8. DEVELOPMENT OF FERTILIZATION FOR RICE CULTURE IN JAPAN

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Introduction

According to the first reliable statistics compiledin Japan about 90 years ago, the yield of brown rice was only about 1.9 tons per hectare, while it has reached about 4.5 tons/ha recently. Especially, an increase of yield per unit area is remarkable in the last 20 years.

It is needless to say that such an increases in yield has been achieved by a synthesis of the techniques in all the fields related to rice production. However, there is no doubt that among the factors connected with the yield, varietal improvements, increased fertilizer applications, and improvements in the fertilizer application techniques made greater contributions to the achievement. The question of variety improvement has already been discussed in this symposium. The author wishes here to review the characteristic of the development of fertilization method from a viewpoint of nutritional physiology and to explain the role of fertilization techniques in the increase of the rice yield.

Increase of the amount of fertilizers applied and its relation to the yield

A hundred years ago, main fertilizers used in Japan were compost, stable manure, green manure, oil cakes and fish meals' and the amount of their components applied for

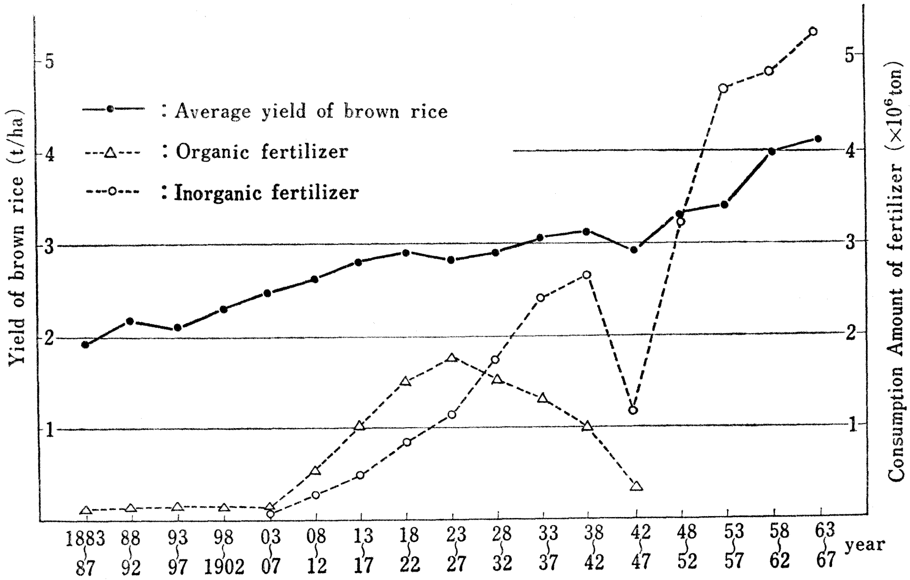

Fig. 1. Transition of average yield of brown rice and consumption of fertilizers in Japan

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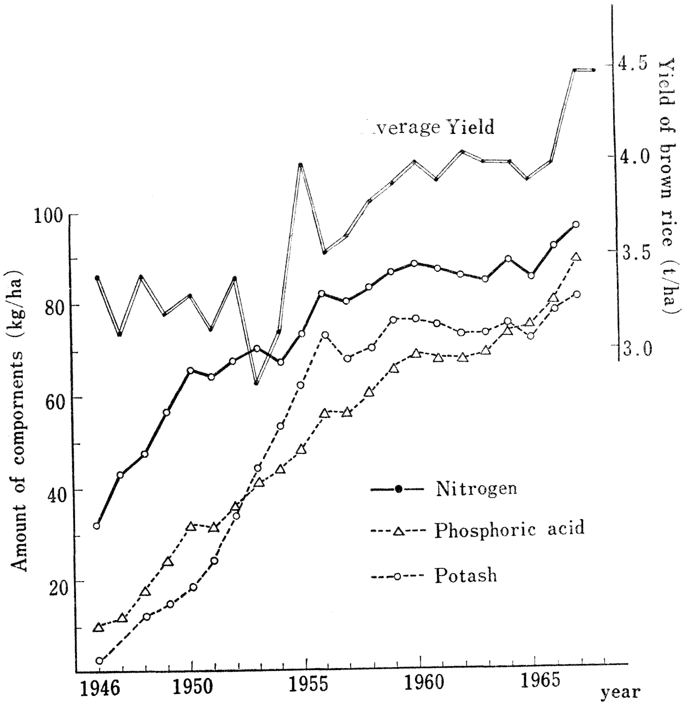

