; lamb slaughtered on March 23.
c; lamb slaughtered on April 29.

Improvement of volcanic ash soils by broadcasting application of phosphate. Improvement method at the second stage of the weathering sequence

The low fertility of volcanic ash soils at the second stage of the weathering sequence is attributed mainly to the low availability of phosphorus and the higher phosphorus fixation which is associated with the existence of greater quantities of hydrous aluminum oxides of allophane, the main clay mineral of these soils. If water-soluble phosphate is applied to the soil, it is easily fixed as aluminum phosphate and hardly becomes available to crops. Only 10 to 20%of applied phosphate is absorbed by plants whereas the rest is fixed by the soil. As a result, almost negligible amounts of available phosphorus are commonly found in newly reclaimed Ando soil fields where there is no history of phosphate application.

These characteristics of volcanic ash soils do not change if the soils are left under natural conditions. But they change gradually during cultivation. During the initial ten to twenty years after reclamation of virgin lands, phosphorus fixation of the soils decreases, available phosphorus increases and thus the fertility of the soil increases (Table 3) (Smith and Leeper, 1969). This phenomenon which is the result of the inactivation of aluminum by accumulation of phosphorus may also be due to crystallization of free hydroxy aluminum oxides or downward removal of these aluminum compounds by humus transformation during cultivation (Takahashi, 1966).

These phenomena are usually designated as the "maturing process of volcanic ash soils" in Japan. Because of these changes in soil chemical properties, fertility is improved in mature soils.

Table 3 Changes of soil chemical properties in virgin and mature soils

	Virgin soil	Mature soil	Difference between means sig. at
P absorption coefficient*	2,720 ± 20	2,380 ± 190	0.5% level
Al-extracted, mg/100g soil	1,177 ± 95	523 ± 183	0.1% level
Al-type P, ppm/soil	675 ± 78	1,058 ± 211	0.1% level
Truog's available P, ppm/soil	11 ± 3	22 ± 13	5% level

Note: * The coefficient is defined as follows: A 2.5% neutral ammonium phosphate solution is added to the soil in the ratio of 1:2.5, it is allowed to stand overnight with intermittent shaking, filtered and analysed for P_2O_5 in the filtrate. The P_2O_5 absorbed by soil is calculated and expressed as P_2O_5 mg per 100g soil on an oven-dry basis.
Kuroishibara volcanic ash soil is used.

1 Broadcasting application of phosphate; similarities and differences of soil chemical properties with maturing process

The amount of phosphate in the broadcasting application is usually based on the phosphate absorption coefficient. For instance, P_2O_5 equivalent to 10% of the coefficient is applied to the soil. The broadcasted phosphate is plowed, incorporated and mixed with soil thoroughly. Usually 1,000 kg of P_2O_5/ha or 5,000 kg of fused phosphate/ha are applied to a depth of 10 cm in the plowing layer. After this practice, a very small amount of basal phosphate is applied in band.

Phosphate application decreases soil aluminum (Fig. 3), but the rate of the decrease is far lower compared to the decrease in aluminum in mature soil. Ten percent application of phosphate as shown in Fig. 3 is equivalent to 0.27 g P_2O_5. On the other hand, the estimated amount of phosphate accumulated in the mature soil may not exceed 0.5 g P_2O_5 during cultivation. Thus we have to consider that the broadcasting application of phosphate differs from the maturing process which includes inactivation of soil aluminum by some other mechanisms as mentioned before (Smith and Leeper, 1969).

Soil chemical properties of the field 3 years after the broadcasting application of phosphate were determined (Table 4).

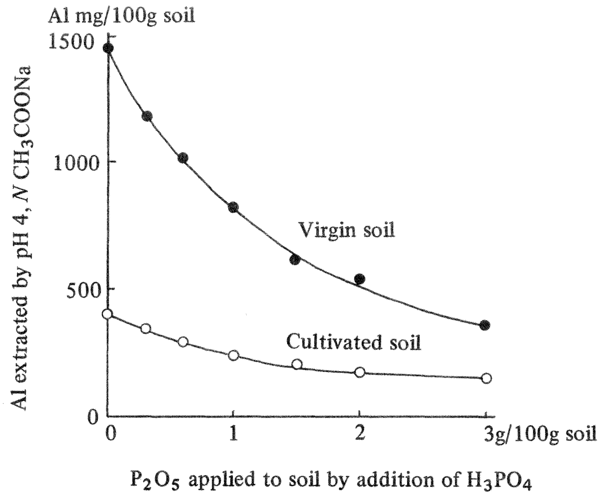


Fig. 3 Changes of extractable Al by addition of H_3PO_4

Table 4 **Soil chemical properties after 3 years of broadcasting application of phosphate at the rate of 10% of phosphate absorption coefficient***

