19. EFFECTIVENESS OF SILICATE FERTILIZER TO JAPONICA VARIETIES

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Introduction

It is since 1952 that experiments have been widely carried out on the use of silicate slag as a source supplying silicon to rice plants. In U. S. A. and Germany it had been noticed before 1930 that slag is an effective material for improving acid soils, making clear that blast furnace slag is more effective than calcium carbonate for this purpose. The utilization of slag in Japan, however, is remarkable in the point that it has developed for supplying silicon to rice plants. The wide use of silicate slag produced at the time of refining metals started when experiments were carried out in prefectural agricultural experiment stations, includi ng the stations designated by the Ministry of Agriculture and Forestry, with K. Imaizumi as leader on the effects of applying salts degraded paddy fields, obtaining the results that the application of silicon and other salts was effective. After that, the extensive works of S. Obata et al. and M. Ota et al. have made clear that the main fertilizing effect of silicate slag is due to silicon contained in it. The silicate slag was authorized as a silicate fertilizer in 1955, and its official standard was fixed. Properties and standard fertilizing effects of various kinds of slags were gradually made clear, and the official has been changed step by step until now.

The yearly consumption of silicate fertilizer was about 300, 000～370, 000 tons during the years from 1957 to 1963, showing no sharp increase. This is a period which corresponds to

Table 1. Shipping Amounts of Silicate Fertilizer.

Year	Shipping Amounts	Contrast with 1957 year
1957	338, 822 t	100
58	321, 705	95
59	348, 895	103
60	372, 596	110
61	317, 298	94
62	303, 876	90
63	321, 857	95
64	391, 833	116
65	534, 458	158
66	742, 967	219
67	995, 587	294

the 10 years after the start of the studies on silicate slag. Many experimental results have been accumulated on silicon in this period, centering around the analysis of its fertilizing effects. The studies took up various problems among which topics on the techniques of applying silicate fertilizer were : 1) effects of silicate fertilizer in different sorts of soils, 2) amounts of silicon naturally supplied from soil and irrigated water to rice plants, 3) a standard to judge the need of the supply, 4) processes of the decomposition of silicate ferti-

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lizer in the soil, 5) effects of the fertilizer on the growth of rice plants, 6) analysis of the effect, 7) influence of the fertilizer on the physical and chemical properties of the soil, 8) methods of application, 9) influence of the heavy metals contained in silicate fertilizer on the growth of rice plants, 10) effects of different kinds of silicate slags, etc.

The consumption of silicate fertilizer has continued to increase in amount since 1964, amounting to about 1,000,000 tons in 1967. Such a sharp increase in amount of the consumption is considered to be due to the reasons as follows. 1) Silicate fertilizer is not only effective as a source supplying silicon to degraded paddy fields and peat paddy fields but also for improving the soil in the other sorts of paddy fields. There are increasing examples which show its good effects even in such paddy fields where it has never been effective in case it is applied in large quantities or in combination with other fertilizers. 2) Accompanied with popularization of high yield rice varieties, application of fertilizers has remarkably increased in amount, and the effect of silicate fertilizer is frequently noticed in such a much-fertilized cultivation of rice plants. 3) Silicate fertilizer is much used by such farmers as harvesting more than 8 tons of brown rice per hectare. It seems that the increse in consumption of silicate fertilizer is also a reflex of the recent situation of agriculture in Japan, that is, the high price of rice or a fall of soil fertility come from a decrease in amount of the application of farmyard manure due to a shortage of labor.

Need or not of the supply of silicate fertilizer

Table 2. Effect of silicate fertilizer on yields in numerous soil types.

District		Experimental years	Item	Soil Type								
				Peat	Muck	Strong gley	Gley	Gray	Gray brown	Yellowish brown	Black	Gravelly and gravel layer
South west Japan	Hiroshima Prefecture	1953 ~ 1962	Number of Expt. field	—	—	3	4	1	14	—	1	2
			Ave. percent of increased yield	—	—	2	2	18	4	—	0	7
	Hyogo Prefecture	1955 ~ 1964	Number of Expt. field	—	—	—	2	2	9	5	2	7
			Ave. percent of increased yield	—	—	—	8	1	4	4	2	8
	Aichi Prefecture	1955 ~ 1963	Number of Expt. field	1	—	8	11	15	14	7	10	2
			Ave. percent of increased yied	14	—	8	10	8	7	16	7	3
North east Japan	Ibaragi Prefecture	1953 ~ 1961	Number of Expt. field	4	—	—	4	4	3	1	3	—
			Ave. percent of increased yield	8	—	—	1	6	5	1	9	—
	Fukui Prefecture	1954 ~ 1962	Number of Expt. field	—	3	18	3	—	5	2	2	3
			Ave. percent of increased yield	—	10	8	11	—	11	11	12	7

(1) Effects of silicate fertilizer in different soils

Silicate fertilizer is much effective in degraded paddy fields where the mother rocks are granite and rhyolite, or in peat paddy fields which the supply of silicon from the soil is insufficient. On the other hand, it has been thought that the fertilizer can not be expected to be effective in paddy fields where the mother rock are volcanic ash and andesite being sufficient in supply of silicon, or in strongly gley paddy fields where penetration of water is bad.