Fig. 2. The change in amount of applied fertilizers for paddy rice in Japan

rice culture was rather small. The consumption of fertilizers, however, has gradually increased in amount with the time. And a change has occurred in the form of fertilizers used, that is, inorganic chemical fertilizers took the place of organic ones accompanied with a great diversity of components. It is shown in Fig. 1 that the consumption of fertilizers has increased in amount in parallel with an increase of yield of rice per unit area. The transition of fertilizers from organic to inorganic ones took place from 1920's through 1930's, and it is noteworthy that the increase of yield of rice was stagnant in those years. This period was a turning point in the development of fertilization techniques in Japan as mentioned below.

Both the consumption of fertilizers and the yield increased sharply after World War II. The change in amount of the application of fertilizers is shown in Fig. 2 by the components, nitrogen, phosphatic acid and potash. In the period from the destruction to reconstruction after the war, an increase of the application was observed at first in nitrogenous fertilizers, and in phosphatic and potash fertilizers several years later. This fact seems to show that nitrogenous fertilizers are especially important for increasing the yield. But the level of yield was liable to change at this time. It is after 1955, when phosphatic acid and potash increased together with nitrogen, that the yield has been kept in high and stable state. It is also characteristic of the fertilization technique for rice culture in Japan that the application of silica, lime, magnesia, iron and manganese has been increasing recently. These components are supplied from various kinds of slags and fused magnesium phosphate. It is considered that such a diversification of components applied is effective to attain a balanced supply of various nutrients corresponding to an increased application of nitrogenous, phosphatic and potash fertilizers, and to a decrease of the application of organic fertilizers such as stable manure, compost and green manure.

Development of fertilization techniquse in Japan

Organic fertilizers are gradually decomposed in the soil. Accordingly, they are suitable to be applied as basal dressing. On the contrary, such an inorganic fertilizer as ammonium sulfate has a quick effect, but the effect is short-lasting. As mentioned above, in the 1930's when inorganic materials became the main source of fertilizer, the increase of rice yield showed a tendency of stagnation in Japan, though the consumption of fertilizers increased even in this period and it was noticed that the nutrients of fertilizers absorbed by the crop tended to be small compared with amount applied.

Shioiri *et al*[1]. (1930's) studied the behavior of nitrogen in the soil to improve the utilization by rice plants of the nutrient applied, and made it clear that under flooded condition, nitrogen in the form of ammonium salts applied to the interior reduced layer of the soil was stable, while it changed to the nitrate form in the oxidized surface layer of the soil and was lost by leaching of denitrification. Nitrogenous fertilizers in the form of ammonium salts are accordingly better utilized when applied to the reduced layer. However, it is difficult to apply them entirely to the reduced layer of the soil. In practice, therefore, fertilizers are broadcast and mixed with plowed soil as sufficiently as possible to reduce their distribution in the oxidized layer. This method of application is called whole-layer fertilization in Japan. The improved utilization of fertilizer nitrogen and an increase of yield of rice by this method of application is shown in Table 1.

Table 1. Whole layer fertilization of ammonium sulphate to paddy rice field
(Shiga Agr. Exp. Sta.)

Plot	Brown rice yield (t/ha)	Amount of N absorbed (kg/ha)	Percentage of ammonium sulphate N absorbed (%)
Before plowing application	5. 14	95	47
After first-plowing application	4. 94	97	48
After harrowing application (submerged immediately after mixing with mud)	4. 51	82	33
Before puddling application	4. 05	73	23
After final-puddling application	3. 90	70	20
Non-N plot	3. 13	51	—

Another way of application of quickly acting fertilizers is their use for top-dressing. Rice plants growing with well-spread roots absorb quickly nutrients applied as top-dressing. They can also utilize at a high rate nitrogen in the form of ammonium salts applied to the surface layer of the soil. However, top-dressing must be done at the best time to produce satisfactory results. The time of top-dressing is determined on the basis of the nutritional physiology of rice plants and on the fertility of soils. In Japan, it is popular to apply nitrogen at the time when the ear primordia are formed and growing, and this application is called "hogoe" top-dressing, literally meaning fertilization for panicles.

