Occurrence of Cobalt Deficiency of Ruminants in the Grasslands of Volcanic Ash Soils

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Since 1934, cobalt has been recognized as an essential mineral for the normal growth of ruminant animals. Cases of the malnutrition of ruminants, formerly known by different local names, has been revealed that the deficiency of cobalt is responsible for the nutritional disorder. In Japan the granitic soils in some areas in Chugoku district, the western part of Honshu Island, have been considered to be the only cobalt deficient soils, on which endemic nutritional ailment called Kuwazu, the local Japanese name for this ailment, occurs. The Kuwazu syndrome had already been studied and was clarified as cobalt deficiency of ruminants[9].

On the other hand, a nation-wide survey on mineral compositions of herbages and grassland soils was carried out in 1971–74 with the cooperation of soil scientists from 6 national research institutes[8].

The results of the survey indicated that much more cobalt deficient areas would be expected than formerly believed. In this survey, 35% of grasslands had herbage cobalt contents lower than 0.1 ppm and 20% lower than 0.07 ppm assuming 8 : 2 grass-legume mixture condition. The areas considered as cobalt deficiency by the above standards were concentrated on soils of volcanic ash origin where no cobalt deficiency was ever suspected because parent minerals of these soils are not rhyolitic but mostly andesitic[5]. It is well known that there is a correlation between soil total cobalt and herbage cobalt and usually soil total cobalt less than 5 ppm is deficient for the normal growth of ruminants[6] Occurrence of cobalt deficiency of ruminants on rhyolitic volcanic ash soils in New Zealand and granitic soils in the United States and Japan was considered as a result of low soil total cobalt contents. The suspected areas by that survey, however, have soils mostly of andesitic volcanic ash origin and thus they are the soils with total cobalt contents higher than 5 ppm, the threshold value for the deficiency.

Experiment I. Availability of soil cobalt and characteristics of cobalt deficient Volcanic Ash Soils

The soil samples were collected from A-horizon of virgin soils or 0–5 cm layer of grassland surface soils. These soils are of all volcanic ash origin from 21 representative volcanoes where grassland farming is of major importance in the land use. The places of sampling are given in Table 1 and Fig. 1. The soil samples were air-dried, passed through a 2 mm plastic sieve and ground to finess in an agate mill. Cobalt contents of samples were determined colorimetrically using *o*-nitrosocresol method on both the solutions obtained from Na_2CO_3 fusion (total-Co) and HNO_3-$HClO_4$ digestion ($HClO_4Co$).

Soil cobalt contents after the above two digestions are shown in Table 1. The total-Co contents ranged from 4.3 to 42.3 ppm. Excepting one sample from Towada-Hakkoda

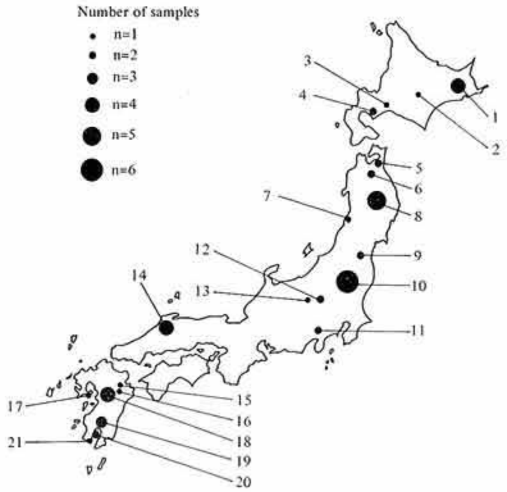

Fig. 1. Places of soil sampling
Note: Numbers in the figure infers those in Table 1.

origin, all the other 47 samples gave the contents higher than 5 ppm. Thus, according to the conventional interpretations, the occurrence of cobalt deficiency is scarcely expected in the grasslands of volcanic ash soils in Japan.

Mineralogical influences on the total-Co contents, however, are observed in the results of Table 1.

The total-Co contents are affected by the amounts of heavy minerals in the soil parent materials. The major part of cobalt in parent rocks is in the mafic minerals, especially in olivine[7]. It is already reported that the olivine type volcanic ash soils are derived from Volcanoes Fuji, Iwate, Aso and Kaimon[5]. Total-Co contents of these basaltic volcanic ash soils are apparently higher than those of other soils. On the other hand, soils developed from acidic rocks as the parent materials have lower cobalt contents[4] Soils derived from Volcanoes Meakan-Mashu, Towada-Hakkoda and Daisen-Sanbe have medium total-Co contents because of andesitic ejecta of these volcanoes[2].

As mentioned before, total-Co has been

Table 1. Cobalt contents of volcanic ash soils from different volcanoes

Sample No.	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	6.5–13.0	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	Kujiu	—	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	Sakurazima	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 × 100 ** The origin is unknown.

used as a parameter of occurrence of cobalt deficiency, however, the doubt was brought by the results of $HClO_4$-Co in Table 1.

