Sulphur Supplying Power of Japanese Grassland Soils

An outline of sulphur survey of grassland soils and pasture plants

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There have been only two reports so far on sulphur deficiency of crops in Japan, and these results were obtained from pot experiments. Otsuka (1962) reported sulphur deficiency of upland rice, corn and tomatoes, which were grown on surpentine soils in Mikkabi-cho, Shizuoka Prefecture, and Araki (1954) reported sulphur deficiency of wheat.

It was not until the 1950s that sulphur was surveyed as an item of the total chemical analysis of weathered parent materials from rocks, and soils classified geologically. There was, however, little or no survey of sulphur in soils and crops. Meanwhile, in order to elucidate the problem of "Akiochi", excellent works in the field of soil chemistry of paddy fields were conducted by several workers. The results showed that the formation of sulphides exerted harmful effects on rice roots in soils with a low oxygen tension under the submerged condition. Earlier works had shown that when lands were reclaimed from the sea, they became strongly acidic due to the oxidation of sulphides to sulphuric acid.

As it was common in other parts of the world, sulphur was a neglected nutrient element. Responses to sulphur fertilizer applications have not been found to be widespread until the 1960s. Unlike other countries in Europe, Australasia and the United States, sulphur deficiency in Japanese arable land has never been taken into serious consideration.

Sulphur is an essential element for the synthesis of cystine, the main sulphur-containing amino acid of wool fibre. For this reason a considerable amount of experimental work has been done in such wool-producing countries as New Zealand and Australia.

With the cooperation of several agricultural stations of the Ministry of Agriculture & Forestry, herbage samples from pastures and wild grasses in virgin soils adjacent to improved pastures were collected from various districts in Japan between 1971 to 1974.

The results of survey of sulphur contents of these samples are presented here together with discussion on main findings.

Materials and methods

All the soils analysed were virgin soils. They were sampled according to genetic horizons. More than 200 samples were taken including 43 sites of volcanic ash soils, 25 sites of non-volcanic ash soils and 3 sites of peat soils.

Herbage samples analysed were mainly orchard grass (*Dactylis glomerata*) and Ladino clover (*Trifolium repens*) at the first cutting in spring. Wild grasses taken from the virgin soils were Sasa (*Sasa*) and Susuki (*Miscanthus sinensis*). Sasa was sampled at the same time as the other herbages, but Susuki was sampled at the beginning of the flowering stage which was usually in September. More than 250 herbage samples were taken.

The total sulphur content of both soils and plants was determined by the X-ray fluorescence method (Tsuji, unpublished).

Results and discussion

1) Total sulphur content of soils

As soil samples were taken from soils up to a depth beyond the rhizosphere, the depth of each horizon was different. For this reason, data were compared only with A horizon.

Most of the soils derived from granite contained less than 0.025% of total sulphur. However, slightly more sulphur was found in coarse textured volcanic ash soils in Sobetsu district belonging to the Usuzan—Date series (Otowa et al., 1968), and in the most recent volcanic ash soils in Hokkaido.

Soils derived from serpentine, rhyolite and sandstone contained up to 0.050% of sulphur and volcanic ash soils such as Asama and Sakurajima contained between 0.050 to 0.075%. Most of the humic volcanic ash soils contained more than 0.100%. However, soils from districts such as Konsen and Kamishiro (both in Hokkaido) contained less than 0.100% of total sulphur. Humus-rich volcanic ash soils from districts in the northern somma of Mt. Aso and Kujyu (both in Kyushu) contained more than 0.2% of total sulphur. Peat soils of Sarobetsu district (Hokkaido) contained large amounts of sulphur which was related to the depth of the soil horizon.

Hence, it can be concluded that the sulphur content of the soil is closely related to its organic matter content. As shown in Table 2 a considerable proportion of the total sulphur is organic sulphur. The ratio of C:N:S:P in soils has been found to be closely approximated as 100:10:1:1 (Walker and Adams, 1958). The results calculated as means of the sulphur contents of the A horizons of three different parent materials are shown in Table 1.

The mean sulphur content of volcanic ash soils varied between 0.03% to 0.25%. However, differences in the mean sulphur contents between volcanic and non-volcanic ash soils were significant at the 0.1% level. It can thus be concluded that generally 0.13 to 0.10% sulphur was present in volcanic ash soils, while 0.06 to 0.04% in non-volcanic ash soils.

2) Chemical nature of soil sulphur fractions extracted by various extractants

Generally, soil sulphur is fractioned as inorganic and organic sulphur. Lower (1964) showed that up to 58% of the total sulphur in some Quebec soils was directly bonded to carbon. Phenolic sulphates and choline sulphates have been identified to be the main components of sulphur esters in the organic sulphur of soils (Freney and Stevenson, 1966).