Kimura and Chiba[2] (1943) showed that there were two peak times in the effect of absorbed nitrogen on the yield of rice as shown in Table 2. As seen from the Table, the maximum partial efficiencies appeared twice in the block 3, 4, 5, of moderate nitrogen supply. The first is considered to fall on the time of basal dressing and the second on that

Table 2. Partial efficiency of nitrogen for the production of rice grain as influenced by the period of absorption
(J. Kimura & H. Chiba 1943)

Block	N Concentration (ppm)	Period of absorption								
		June 23 July 6	July 6-15	July 15-23	July 23-31	July 3 Aug. 8	Aug. 8-18	Aug. 18-30	Aug. 30 Sep.15	Sep.15 Oct.14
1	1.0- 3.8	39	−46	−58	67	**73**	**75**	53	23	10
2	1.5- 6.1	35	41	57	**70**	**69**	56	50	41	13
3	2.0- 6.8	37	43	**73**	65	55	**58**	38	22	4
4	2.5- 9.2	36	59	**67**	60	35	**47**	30	21	9
5	3.5-12.4	39	**64**	58	35	23	**41**	21	12	−45
6	5.0-16.7	33	**62**	47	26	22	21	20	21	2
7	6.0-22.5	25	**64**	41	26	24	16	16	− 6	—

The gothic figures show the maxima or the approximate maxima in the each block

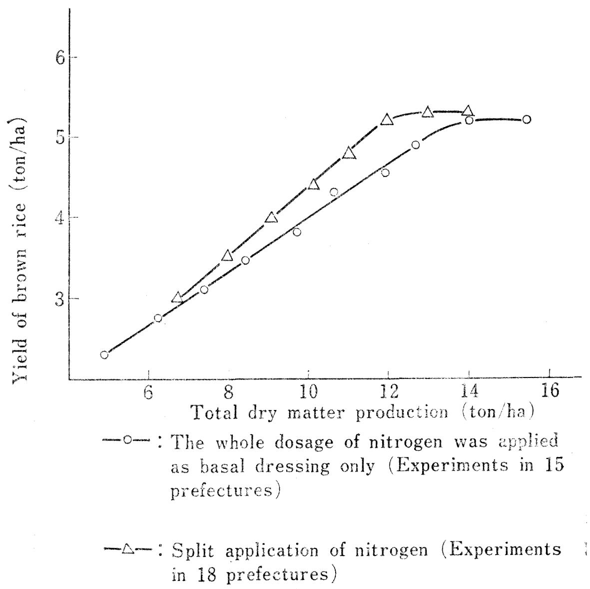

Fig. 3. Relationships between dry matter production and the yield of brown rice (N. Murayama 1967)

of "panicle" top-dressing.

Figure 3 illustrates the relationship between total dry matter production and brown rice yield as affected by the rate and method of nitrogen application; that is non-split and split application.[3] The data are based on experiments conducted in various locations in Japan about 10 years ago. A high degree of linear correlation exists between the dry matter production and grain yield. If compared on the the same level of dry matter production, the rice plants to which nitrogen is split-applied give higher yields of brown rice than those, to which the whole dosage of nitrogen is given as basal dressing. This implies that the total dry matter porduction is increased by raising the dosage of nitrogen, but the efficiency for grain yield can be enhanced by the split application. It can be said, therefore, that "hogoe" or panicle top-dressing is an effective method to increase the paddy/staw ratio.

As mentioned above, a standard method of applying quickly acting fertilizers, *whole-layer* fertilization plus "hogoe" or panicle top-dressing, was established in Japan in the 1940's. The ratio in the dosage of basal to top-dressing was about 8 : 2 at that time. But the fraction of top-dressing shows a tendency to increase gradually accompanied with an increased frequency of application. Top-dressing is often practiced several times during the period from the formation of ear primordia to the completion of heading. The increase in nitrogen consumption in recent years is mostly due to the increase in rate of top-dressing in the latter half of the growing period of rice plants. The physiological basis of this method of application has been discussed in Section I.