	Ca-P	Al-P	Fe-P
	ppm	ppm	ppm
No broadcasting application of phosphate	2.6	192	83
Broadcasting application of phosphate	7.0	563	205

Note: * During 3 years, wheat, corn and potato were rotated successively with small amount of phosphate application in band.
Kuriyagawa volcanic ash soil is used.

The largest amount of phosphorus remaining in the soil was mainly of the Al-type followed by the Fe-type. Very small quantities of Ca-type of P were found, which had been considered as the only available form of soil P under acidic soil conditions (Yamamoto, 1965). However, the trend of the increase in the amount of Al-type P by the broadcasting application is almost the same as that during the maturing process as seen in Table 3.

Recoveries of available phosphorus applied in band were examined in the fields with and without broadcasting application of phosphate (Table 5). Higher recoveries of phosphate applied in band were observed in the plot that received the broadcasting application of phosphate (Yamamoto and Takahashi, 1967). This is a reflection of the decrease in aluminum activity following broadcasting application as seen in Fig. 3.

On the basis of these results, it was considered that the changes of soil chemical properties induced by the broadcasting application of phosphate were not exactly but almost identical with the changes occurring during the maturing process of volcanic ash soils. These consist of a lowered activity of soil aluminum, accumulation of Al-type phosphorus, increased amount of available phosphorus and also increased recovery of applied phosphorus in available form.

Table 5 Recovery of available phosphorus applied in band with and without broadcasting application of phosphate

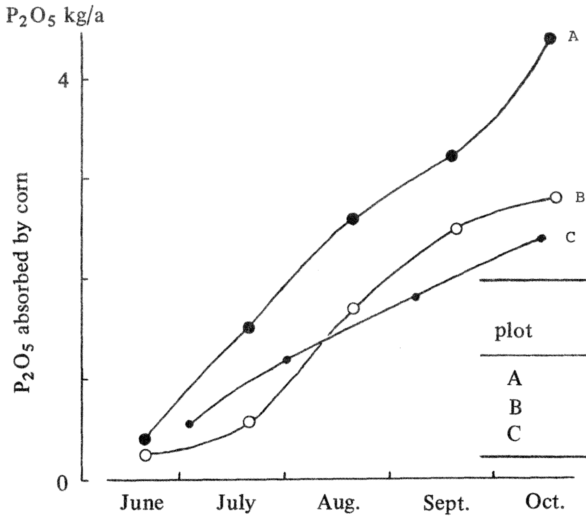
	Truog's P		
	in between bands	band	difference
	ppm	ppm	ppm
No broadcasting application of phosphate	0	6	6
Broadcasting application of phosphate	106	128	22

Note: Toshima volcanic ash soil is used.

2 Broadcasting application of phosphate and crop growth

Although several field trials have been analysed already, the results of two field experiments are presented in this paper.

Using corn, a field experiment was carried out to determine whether Al-type P in volcanic ash soils was available to crops or not (Fig. 4)(Takahashi and Yamamoto, 1967). Two plots used in this experiment had been subjected to broadcasting application of phosphate 6 years prior to the experiment; plot A, to which a phosphate equivalent of 10% of the phosphate absorption coefficient was applied, and plot B, which received half the amount of phosphate. Al-type P was 296 ppm/soil and 192 ppm for plots A and B, respectively. In plot C, a virgin soil field, 96 mg Al-type P was found. In band, 20 kg/ha P_2O_5 was applied to plots A and B, whereas 150 kg P_2O_5 was applied to plot C. At the early stage of growth, P_2O_5 absorbed by corn from plot C was higher than that of plot B reflecting the larger amount of phosphate applied in the band. However, much larger amounts of P_2O_5 were absorbed by corn in plots A and B at the later stage of growth. Therefore, the accumulated phosphorus, expressed as Al-type, should be con-



plot	grain kg/a	grain/straw
A	72	0.98
B	64	0.89
C	64	0.77

Fig. 4 P_2O_5 absorption pattern of corn at different Al-type P levels with different basal application rates of P_2O_5.

sidered as the available form at the later stage of crop growth when extended root systems can absorb less soluble soil phosphorus.