The major form of inorganic sulphur in soils has been found to be mainly the adsorbed sulphate. This has been postulated to be due to adsorption of the sulphur by the hydrous oxides of iron and aluminium. However, the amount and nature of adsorbed sulphate in Japanese soils has not been investigated.

The determination of so-called "plant available sulphur" has been investigated by several workers either as the "A value" or the amount extracted by various extractants in soil tests. Barrow (1967) found a high correlation between the decrease in the level of phosphate-extractable sulphate in soil and the amount of sulphur taken up by plants. However, it may be difficult to obtain a universal extractant applicable to all soils. "Hot water-soluble sulphur" and "Reserve sulphur" are considered

Table 1. T-S in virgin soils (A horizon)

Parent materials	95% confidence limit %		max.-min.	CV %	n	s.d.
Volcanic ash soils	0.114±0.016	sig. (0.001)	0.246-0.027	46	44	0.052
Non volcanic ash soils	0.046±0.009		0.114-0.010	49	27	0.022
Peat soils	0.229±0.157		0.318-0.173	28	3	0.063

(% in dry basis)

Table 2. Total sulphur and extractable sulphur in various soil horizons

Soils (Prefecture)	Annual rainfall (mm)	Virgin cover	Parent material	Soil depths (mm)	pH (H_2O)	T-C* (%)	T-S* (%)	Organic S** (%)	0.1N-NaH_2PO_4 in 2N-HOAc	0.01N-$Ca(OAc)_2$	N-$Ca(OAc)_2$	N-NH_4OAc	N-HCl	H_2O	N-NaOH
Tateka	864	scrub	Volcanic	0–22	6.2	1.28	0.027	96	7	11					
(Hokkaido)		Sasa	ash	22–35	6.5	0.46	0.024	98	2	4					
				35–55	6.7	0.23	0.021	99	3	3					
Tateka		(grassland)		0– 5	7.2	0.93	0.024	99	3	2	3	3	5	3	13
				5–10	7.5	0.75	0.021	99	2	3	4	2	5	3	10
				10–20	7.1	0.52	0.020	99	2	2	3	3	5	2	9
Fujinita	1709	scrub	Volcanic	0–20	5.3	16.42	0.157	93	29	117	213	203	119	18	314
(Tochigi)		Miscanthus	ash												
Okuizumo		scrub	Granite	0– 7	5.3	2.20	0.026	93	14	18					
(Shimane)		Sasa, Mis.		7–25	5.6	0.77	0.020	93	10	14					
				25–50	6.7	0.03	0.014	99	3	2					
				50–100	6.5	0.07	0.015	99	3	2					
Funehiki	1255	scrub	Granite	5–30	5.3	0.20	0.021	84	28	33	34	38	22	4	48
		Sasa													
Gokuraku	1330	forest	Granite	10–30	5.3	0.16	0.028	76	42	67	60	44	20	5	82
(Fukushima)															
Takenowa		forest	Serpentine	2–30	6.5	1.29	0.031	95	10	16	18	6	2	8	41
Mikkabi	1905	scrub	Serpentine	2–30	6.5	1.82	0.031	98	2	7	6	6	2	2	42
(Shizuoka)		Mis.													
Sarobetsu		bog,	Peat	0– 8	4.5	25.14	0.318	—	107						
(Hokkaido)		Alnus,		8–20	4.7		0.489	—	71						
		Phragmites		20–45	4.4		0.626	—	82						
pH of extractants									2.3	3.7	7.7	6.9	—	—	—

Notes: Condition of extraction; soil : solution=1 : 5. at 20°C, for 30 min

* Oven-dry basis. But extractable-S was showin in ppm on air-dry basis

** Organic $S=\frac{\text{Total S}-0.01N\ Ca(H_2PO_4)_2\text{-extractable S}}{\text{Total S}}\times 100$

to be the major form of plant available sulphur in organic soils by some workers (e.g. Spencer and Freney, 1960, Bardsley and Lancaster, 1960). Chloride and neutral to acidic ammonium acetate-extractable sulphur are considered to be useful extractants for plant available sulphur in coarse soils (Williams and Steinbergs, 1960).

In the present studies, several extractants were compared because the amount of sulphur extracted varied according to the kind of salt, acid and alkali used.

Soils used were as follows:

Volcanic ash soils, three granite soils, two serpentine soils and one peat soil. The results are shown together with the location of each soil, the annual rainfall and virgin cover (Table 2).

Main features of each soil were as follows:

Tateka belongs to the Usuzan-Date series, the most recent volcanic ash soils in Hokkaido, coarse textured, less humus and rich in bases. Fujinita belongs to Nasu volcanic ash, very abundant in humus. Mikkabi soil was taken from the same site where the sulphur deficiency was reported. Peat soils are widely distributed in the Sarobetsu area (Hokkaido).