There are also many studies and experiments on the application of phosphoric acid and potash. The earlier phosphoric acid is absorbed by rice plants in the growing period, the higher is the productive efficiency for grain yield.[5] Therefore, aside from such a special case as a paddy field of volcanic ash soil, the whole amount of phosphatic fertilizers is applied as basal dressing. A part of potash fertilizers is used together with nitrogenous fertilizers for top-dressing at present. Kiuchi[6] (1951) made it clear that the efficiency of absorbed potash is higher at the beginning of the tillering stage and about 34-45 days before the heading time. This has also been confirmed by reports from other countries.

The use of sulfur-free fertilizers such as urea and ammonium chloride has been recommended on the basis of knowledge on the formation of hydrogen sulfide in degraded paddy fields and its inhibiting effect on the absorption of nutrients by the roots[7]. Such fertilizers are now in the wide use in order to keep the roots as healthy as possible, their use being not limited to degraded paddy fields only.

The use of silicic materials also started as a control measure against "*akiochi*", a physiological disease, in degraded paddy fields. S. Yoshida[8] (1965) showed that silicon is distributedmainly in the surface layer of the body of rice plants and forms a cuticle-silica double layer there, being of use for preventing damage by pathogenic fungi and insect pests, for regula- ting transpiration, and for keeping the leaves in a more erect posture. Silicic materials are now in use not only for controlling "akiochi" but also for keeping a healthy growth of riceplants cultivated under heavy application of nitrogen. Accordingly, the consumption of slags is now remarkably increasing in amount. It is interesting that a large quantity of silicicmaterials has come into practical use as fertilizers before the essentiality of silicon to the growth of plants wins public recognition.

High yield and fertilization

The average yield of brown rice in recent years is about 4.5 tons/ha. but the maximum yield in each year is much higher, reaching 10.5 tons/ha in 1960. In case of a high yield the rate of application and uptake of nutrients by the plants are naturally larger in amount. The average values of nutrient uptake throughout the country and the actual amount taken up by the crop of a high yield farmer are shown in Table 3.

However, heavy application of fertilizers dose not always result in a high yield. It is well known that excessive application of nitrogenous ferilizer often causes heavy mutual shading of leaves, lodging, diseases and insect damage, and resulting in a decrease of the yield due to inferior ripening of grains.

The farmers obtaining a high yield in Japan have made efforts to raise soil fertility by keeping it in mind that rice plants must be supplied with plenty nutrients from the soil, but not only from chemical fertilizers, to aviod the dangers mentioned above. When Shiro-

Table 3. Absorption of nutrients by high yield rice

year	Names	yield of brown rice(t/ha)	Nutrient absorption (kg/ha)			
			N	P_2O_5	K_2O	SiO_2
1960	Mr. Kudo	10.5	177	65	197	1,107
1967	Mr. Watanabe	9.0	185	97	199	1,007
1967	National average	4.5	90*	45*	135*	