Many systematic studies were made on the proper application of silicate fertilizer in various places of Japan from 1953 to 1962, showing that the fertilizer had an good effect in degraded paddy fields and in peat paddy fields. Many experiments also showed its effects in other sorts of soils. Since 1965, accompanied with a rise of the standard of yield, experiments on this problem have decreased in number. However, it is noticed that some of them, as before, reported the effectiveness of silicate fertilizer in various sorts of soils. It is presumed from those results that the silicate fertilizer is not only effective through the supply of silicon but also has some other good influences upon the growth of rice plants.

(2) Effets on the growth of rice plants

In many cases it has been reported that silicate fertilizer inhibits the growth of rice plants in the early stage of growth. But there are also some experiments reporting opposite results. The effect is different in different sorts of soils. It is also greatly influenced by the dose and the time of application.

Among the yield constitutional components, the number of ear tends to increase in case the fertilizer is effective, though such cases are smaller in number in the southwestern part of Japan. An increase in percentage of bearing tillers is universal. The number of spikelets per panicle shows an increase in many cases. The percentage of ripened grains and the weight of 1,000 kernels increase in some cases, but results are variable in many cases. From the viewpoint of development, it is noticed that the growth of rice plants increases from the early stage of panicle formation to the heading stage, and the grain/straw ratio becomes higher. The amounts of silicon, nitrogen and potassium absorbed by rice plants increase in general, though there are many cases showing a decrease in nitrogen content of the plant in degraded paddy fields. The exchangeable calcium increases sharply in amount in the soil, while the calcium content of the straw at the harvest stage tends to decrease. There are some reports saying that the phosphorus content of the plant decreases, though

Table 3. Amounts of nitrogen and silicon absorbed by rice plant at several growth stage. (1967~1968, Hokuriku Agr. Expt. Sta.)

Soil type	Treatment	Final emergence time of bearing tillers		Early stage of panicle formation		Full heading time		Milk ripening stage		Harvest stage	
		N kg/ha	SiO_2 kg/ha	N kg/ha	SiO_2 kg/ha	N kg/ha	SiO_2 kg/ha	N kg/ha	SiO_2 kg/ha	N kg/ha	SiO_2 kg/ha
Black soil 1)	No supply	48	57	60	106	72	310	93	374	82	377
	Continuous supply	46	57	65	112	99	489	118	579	115	578
Strong gley soil 2)	No supply	32	34	77	160	117	466	158	807	155	954
	Continuous supply	42	82	76	199	129	746	142	1104	153	1208

Remarks : 1) Black soil : Loamy, humic volcanic ash

2) Strong gley soil : Heavy clay, mottled type

there are also many results showing its increase.

In addition to those, there are many results that the leaf blade becomes vertical and absorbs effectively the solar radiation, or the plant becomes resistant to such diseases as blast, brown spot and sheath blight.

(3) Effects of silicate fertilizer in connection with the silicon contents of the soil and the rice plant

K. Imaizumi and S. Yoshida reported in 1958 that the effect of silicate fertilizer is expected to be remarkable in the paddy field where acetate buffer soluble SiO_2 is below 10.5 mg in the content per 100 gram of the soil, saying that the fertilizer is not only little in the effect but also harmful to the rice plant in case the SiO_2 content is above 13 mg. However, according to collective examinations of the results reported after that, there are many cases showing that the fertilizer is effective in paddy fields where the SiO_2 content is above 15 mg, though it has a remarkable effect, as pointed out by Imaizumi, in the paddy field where the SiO_2 content is below 10 mg. The level of 20 mg in the SiO_2 content, therefore, is recently considered as a standard for improvement of the soil by the application of silicate fertilizer in the Kanto-Tozan district. Some experiments have been carried out, as mentioned below, on the continuous application of silicate fertilizer for a long time, showing that the SiO_2 content often reached about 50~100 mg and the effect of the fertilizer did not fall in many cases of such continuous application when nitrogen was properly supplied with it.