Another example of availability and plant absorption of soil phosphorus is presented in Fig. 5 (Takahashi and Yamamoto, 1967). The amount of P_2O_5 absorbed by corn was plotted against Al-type P in surface soil. The amount of P_2O_5 applied in band was 20 kg/ha for all plots. The finding that the later the growth stages of corn, the higher the regression coefficients, suggests that accumulated soil phosphorus, expressed as Al-type, is becoming more important at the later stage of crop growth.

The grain yields of corn in Fig. 5 are not only correlated with total dry matter production but also with grain/straw ratio of corn (Table 6). On the other hand, a higher grain/straw ratio can be obtained if phosphorus absorption by plant is larger at the later stage of growth. Thus correlation between grain/straw ratio and P_2O_5 in grain/P_2O_5 in total dry matter was also high (r=0.86, sig. at 0.1% level).

From the agronomic viewpoint, the higher grain/straw ratio makes it possible to achieve a better grain yield with a higher plant density. The LAI of corn was not examined in this experiment, however, these results indicate that unit grain yield can be obtained at lower LAI values under higher grain/straw ratio conditions. Therefore, higher density of plants could be cultivated with optimum LAI for maximum yield production of corn.

Even though the rate of this broadcasting application of phosphate is higher than that of usual band application, good economic return by this method has been recorded, especially for vegetables. As shown in Fig. 5, residual effects persist at least for 6 years, and cultivation of at least one or more vegetables is a very common practice during the 6-year rotation in Japanese farming. Therefore, yield increase of the other field crops in the rotation is considered to merely compensate for the production costs.

At present, this method is widely used by the Japanese farmers and fairly good farming became very common on volcanic ash soils with high phosphorus fixation at the second stage of the weathering sequence.

Table 6 Relationship between grain yield and dry matter production as well as grain/straw ratio of corn

	r
Grain yield *vs*. total dry matter production	0.98***
Grain yield *vs*. grain/straw ratio	0.89***

Note: *** Significant at 0.1% level.

Occurrence of molybdenum deficiency in soils of volcanic ash origin. Molybdenum availability in soils at the second and third stages of the weathering sequence

In Iwate prefecture, molybdenum deficiency was observed in legumes at least as far as nitrogen fixation is concerned. Thus samples of red clover leaves and rhizospheric soils were taken from two different soil series (Iwate-san and Hizume soil series). Both soils were derived from volcanic ash origin. Iwate-san soils are considered to be at the second stage and Hizume soils at the third stage of the weathering sequence. Molybdenum deficiency in legumes was only observed on Hizume soils but not on Iwate-san soil fields. Results of analysis are presented in Table 7.

Occurrence of Mo deficiency is confirmed by the presence of significantly lower leaf Mo content in Hizume soils. On the contrary, average contents of total Mo and available Mo of Hizume soils were significantly higher than those in Iwate-san soils (Takahashi, 1972). This reverse relationship can be attributed mainly to two causes.