* Estimated value

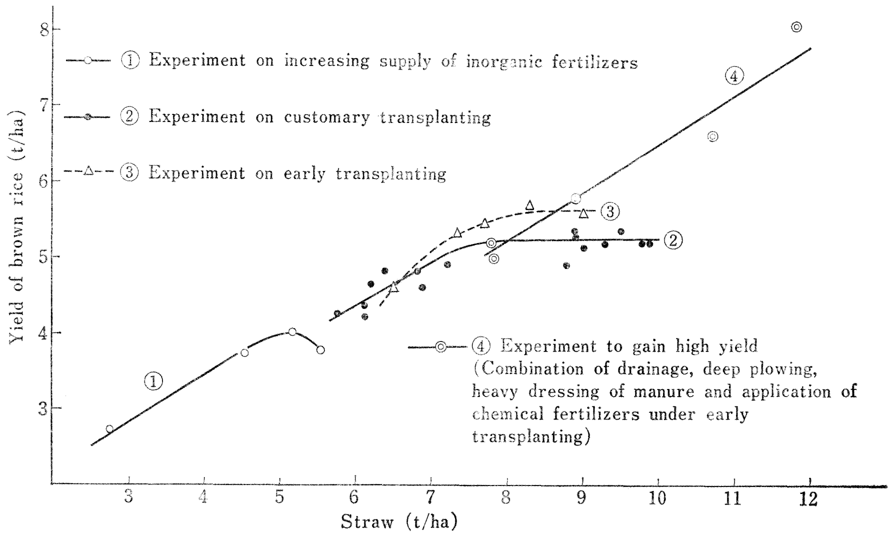

Fig. 4. Relationships between the weight of straw and the yield of brown rice (N. Murayama 1966)
(From Shiroshita's data carried out at Konosu Exp. Station)

shita *et al.*[9] (1962) obtained a high yield of more than 8 tons/ha at Konosu, they applied a large quantity of compost amounting to 56 tons/ha.

Their data are arranged in Fig. 4 to show the relation between straw weight and grain yield[10]. According to this figure, the high yield of 8 tons/ha was achieved at a point where the production of straw was 12 tons/ha. And it is inferred from this that a large amount of nutrients is also necessary for increasing the production of straw. As compared with this, the rice yield reached a maximum of 4 tons/ha at a point where the production of straw was 5 tons/ha in case only inorganic fertilizers were applied. These results suggest that the application of compost and stable manure is important for obtaining a high yield, though it is needless to say that the application of much compost and nitrogenous fertilizers is not the only factor contributing to a high rice yield of 8 tons/ha.

However, it is practically difficult to apply much compost and stable manure to a paddy field every year. Especially, recent shortage of labor in farms made it difficult to apply even 10 tons/ha in Japan. In place of compost, therefore, the application of rice straw is being promoted now. A new fertilization technique has also developed in this situation.

This new technique is composed of the application of a large amount of the materials containing silica, bases, iron and manganese in addition to the three essential elements, and nitrogen top-dressing in the latter half of the growing period. The soil, compost and stable manure supply various nutrients to rice plants continuously throughout the whole growth period, and this continuous supply of various nutrients is considered to be a characteristic of them. The new fertilization technique is now aiming to approach this characteristic.

The high yield records in farmer's contest in Japan were largely due to a build-up of soil fertility by means of soil dressing, compost, and stable manure application. But recently, similar results have been obtained by farmers who make more efficient use of inorganic chemical fertilizers by devising a better fertilization technique. This tendency is shown in

Table 4. Amount of fertilizers applied by the farmers obtaining a high yield and the average values of these amount throughout the country

Item	Yield of brown rice (ton/ha)	Amount of fertilizer applied (kg/ha)											
		N				P_2O_5				K_2O			
		Chem. fert.			M. T.	Chem. fert.			M. T.	Chem. fert.			M. T.
		a	b	t		a	b	t		a	b	t	
1952—'63 No. 1 Prize winner	9. 46	102	11	113	126 239	119	14	132	51 183	118	23	141	132 273
1965—'68 No. 1 Prize winner	9. 11	50	104	154	61 215	148	75	223	27 250	107	53	160	68 228
1967 National Average	4. 5			96				89				81	

Chem. fert. : Chemical fertilizer,
a : Basal, b : Top-dressing, t=a+b,
M : Manure, T=a+b+M

Table 5. Design of fertilization at Mr. Nishizawa's field (I. Iida 1969)

Nutrient	Date and growth stage						
	11 May Basal dressing	15 Trans-planting	16 July 25days before heading	22 20days before heading	11 Aug. Heading	Ripening	17 Oct. Harvest
Nitrogen	60kg/ha		21	52			
Phosphoric acid	240			68			
Potash	180			48			
Slag	2000— Applied in the preceding autumn						
Straw	5000— Applied in the preceding autumn						
Fused phosphate	—— Applied in the preceding autumn						

Table 4. The highest yield in 1968 was achieved by Mr. Nishizawa in Nagano Prefecture with a record of 9.42 tons/ha. brown rice[11]. His fertilization method is shown in Table 5. He applied rice straw, calcium slilcate and fused phosphate in the preceding autumn. The basal dressing was composed of mainly phosphoric acid and potash, limiting the amount of nitrogen to 60 kg/ha. Out of a total of 133 kg N, 73 kg-more than half was applied after the time of ear primordiaformation. It may be said that a reformation of fertilization technique has recently occurred in the rice culture for obtaining high yield in Japan. The old techniques were mainly based on improvements of soil fertility, while the new ones are aiming at a more efficient use of chemical fertilizers in addition to the improvement of soil fertility. Nitrogenous or other fertilizers are used according to the growth performance of rice plants as a measure for regulating the growth to a direction wanted.