HNO_3-$HClO_4$ digestion of soils does not destroy most of the primary minerals of 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 possibilities to become available for herbages. 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. 2). Increasing the sand fraction, the lower is the ratio.

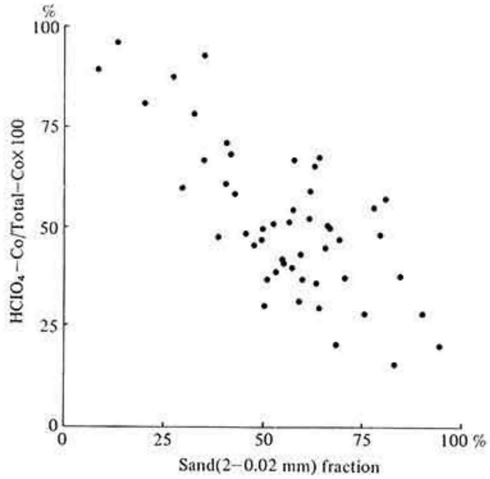

Fig. 2. Relationship between soil sand fraction and $HClO_4$-Co/Total-Co ratio

The sand fraction of soils is closely related to the weathering sequence of volcanic ash soils. In soils of the early stage of weathering, sand/clay ratio of soil is high, whereas the ratio decreases in soils of the advanced stage of weathering[5]. Thus the ratio of $HClO_4$-Co to total-Co is a reflection of the weathering sequence of soils.

As far as the volcanic ash soils are concerned, soil total-Co might hardly be a reliable parameter for estimating the availability because of their wide variation in the weathering sequence. In Hawaiian volcanic ash soils, no correlation was obtained between total-Co and the plant uptake[1], but better correlation might be obtained if $HClO_4$-Co was used as a parameter for soil cobalt availability. In the Japanese volcanic ash soils in Table 1, soils derived from Volcanoes Tarumae, Zao and Sakurajima have relatively higher total-Co contents because of their mafic parent rock origin, but they showed lower $HClO_4$-Co/total-Co ratios because they belong to the group of the early stage of weathering. No higher cobalt contents of herbages can be expected in these soils. Therefore, not only rhyolitic volcanic ash soils but andesitic or even basaltic volcanic ash soils can be cobalt deficient if they are at the early stage of weathering. Without the notice on the weathering sequence, no good estimation is expected for finding cobalt deficient grasslands as far as the volcanic ash soils are concerned.

An example of the relationship between soil cobalt and herbage cobalt is shown in Table 2. At the soil total-Co contents over 5 ppm, orchardgrass showed cobalt contents lower than 0.07 ppm, the minimum value for ruminants need. $HClO_4$-Co of these two soils are much lower than 5 ppm, the commonly used maximum value for cobalt deficient soils. The level of herbage cobalt is considered to be in

Table 2. Cobalt contents of herbages and soils in pastures of Meakan-Mashu volcanic ash soil

Location	Orchard grass-Co (n=15)		Timothy-Co (n=3)	Soil-Co (n=5)	
	Range	Average	Average	Total-Co	$HClO_4$-Co
	ppm	ppm	ppm	ppm	ppm
Nemuro	0.03–0.05	0.04	0.03	6.4	3.9
Teshikaga	0.03–0.06	0.05	0.04	6.0	2.6

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 rocks and are the deficient soils irrespective to the weathering sequence. But very few cases are expected in Japanese grassland farming. Group B and C soils have andesite to basalt as their parent rocks and belong to the medium to early stage of weathering sequence.

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

Experiment II. Cobalt deficiency in ruminants evidenced on Meakan-Mashu Volcanic Ash Soil[3]

The Stock Farm of Tamagawa University is situated at Teshikaga, Konsen district, Hokkaido where the soil belongs to Meakan-Mashu series which was classified as one of the cobalt deficient soils in Experiment I. A feeding experiment was carried out at the Stock Farm to confirm whether or not cobalt deficiency occurs in ruminants fed on herbages grown there. On June 21, 1978, 11 Suffolk × Corriedale cross-bred lambs were divided into two groups on the basis of body weight. The two groups were fed only on 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. The each lamb was weighed and the blood was tested fortnightly. The experiment was run for 52 weeks.

Between the 20th and 22nd week the Co-nonfed animals began to show a gradual decrease in weight as shown in Fig. 3. Because of extreme emaciation, 3 out of the 7 Co-nonfed animals were slaughtered to anatomize during the course of this experiment. The control animals gained on an average 17.7 kg in 44 weeks, whereas the remaining 4 Co-nonfed animals lost 0.5 kg/head.