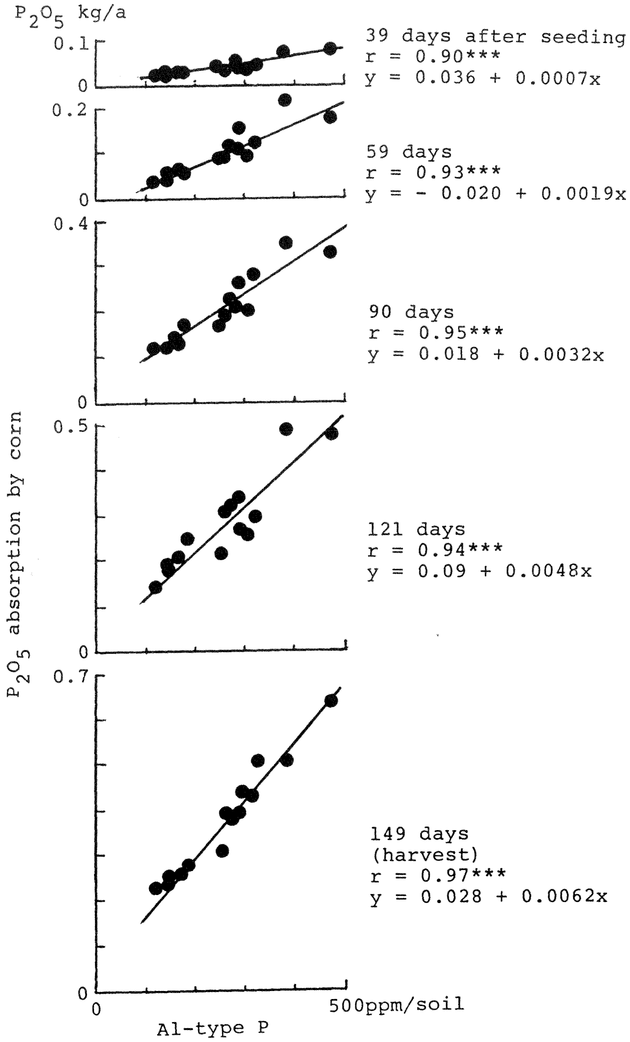


Fig. 5 Relationships between soil Al-type P and P_2O_5 absorption by corn at different growth stages.

Note: Grain yield;	Highest	103 kg/a
	Lowest	43 kg/a
Variety;	Ko 7 (Japanese F_1 hybrid)	
Population of plant;	830/a	

First, changes in the pH of the filtrate during Grigg's extraction could be responsible for the lower availability of Mo in Iwate-san soils. The average pH for filtrates of Iwate-san soils was 6.48 whereas that for Hizume soils, was 4.17. Since the initial value of pH was 3.3, it is apparent that large pH changes occurred during the extraction. Consequently the effect of pH of ammonium oxalate on Mo extraction from soils was studied (Fig. 6).

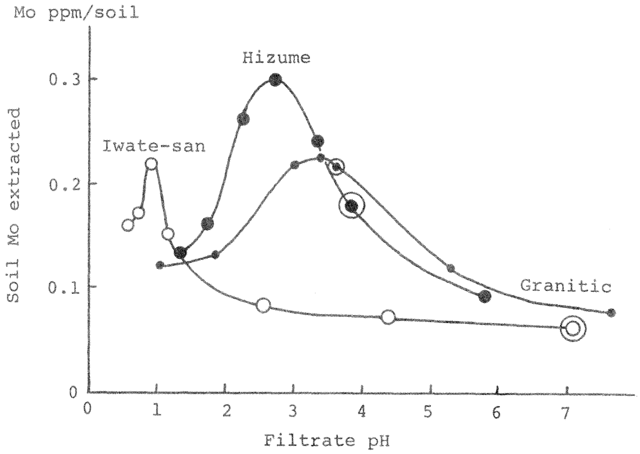


Fig. 6 Effect of pH of 0.55N ammonium oxalate on extraction of soil Mo.

Note: Double-circled dots indicate the results obtained by ordinary pH 3.3 extraction.
Left three dots of Iwate-san soil were obtained by HCl additions to the oxalate solution.

In Iwate-san and Hizume soils, the highest amount of Mo was not extracted by ammonium oxalate at pH 3.3 but rather at much lower pH values even when the –COOH concentration remained constant. In the filtrate at pH 0.92 the amount of Mo extracted from Iwate-san soils was 3.16 times greater than that extracted by customary ammonium oxalate at pH 3.3 which resulted in a filtrate with a pH of 7.07. For Hizume soils, 1.76 times as much Mo was extracted in a filtrate at pH 2.70 as obtained by extraction at pH 3.3 which resulted in a filtrate with a pH of 3.83. The highest yield of Mo in granitic soils was obtained by the customary extraction at pH 3.3. Only a very small change in the pH of the filtrate was observed in this case. Results obtained by the customary ammonium oxalate extraction at pH 3.3 tend to underestimate soil available Mo in these two soils, especially in Iwate-san soils. As mentioned previously, the highest phosphate fixation for which free hydrous sesquioxides are responsible appears in soils at the second stage of the weathering sequence. The large pH changes in Iwate-san soils during extraction could result from the dissolution of these sesquioxides. In Iwate-san soils, free hydrous Al oxides are greatly responsible for the large changes because the content of free hydrous Fe was lower than that in Hizume soils (Takahashi, 1972).

Second, it is known that free hydrous Fe oxides are important for estimating the availability of soil Mo, especially if acidic ammonium oxalate is used for soil extraction. The free hydrous Fe oxides are thought to combine with soil Mo to produce an unavailable form of Mo (Smith and Leeper, 1969) This Fe-type Mo, however, is dissolved in the acidic ammonium oxalate solution (Grigg, 1960).

