1. THE CHANGES IN PADDY FIELD RICE VARIETIES IN JAPAN

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Introduction

Since B. C. 200, the Japanese have been cultivating rice for their staple food, gradually expanding its cultivation from Kyushu, the southernmost district to northernmost area. Before the 19th century rice varieties were recognized by the people, but the first leading variety in modern meaning, OMACHI was released from a farmer in 1869. In 1877, various fertilizers were demonstrated at the Exhibition and varietal trials of foreign rice varieties were started in 1878. In 1880, the soil survey was started and the consumption of fish-meal was increased, and a seed multiplication union for rice was organized in 1883. In 1888, the manufacturing of super-phosphate was started, and all rice varieties in Japan were collected for breeding purposes in 1892. In 1893, the National Agricultural Experiment Station and its branch stations were opened in succession. Before 1896, famous leading varieties, SHINRIKI, AIKOKU and BOZU etc. had been released from farmers, and in this year 5 tons of ammonium-sulphate was first imported and the import was increased to 1, 741 tons in 1900. The first cross hybridization origin variety, named OOMI-NISHIKI was released in 1906 from Shiga Prefectural Experiment Station and a famous hybrid origin modern variety, RIKUWU 132 was released in 1921 from Rikuwu Branch, National Agricultural Experiment Station. The preparation for making the standards of fertilizer application in each district was started in 1916 and the standards were completed in 1946. And also the plots of heavier fertilizer application were added to the standard plots in all of the yield tests after 1916. The import of soybean cake was maximum in 1919 but the percentage of selfsufficiency of ammonium-sulphate reached 81% in 1932, and the production of ammonium-sulphate exceeded the consumption of soybean cake in 1935. The systematic rice breeding network of the Government was organized in 1928 and the changes of rice varieties have thereafter been very rapid especially after 1955. The sequence of changes of varieties and their backgrounds are explained in the following chapter.

Changes in leading paddy field rice varieties.

The sequence of changes in leading paddy field rice varieties from 1908 to 1968 is shown in Figure 1. A leading variety in this report means a variety planted over 10, 000 ha. The diagram has prepared based on the total planted area of leading varieties in 1908, '25, '32, '39, '45, '51, '55, '57, '59, '61, '63, '65, '67 and '68. Classification of leading varieties by origin and by planted area is also given as in the remarks in Figure 1.

The total planted area of paddy field rice in Japan is about 3 millions ha and has no big variation after 1900. The total planted area of leading paddy field rice varieties is about 1. 5 to 2. 2 millions ha with three concaves in 1925, 1945 and 1961 and four convexes in 1908, 1939, 1955 and 1967. It could be said that the modern rice culture in Japan was started after 1908, and the main points of the changes in rice varieties are as follows : -

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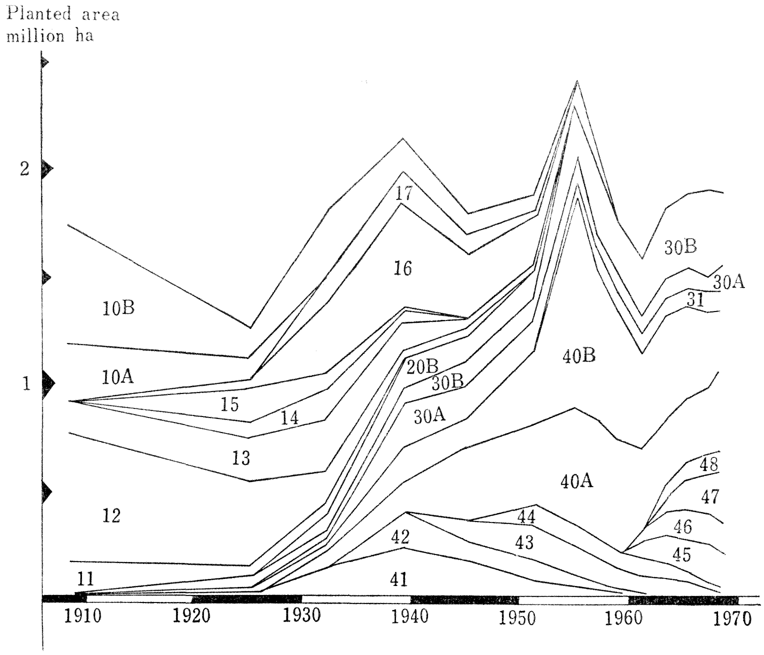