Increase of fertilizer efficiency

In general, the method of increasing the fertilizer effect may consist of variety improvement and better fertilization techniques in accordance with various environmental conditions as it is seen in the plan of this symposium. However, when the conditions to be considered are given, it comes into our consideration on how to raise the efficiency of fertilizers and how to increase the efficiency of absorbed nutrients for grain production. As mentioned before, the techniques of *whole-layer* fertilization and *"hogoe"* or panicle top-dressing have resulted from considerations in Japan.

On the other hand, it is generally said that there is the law of diminishing returns in

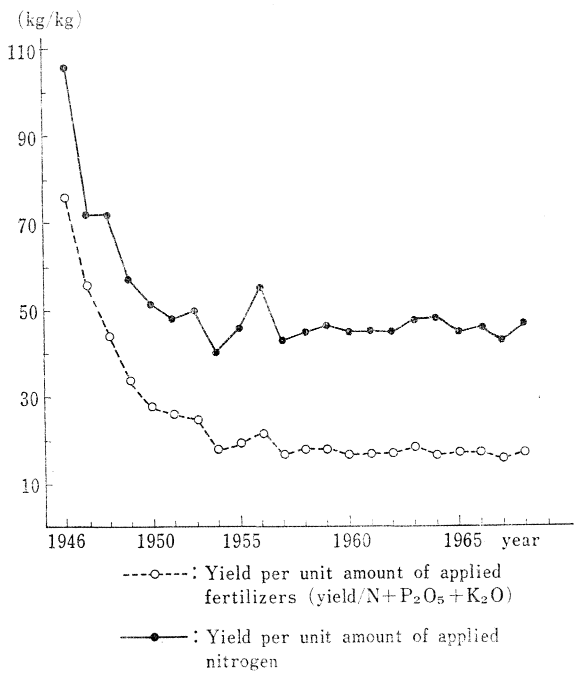

Fig. 5. The change of the yield of rice per unit amount of applied fertilizers and nitrogen only

the relation between the amount of fertilizers applied and the yield. And it is now a problem in Japan whether or not the increased application of fertilizers has caused any decrease in efficiency of the rice production.

By examining data presented in Fig. 4, it is noticed that there is a decrease of yield indicating a tendency towards the law of diminishing returns. But it is understood that the yield can be gradually increased by introduction of new techniques based on the analysis of the factors connected with rice production. The law of diminishing returns, therefore, does not seem to be a rule showing the limit of the production of rice.

Fig. 5 was obtained by an examination of th fertilization in Japan from a viewpoint of its efficiency. According to this figure, the yield of rice per unit amount of nutrient was higher in some years after the war when fertilizers were insufficient in amount, while it showed a sharp decrease with an increased supply of fertilizers later on. This change appears as if it showed that an increase in amount of fertilizers applied was the cause of a decrease of the fertilizer were efficiency. However, it is not reasonable to compare the result at the time when fertilizer were insufficient directly with the tendency after that, because the yield was kept on a higher level by the supply of necessary nutrients from the soil in a condition short of fertilizers. And it is noteworthy that the efficency of fertilizer has been kept on a nearly constant level since about 1953 irrespective of a continuous increase in the rate of application as shown in Fig. 2. The increase in fertilizer use in recent years has thus resulted in a nearly corresponding increase of the yield, showing no clear sign of its decrease. Therefore, it may be said that fertilizers are used effectively there.