K. Imaizumi and S. Yoshida also proposed a standard for judging the need of the application of silicate fertilizer from the viewpoint of the silicon content of the rice plant. They thought that the fertilizer can be expected to be effective in such a field where the SiO_2 content of the straw is below 11% at the harvest stage. The results obtained thereafter in various places, however, indicate that its application is effective in many fields where the SiO_2 content of the straw is up to about 15%, though the effect is noticeable in case the content is below 10%. The effect in case tne SiO_2 content of the straw is above 13% can not be explained only by the supply of silicon, because there are some cases where applicate fertilizer caused a decrease in yield. It seems that effects of some other nutrients or changes in soil behavior by the application of silicate fertilizer has relation to this problem.

(4) Effects of silicate fertilizer applied together with other fertilizers

The straw of rice plants increases as a rule in amount with an incresed amount of application of nitrogen fertilizers, while the brown rice not always increases in yield with

Table 4. Effect of silicate fertilizer applied together with increaesed amount of application of nitrogen fertilizer. (1955~1957, Tokai-Kinki Agr. Expt. Sta.)

Treatment		Yields of brown rice t/ha	Index	Contents in flag-leaf at harvest stage					
Silicate fertilizer	Nitrogen supply			SiO_2 %	N %	P_2O_5 %	K_2O %	MgO %	CaO %
No supply	90kg/ha	4.1	100	18.08	0.98	0.25	1.40	0.21	0.16
	110	4.3	106	15.33	1.08	0.29	1.48	0.27	0.13
	150	3.7	90	12.55	2.45	0.33	1.61	0.20	0.13
Supply	90	4.5	112	20.78	0.97	0.22	1.38	0.19	0.14
	110	4.6	114	17.13	1.05	0.25	1.45	0.20	0.13
	150	4.7	116	14.74	1.43	0.28	1.55	0.20	0.12

Remark : Soil ; Heavy clay gray brown soil, structured type the amount of nitrogen fertilizers. And in many cases a decrease is observed in the yield in case nitrogen fertilizers are applied beyond the optimum amount. The application of silicate fertilizer has an effect to raise the upper limit of the dose of nitrogen fertilizers.

Silicate fertilizer has also a good effect in humic volcanic ash paddy fields in case it is applied with fused magnesium phosphate, or in degraded paddy fields and peat paddy fields when it is applied with bauxite slag or limonite.

(5) Dose and method of application

Silicate fertilizer is effective when it is applied in large quantities, and the optimum dose is considered to be 1.5~2 tons per hectare in many places, but there are also many case where the use of the fertilizer up to 4~5 tons per hectare is still effective for increasing the yield of rice. As to the application of silicate fertilizer, some people attach importance to keep the soil fertility and have an opinion that the fertilizer must be applied at a dose sufficient to supply the amount absorbed by rice plants from the soil.

The after effect of silicate fertilizer continues for 2~3 years when it is applied at a dose of about 2 tons per hectare, and for several years at more than 4 tons, though it can hardly be observed at about 1 ton per hectare.

Silicate fertilizer is most effective when it is applied as basal dose, though top dressing has an effect until the tillering stage.

Effects of the continuous supply of silicate fertilizer

(1) Effects on the yield of brown rice

Most of the results reported on the continuous supply of silicate fertilizer are the cases of 3~5 years' continuation, showing that a decrease in the effect due to continuous supply is observed mostly in coase textured dry paddy fields.

There are only 3 cases of continuous supply for more than 10 years. Among those the results obtained by the Tokushima and Fukui Prefectural Agricultural Experiment Stations show an increse of 10-12% in average in the yield (Table 5). The field of the Tokushima Pref. Agr. Expt. Sta. is of loamy gray soil and that of the Fukui Pref. Agr. Expt. Sta. is of clayey strong gley soil, mottled type. In the Hiroshima Pref. Agr. Expt. Sta., where the yield began to decrease in the 8 th year of continuous supply, the field is of loamy graybrown soil, manganese type and its surface soil is alluvial sandy loam, the mother rock

Table 5. Effect of continuous supply (1954~1964, Fukui Agr. Expt. Sta.)

Treatment	Item	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year	9th year	10th year	11th year	Average
No supply	Yields of brown rice (t/ha)	4.1	5.2	5.5	5.0	5.1	5.3	5.2	5.5	5.4	4.9	5.3	5.1
	Index	100	100	100	100	100	100	100	100	100	100	100	100
Continuous supply (1.1t/ha)	Yields of brown rice (t/ha)	4.6	6.0	5.8	5.5	5.5	5.4	5.5	5.9	5.9	5.4	5.7	5.6
	Index	111	115	104	108	109	103	107	107	110	109	107	108
Continuous supply (3.4t/ha)	Yields of brown rice (t/ha)	4.6	7.2	5.6	5.5	5.6	5.7	5.7	5.9	5.8	5.9	6.0	5.8
	Index	112	140	102	110	110	108	111	106	109	120	112	112

Remark : Soil ; Clayey strong gley soil, mottled type

Table 6. Changes in physical and chemical properties of soil in paddy field planted rice. (1967, Hokuriku Agr. Expt. Sta.)