Fixation of Mo by soils plays an important role in Mo absorption of crops. Because phosphate rocks and serpentine rocks contain Mo (Yamazaki *et al.*, 1959), the application of phosphate fertilizers results in supplying Mo at the same time. Mo quantities in phosphate fertilizers sometimes exceed those removed from soils by crops (Yamazaki *et al.*, 1959). So Mo nutrition of crops should depend partly on the degree of Mo fixation of soils.

A pot experiment was performed using virgin soils of the two soil series to determine the effect of Mo application on the Mo content of red clover leaves (Uesaka and Chang, 1953). Mo as $Na_2MoO_4 \cdot 2H_2O$ was added to the upper half of pot soil at a concentration of 0.7 ppm/soil. Soil pH was adjusted with and without $Ca(OH)_2$ addition. Results are given in Fig. 7.

Remarkably low Mo recovery in plant was observed in Hizume soils compared with that in Iwate-san soils. This may explain the low content of leaf Mo with high available Mo in Hizume soils as shown in Table 7.

As already mentioned, weathering from the second to the third stage is essentially a process of crystallization of free hydrous sesquioxides and allophane to 2 : 1 and 1 : 1 type minerals. During the process, the hydrous sesquioxides crystallize with age and Mo might become occluded by Fe and hence unavailable. This may also explain the low leaf Mo content in spite of the high total content of Mo in Hizume soils.

Irrespective of the soil chemical analysis, volcanic ash soils at the third stage of the weathering sequence tend to be deficient in Mo, even though the parent ashes and soils have higher total Mo contents. There is an obvious relationship between the availability of soil Mo and the degree of Mo fixation, free hydrous Fe content and modes of Mo release relating to pH of ammonium oxalate extract. These are the reflection of changes in the nature of soils at the advanced stage of the weathering sequence. These phenomena should be considered carefully in order to identify Mo deficient soils and apply sufficient but not excessive amounts of Mo to avoid toxicity for grazing ruminants.

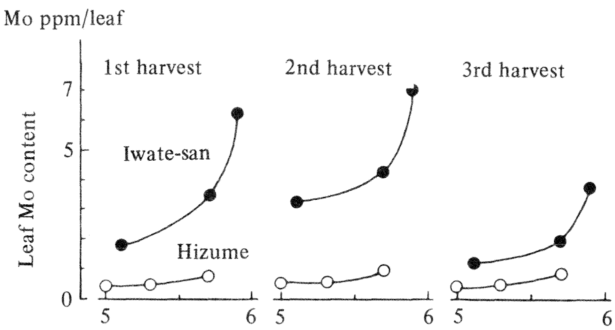


Fig. 7 Leaf Mo content of red clover at 0.7 ppm Mo application to pot soils.

Note: Plastic pot, depth 30 cm, diameter 25.5 cm was used in 4 replications. Twelve red clover (*var.* Kenland) seeds were planted on May 15. After 3 weeks, plants were thinned to 6/pot and grown to November. Tissue was harvested at 3 dates (July 17, Aug. 29, Nov. 4) and leaf Mo was determined. Pots were watered with deionized water.

Table 7 Mo content of red clover leaf and chemical properties of soils

	Leaf Mo	Soil pH (water)	Total Mo	Available Mo*	Free hydrous Fe oxides
	ppm		ppm	ppm	Fe mg/100g
Iwate-san	1.13 ± 0.83	5.7 ± 0.6	0.74 ± 0.25	0.064 ± 0.030	238 ± 145
Hizume	0.39 ± 0.28	5.4 ± 0.4	2.13 ± 0.71	0.216 ± 0.114	966 ± 221
Difference between means sig. at	1% level	n.s.	1% level	1% level	1% level

Note: * Grigg's extraction, extracted by pH 3.3, 0.55*N* ammonium oxalate.