Generally, however, the productive efficiency for grain of an absorbed nutrient tends to be lowered with the increase in yield. As shown in Fig. 6, Seino[12] (1968) reported that there was a close positive correlation between the yield and the uptake of nitrogen per unit yield of grain, but that the yield reached a maximum at a certain level of nitrogen uptake. This critical level was found to be approximately 2. 0 kg N/100kg brown rice, which corresponds to 50 kg brown rice/kg N as expressed in terms of productive efficiency of absorbed nitrogen. This would indicate that the productive efficiency of nitrogen should be maintained around 50, though it is necessary to promote the uptake of nitrogen for

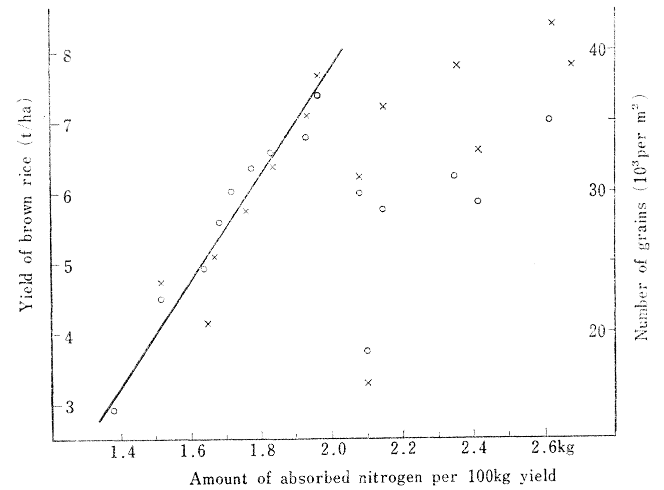

Fig. 6. Relationship between yield of brown rice and the amount of absorbed nitrogen per 100kg yield. (K. Seino 1968)

Tadle 6. Productive efficiency for grain yield of nutrients absorbed by high yield rice (K. Seino 1968)

Names and locations		Yield of brown rice (t/ha)	Productive efficiency		
			N	P_2O_5	K_2O
No. 1 Contest Prize Winner	Kato	10.8	69	128	48
	Kameyama	10.8	46	125	54
	Kudo	10.6	60	164	54
	Joraku	10.2	49	139	34
	Kitahara	10.2	53	102	31
	Tan	9.2	75	141	43
	Koike	7.9	50	439	53
	Mean	10.1	57.4	177	45.3
Experimental Station	Zentsuji	8.2	47	118	50
	Konosu	8.1	34	83	28
	Kagawa	8.1	49	189	44
	Morioka	7.8	45	135	50
	Fukuyama-1	7.8	42	70	32
	Kuroishi-1	7.7	52	—	—
	Hainuzuka	7.6	33	108	30
	Takada-1	7.5	52	—	42
	Kuroishi-2	7.4	50	99	32
	Fukuyama-2	7.4	46	90	31
	Fukushima	7.2	55	124	39
	Takada-2	7·1	38	85	25
	Fukuyama-3	7.0	38	95	26
	Saijo	6.4	47	121	43
	Mean	7.5	44.8	110	36.3
Total average		8.3	49.1	134	39.5

Productive efficiency=yield/absorbed nutrient

obtaining a high yield.

An example of the efficiency at higher levels of the yield is shown in Table 6. The table shows that the productive efficiencies of nitrogen, phosphorus, and potassium are higher at the yield levels of 10 tons/ha, which were achieved by farmers in high yield contest, than at 7 tons/ha obtained at various experimental stations. This may indicate that the productive efficiencies of nutrients are not always decreased with the increase of the yield. To increase the efficiency, however, close attention must be paid to the choice of variety and season, management of the soil and water, and prevention of diseases and insect pests in addition to improvement of the fertilization method.

Special considerations on recent fertilization techniques in Japan

In the fertilization techniques, spesial considerations should be given to the following :

1) Adequate supply of nutrients : An adequate supply of nutrients is required for attaining a high yield. Since the natural supply of nutrients from soil and irrigation wa-

ter is limited, and for the maintenance of soil fertility, the shortage of nurients must be replenished with fertilizers. Special attention must be paid to silicon because it is absorbed in greater amount compared with other nutrients. Also the depletion of micro elements from the soil must not be overlooked.

2) Placement and timing of application : Placement and the timing of application of fer-filizers are important to ensure the plant to absorb adequate amount of nutrients safely. Deep placement would be an efficient means to increase the plant utility of fertilizer nutrients as the result of its long-lasting effect. Timing of application is one of the most effective means for controlling the performance of the rice plant.