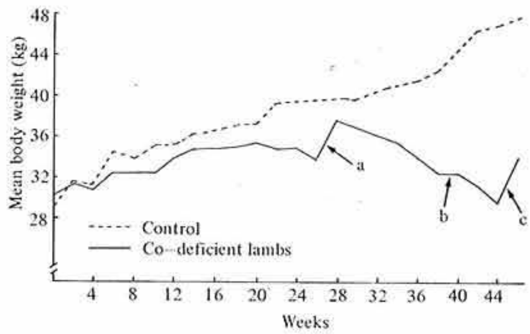

Fig. 3. Growth of lambs
a: 1 lamb slaughtered on 26 Dec.
b: 1 lamb slaughtered on 23 March
c: 1 lamb slaughtered on 29 April

Clinical and pathological signs and biochemical information obtained from the Co-nonfed animals are summarized as follows:

Notable loss of live weight, listlessness, anemia (reduction of the blood corpscle number below normal and lowering of hemoglobin level from normal value), fatty degeneration of the liver, hemosiderosis in the spleen, fatty degeneration of the bone marrow in both sterna and lumba vertebrae, lowering of the level of vitamin B_{12} in both blood serum and liver (determined by radio assay method), marked increase of excretion of methylmalonic acid in the urine (determined by the method of Gutteridge and Wright).

Moreover, remarkable responses of affected animals to both orally-administered Co (7 mg a lamb a week) and intramuscularly-injected vitamin B_{12} (100 μg a lamb a week) were

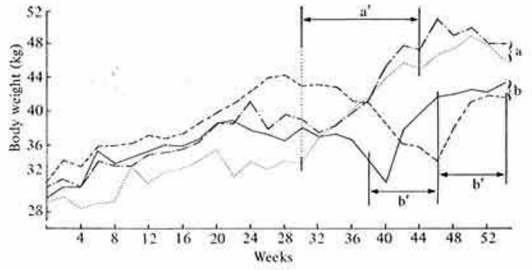

Fig. 4. Response of affected lambs to both vitamin B_{12} and Co
a: 2 lambs dosed orally with Co (7 mg, a lamb a week) for 14 weeks. a' denotes Co dosing period.
b: 2 lambs injected intramuscularly with vitamin B_{12} (100μg a lamb a week) for 8 weeks. b' denotes vitamin B_{12} injection period.

observed as shown in Fig. 4.

The above results indicated that serious cobalt deficiency developed in all the Co-nonfed animals. Although such cobalt deficiency has not yet been reported in the district, the result of this experiment suggests that such deficiencies may have remained undetected.

As far as the volcanic ash soils are concerned, soil cobalt availability to herbages and ruminants may relate to the mineralogical compositions of parent rocks. However, the stages of weathering sequence also exert a strong influence on the availability. To identify deficient areas, these two factors should be considered at the same time.

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References

1) Fujimoto, C. & Sherman, D.: Cobalt content of typical soils and plants of the Hawaiian islands. *Agron. J.*, **42**, 577–581 (1950).
2) Geological survy in Japan: Chemical composition of volcanic rocks. Kasai Printing Co., Ltd. Tokyo (1962).
3) Ishii, T. et al.: Development of experimental cobalt deficiency in ruminants. *Abstracts of the 70th meeting, The Society of Zootecnical Science, Japan*, **70**, 3 (1979) [In Japanese].
4) Kobayashi, Y. & Ogata, T.: The effects of soil condition and fertilization on the mineral composition of pasture plants. III. Cobalt content of volcanic ash soils. *Bull. Natl. Grassl. Res. Inst.*, **5**, 29–34 (1974) [In Japanese].
5) Kobo, K. & Oba, Y.: Genesis and characteristic of volcanic ash soil in Japan. II. Classification of volcanic ash soil according to the degree of weathering and parent material. *J. Sci. Soil and Manure*, **44**, 41–46 (1973) [In Japanese].
6) Kubota, J.: Cobalt content of New England soils in relation to cobalt levels in forages for ruminant animals. *Soil Sci. Soc. Am. Proc.*, **28**, 246–251 (1964).
7) Mason, B.: Principles of geochemistry. p. 136. John Wiley and Sons Inc., New York (1966).
8) Research Council Agriculture, Forestry and Fishries: Studies on mineral compositions of herbages and grassland soils in Japan. Research Report No. 106 (1978) [In Japanese].
9) Uesaka, S. & Chang, T. Y.: Studies on the importance of trace elements in farm animal feeding. I. On the trace element in the soil, river-water and roughages in the district of Komatsu, Shiga Prefecture, which is noted for the appearance of "Kuwazu-disease." *Bull. Res. Inst. Food Sci., Kyoto Univ.*, **11**, 102–114 (1953) [In Japanese].