References

1) GRIGG, J.L., (1960): The determination of molybdenum in the soils of New Zealand. I. Soils of the North Island. *N.Z.J. Agric. Res.* **3**, 69 – 86.
2) KOBAYASHI, Y., ISHII, T. and TAKAHASHI, T., (1980): Occurrence of cobalt deficiency of ruminants in the grasslands of volcanic ash soils. *Jpn. Agric. Res. Quart.* **14**, 63 – 67.
3) KUBOTA, J., (1964): Cobalt content of New England soils in relation to cobalt levels in forages for ruminant animals. *Soil Sci. Soc. Amer. Proc.* **28**, 246 – 251.
4) RESEARCH COUNCIL, MAFF (1978): Studies on distribution of minerals in the grasslands of Japan. *Research Publication* **106**, 1 – 208.
5) SMITH, B.H. and LEEPER, G.W., (1969): The fate of applied molybdate in acidic soils. *J. Soil Sci.* **20**, 346 – 254.
6) TAKAHASHI, T., (1965): Aluminum in volcanic ash soils, Changes in physico-chemical properties of soils by cultivation. *Bull. Kyushu Natl. Agric. Exp. Stn.* **10**, 205 – 246.
7) ———— (1972): The relationship between available molybdenum in soils of volcanic ash origin and the molybdenum content in red clover leaves. *Plant Soil* **37**, 665 – 674.
8) ———— and YAMAMOTO, T. (1967): Corn growth after long continued-croppings by an initial heavy application of phosphatic fertilizers, availability of residual phosphorus in a volcanic ash soil. *Bull. Tohoku Natl. Agric. Exp. Stn.* **37**, 139 – 169.
9) UESAKA, S. and CHANG, T.Y., (1953): Studies on the trace elements on farm animal feeding (1). *Bull. Res. Inst. Food Sci., Kyoto Univ.* **11**, 102 – 114.
10) YAMAMOTO, T. and MIYASATO, S., (1971): Studies on soil productivity of phosphate mixture in Iwate volcanic ash soil. *Bull. Tohoku Natl. Agric. Exp. Stn.* **42**, 53 – 92.
11) ———— and TAKAHASHI, T., (1967): Heavy application of phosphatic fertilizer on upland soils. 2. Changes of soil conditions and phosphorus uptake by corn. *Bull. Tohoku Natl. Agric. Exp. Stn.* **35**, 19 – 36.
12) YAMAZAKI, T., SEINO, K., AOBA, K. and ADACHI, M., (1959): Molybdenum content of phosphate rocks, serpentine, fused phosphate and superphosphate, *Bull. Hokuriku Natl. Agric. Exp. Stn.* **2**, 25 – 40.

Discussion

Wada, K. (Japan): In one of the figures you showed the correlation between soil Al-type phosphorus and P_2O_5 absorption by corn. At what stage of growth of the corn did you make the Al-phosphorus determination? Can you use the Al-phosphorus value for predicting the necessary rate of phosphorus application?

Answer: Al-type phosphorus was analysed in soils sampled just after harvesting of corn. We believe that Al-phosphorus value can be used as one of the parameters of phosphorus application rate although in our experiment we did not use it.

Watanabe, I. (IRRI): In Japan we use the phosphorus absorption method in the case of Andosols whereas in other countries, for instance in the U.S.A. the phosphorus absorption isotherm technique is being applied. Since the latter method is rather tedious, do you think that the Japanese conventional method could be applied to the study of tropical soils?

Answer: Phosphorus absorption by soils follows the Freundlich isotherm equation. Therefore, the difference between 2,500 and 3,000 is much larger than the difference between 1,000 and 1,500 in the coefficients as far as the capacity of phosphorus fixation of soils is concerned. This shortcoming is however compensated by the fact that the method enables to run a large number of determinations. Also, as shown by Dr. Amano, if phosphorus fixation is very high, the Japanese method is more suitable than the American method. I believe that the choice of the method depends on the situation. In the tropical soils where phosphorus fixation is high the Japanese method could be used. Also as you may know, the measurement of phosphorus fixation is only important for soils with a high phosphorus fixation.

Shoji, S. (Japan): 1) What are the most important cobalt-bearing minerals in your soil samples? 2) You divided the ash-derived soils into three groups, A, B, C, and you mentioned that group B soils are important in relation to cobalt deficiency in Japanese farming. Could you tell me why B group soils are so important and not A group soils.

Answer: 1) Mafic rock type parent materials are most important. Because of the resemblance of ionic radius between magnesium and cobalt, cobalt is concentrated in mafic rocks. In soils, however, cobalt is concentrated in the manganese oxides precipitates which are separated during the weathering process of soils. This type of cobalt is considered to be available to plants. In this regard, please refer to Dr. Kobayashi's paper which will be published in the forthcoming issue of the Journal of Soc. Soil Manure,Japan. 2) Group A soils are also important as cobalt deficient soils. Since this type of soil is seldom observed in Japanese volcanic ash soils, group B soils are more important under the Japanese conditions.