Item	Treatment	Jun. 6	Jun. 16	Jun. 27	Jul. 6[1]	Jul. 20[2]	Aug 21[3]
Eh_6 (mv)	No supply	222	166	79	46	42	42
	Continuous supply	303	174	129	69	100	70
pH	No supply	4.9	5.1	5.9	5.6	6.1	6.7
	Continuous supply	7.0	6.9	6.9	6.9	6.8	7.0
Ferrous contents (mg/100g soil)	No supply	155	239	423	515	593	869
	Continuous supply	108	186	262	369	496	622
NH_4-N (mg/100g soil)	No supply	9.5	4.5	3.0	1.6	1.0	0.4
	Continuous supply	8.9	7.4	1.2	1.4	0.7	0.5
Available SiO_2 contents (mg/100g soil)	No supply	10	19	30	34	37	42
	Continuous supply	40	93	75	100	98	105
Available P_2O_5 contents (mg/100g soil)	No supply	10	11	17	18	28	27
	Continuous supply	10	11	12	14	22	21

Remarks : 1) Maximum number stage of tillers
2) Early stage of panicle formation
3) Full heading time
4) Soil : Heavy clay strong gley soil, mottled type

of which is granite. The decrease in the yield is inferred from the results of experiments on the increased supply of nitrogen fertilizers to be due to a decrease in amount of the soil nitrogen in the soil. However, in the Mie Pref. Agr. Expt. Sta., where the yield of brown rice decreased sharply in the 3 rd year of continuous supply, the cause is considered to be unbalance of the supply among minor elements due to an increase in amount of bases in the soil in addition to a decrease in amount of soil nitrogen.

(2) Changes in physical and chemical properties of the soil

Available SiO_2 is increased in amount in the soil by the supply of silicate fertilizer and the increase is usually 10~20 mg per 100 g of the soil at an ordinary dose of supply. The increase is very sharp in case of continuous supply. The examples are as follows : 45 mg by 10 years' continuation at 2 tons per hectare, 135 mg by 5 years' continuation at 4 tons and 220 mg by 3 years' supply at 4 tons. Such an increase is mainly observed in the surface soil, being very little in the layers lower than the second.

The NH_4-N content of the soil is generally lower in the paddy field planted with rice plants in case of the supply of silicate fertilizer than in case of no supply. But the absorption of nitrogen by rice plants increase in many cases under the supply of silicate fertilizer. And available nitrogen is increased in amount in the soil supplied with the fertilizer by incubation.

There are also many cases where exchangeable calcium and magnesium are increased in amount in the soil by the supply of silicate fertilizer. Under the supply of the fertilizer, a rise in pH of the soil is universal. A rise of Eh, a decrease in H_2S content and that of ferrous content are also noticed in the soil.

The continuous supply of silicate fertilizer thus increases the amounts of silicon and bases, raises the pH and accelerates decomposition of organic matters in the soil, and increases the supply of soil nitrogen to rice plants. Accordingly, the effect of continuous supply is usually kept for a long time in very fine or fine textured paddy fields where much soil nitrogen is contained. However, there is the possibility that the supply of silicate fertilizer causes a fall in yield as a result of a decreases in amount of soil nitrogen and unbalance of supply among minor elements in coarse textured paddy fields containing a little amount of soil nitrogen. So it is necessary to maintain the soil fertility by the supply of silicate fertilizer together with organic matters.

Silicate fertilizer came into wide use in Japan for the purpose of supplying silicon to degraded paddy fields. It, however, is now widely used for improvement of the soil, resulting in a sharp increase in its consumption. Furthermore, the supply of silicate fertilizer has been adopted as a component of the synthesized techniques of high yield cultivation, and there are many reports of such a high production of brown rice as 7.5~8.5 tons per hectare by the application.

Discussion

H.R. von Uexkull, Germany : Could you indicate the yield levels at which the amounts of N and SiO_2 mentioned in Table 3 absorbed ?

Answer : Expressing with brown rice yields, yields are 5.5t/ha with no supply and 5.8 with continuous supply in black soil, and 6.3 with no supply and 6.6 with continuous supply in strong gley soil.

E. Reyes, Philippines : Could you indicate the influence of continuous supply of silicate fertilizer on the phosphorus contents in soil and rice plant ?

Answer : As it is illustrated in Tables 4 and 6, available phosphorus contents in soil and the contents in rice plant decrease with application of silicate fertilizer.

(Comment) **K. Kawaguchi**, Japan : In general, in Southern Asia silica deficiency may not occur in soils derived from marine, brackish and big river's sediments. Some soils derived from local riverine sediments, especially soils on higher terraces may suffer from silica deficiency.

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