3) Basal application of nitrogen : As for nitrogen, the basal application is indispensable for the maintenance of adequate number of tillers or panicles. But excessive amount of basal application would cause a decrease in yield by bringing about heavy mutual shading or plant lodging. Therefore, it might be safer that the rate of basal application be so controlled as to sustain the plant up to the growth stage of ear primordia formation.

4) ***"Hogoe"*** or panicle top-dressing : ***"Hogoe"*** or panicle top-dressing is an effective means for increase of number of spikelets per unit land area. But at the same time, it exerts an influence on the plant type by elongating the upper leaves. The rate and timing of *"hogoe"* or panicle top-dressing should be determined considering the inter-relationship between the source and sink of photosynthates.

5) Top-dressing at later stage : The top-dressing around the heading time contributes to the production of dry matter through the increase in the photosynthetic rate of leaves. In the case the plant community is of favorable type for receiving the sun-light and it has an adequate number of spikelets per unit leaf area, the top-dressing at this time may increase the yield by raising the percentage of filled grain and weight of 1, 000 grains.

In conclusion, the fertilization method in Japan is developing to such a direction as to keep the nutrition of rice plants in good condition until the latter half growing period. This is achieved by supplying well-balanced nutrients and by the top-dressing practice accompanied with improvements of various other related factors. In other words, fertilizers are now used as a means to regulate the growth of the rice plants into a desired direction.

Discussion

K. Kawaguchi, Japan : 1) How many percentage of rice plant residue is returned to a field now in your country? 2) Has it been increasing or decreasing in recent years? 3) How about near future?

Answer : I don't know the actual amount of straw applied to paddy field in Japan. The statistics would indicate the trend of decreasing. But, in past days raw straw was used for various object such as fuel, rope, bags and so on. Recently these things are not made of straw in Japan. Then, I suppose, larger amount of raw straw would be returned to paddy field. In future, the entire amount of rice straw may be returned to paddy field with the development of mechanized cultivation.

T. Murakami, Japan : In Figure 4, the yield-straw ratio drops in proportion to the rise of yield level even when yield is efficiently acquired. Is it impossible to acquire the high yield without the depression of this ratio?

Answer : Recently Dr. T. Yoshida and T. Kiuchi pointed out that the ratio of grain yield to total dry matter of rice plant follows the rule of relative growth theory ($y=ax^b$).

According to this theory the yield-straw ratio may gradually decrease with the increase of yield level. But, it may be possible to increase the ratio on the lmited range by some adequate techniques.

It was shown in Fig. 3 that "*hogoe*" or panicle top-dressing was an effective method to increase the yield-straw ratio. Recently, a new top-dressing method called "deep-layer application," in which nitrogen fertilizer is injected into a depth of 10-12 cm at a time about 35 days before heading, is gaining popularity in northern Japan with increased grain yields. The rice plant grown by this method has large number of spikelets per unit weight of straw at a heading time, resulting with higher yield-straw ratio. But the permitted limit to increase the ratio may be narrow when the varieties used for experiments are the same.

H. Fukui, Japan : If the meaning of organic material application is merely the continuous supply of nutrient, very high yield could be attained by many split applications or slowly-releasing organic chemical fetilizers. Is this statement correct?

Answer : I stated only on the role of organic matter from the view point of supplier of mineral nutrients. But it has other important roles. Farmers in Japan have set a high value on the application of manure to rice cultivation. Especially, they have believed its specific roles to obtain the higher yield. The first of them is the amelioration of soil structure. It makes the paddy soil in granular structure which is beneficial to water managemant and to keep the plant root healthy, thus contributing to increase the yield. The second is the supply of carbon as an energy source to soil micro-organisms, resulting with the increase of soil fertility. I like to point out the third function of organic matter which would supply carbon dioxide for plant community. I suppose, cabon dioxide produced from the organic matter would be utilized for photosynthesis and increase the yield content during the ripening period of plant. In this case, it is important to control the water level in paddy field, because the production of carbon dioxide from organic matter depend on the oxidative condition of the soil.

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