The sulphur determined by the various extractants represents only the SO_4-S form because filtrates were directly analysed by the Johnson-Nishita method (Johnson and Nishita, 1952).

Owing to the lower pH of NaH_2PO_4 extractant used, less sulphur was extracted as compared to that extracted by $Ca(H_2PO_4)_2$ in most soils. Fujinita soil, which is rich in humus, was also affetced by Ca^{++} ions, which depressed the solubility of organic matter. Tateka soil was not affected by any kind of extractants except NaOH which gave the highest amount of sulphur extracted. The coarse soils of granite origin (Funehiki, Gokuraku) were more affected by differences of pH and anions of extractants. This was probably due to the lower buffering capacity of these soils. Generally, granite soils were observed to have low retention of sulphate.

As mentioned earlier, Mikkabi soil was reported to show sulphur deficiency in pot experiment. The NaOH extractable sulphur of Tateka soil was lower than that of Mikkabi soil and thus Tateka soil is likely to be sulphur deficient.

3) Sulphur content of pasture and native grasses

The data on total sulphur content in each plant species are shown in Table 3.

There was no significant difference between the total sulphur contents of orchard grass and Ladino clover, and also between those of pasture grasses and legumes. Generally, most herbage harvested in the spring contain 0.2% of total sulphur.

The orchard grass from Tateka soil showed the lowest amount of total sulphur (0.09%). Although field experiment to test the presence of sulphur responses of grasses in this soil are yet to be conducted, sulphur deficiency in crops is likely to occur in this soil because

Table 3. T-S in pasture plant and wild grasses

Species	95% confidence limit %		max.-min.	CV %	n	s. d.
Orchard grass	0. 204±0. 012	n. s.	0. 33-0. 09	27	94	0. 056
Ladino clover	0. 209±0. 010		0. 38-0. 13	20	72	0. 042
Grasses	0. 203±0. 010	n. s.	0. 41-0. 09	29	119	0. 058
Legumes	0. 205±0. 010		0. 38-0. 12	22	77	0. 045
Sasa	0. 133±0. 017	sig. (0. 01)		38	38	0. 051
Susuki* (*Miscanthus sinensis*)	0. 056±0. 004			18	26	0. 010

* Susuki: at the beginning of flowering
Pasture plants: at the first cut in spring

Table 4. T-S in pasture plants and native grasses as affected by the soil differences

Species	Soils	95% confidence limit %		CV %	n	s. d.
Pasture plants	volcanic	0. 214±0. 010	sig. (0. 01)	25	122	0. 054
	non volcanic	0. 189±0. 012		24	59	0. 046
	peat	0. 169±0. 032		31	14	0. 053
Sasa	volcanic	0. 116±0. 023	n. s.	41	19	0. 047
	non volcanic	0. 141±0. 030		36	14	0. 050
	peat	0. 173±0. 078		28	4	0. 049
Susuki	volcanic	0. 057±0. 004	n. s.	18	22	0. 010
	non volcanic	0. 048±0. 027		35	4	0. 017

of its low levels of soil sulphur and low precipitation.

Bahia grass (*Paspalum notatum*) harvested from highly humic volcanic ash soils in Southern Kyushu showed the highest sulphur content (0.41%)

Table 4 shows the results obtained when at each site herbage of pasture plants and native grasses were taken and classified according to parent materials (i.e. volcanic ash, non-volcanic ash and peat), and their mean sulphur contents calculated. In these calculations grasses and legumes were combined together because there was no significant difference between these two species. It is evident from the data presented that the sulphur contents of pasture plants from the three different soil types were significantly different at the 1% level. The native grasses show no significant difference in their sulphur contents.

It can thus be concluded that pasture plants from volcanic ash soils, especially from humus-rich volcanic ash soils, contain high levels of sulphur.

Summary

Total sulphur contents in soils, pasture plants and native grasses were determined in a survey using samples taken from various sites across the country

The most recent volcanic ash soils sampled from Sobetsu in Hokkaido showed low sulphur content, however, most of the humic volcanic ash soils contained more than 0.1% of sulphur.

Soil sulphate extracted by several kinds of extractant showed that there were differences in the organic matter content and levels of so-called "plant available sulphur." The latter was probably due to the fact that the various extractants used differed in pH and kind of anions and thus the amounts of "available sulphur" extracted could be a reflection of the buffering capacity of the soils.

Total sulphur content of pasture plants and native grasses sampled mainly at the first harvest in the spring was also investigated. Plant herbage contained approximately 0.2% of sulphur, showing no significant difference between grasses and legumes. Pasture plants from humus-rich volcanic ash soils contained higher levels of sulphur than those from non-volcanic ash soils. Orchard grass sampled from Sobetsu district also showed a low sulhpur content.

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