Remarks : -

10's level - indigenous and/or pure line selection varieties.
20's level - cross hybrid varieties released from farmers.
30's level - cross hybrid varieties released from prefectural experiment stations.
40's level - cross hybrid varieties and induced mutant varieties released from Rice Breeding Network of the Government.

Predominant varieties - Planted over 100,000 ha at least one year.

11. OMACHI	15. KAMENOO	41. RIKUWU 132	45. HONENWASE
12. SHINRIKI	16. ASAHI	42. NORIN 1	46. KOSHIHIKARI
13. AIKOKU	17. GINBOZU	43. NORIN 18	47. FUJIMINORI
14. BOZU	31. KINMAZE	44. NORIN 29	48. HOUYOKU

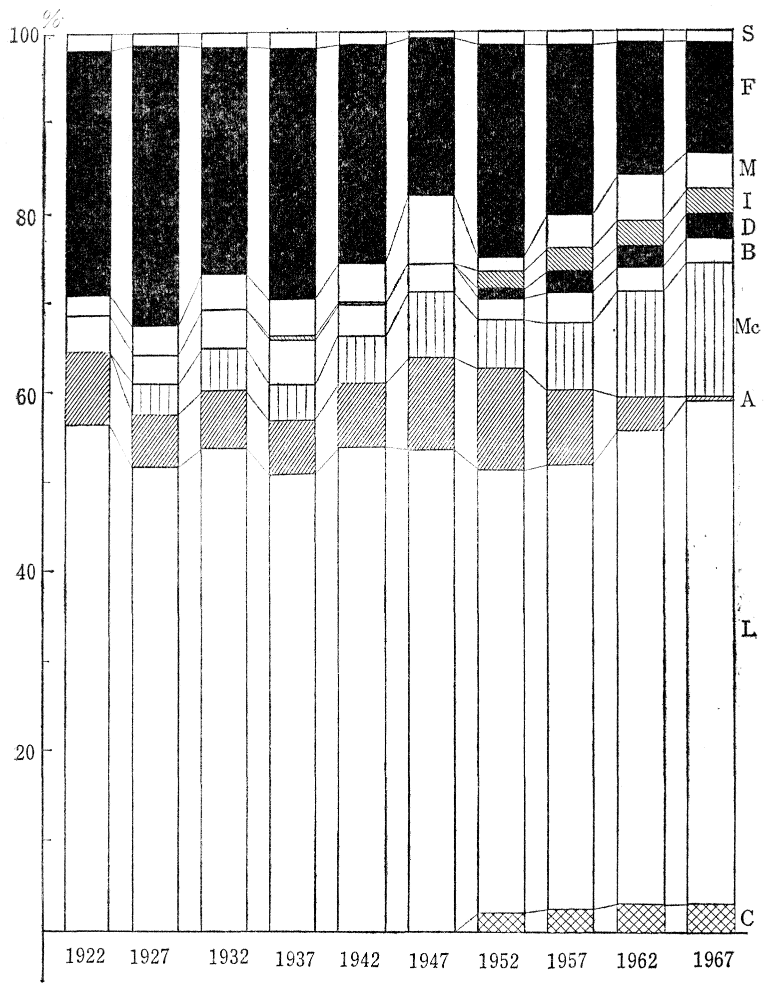
A - total planted area of varieties planted over 50,000 - 100,000 ha at least one year.

B - total planted area of varieties planted over 10,000 ha in each survey year but not included among predominant varieties and A group varieties.

Fig. 1. Changes in leading paddy field rice varieties.

In 1908, the predominance of OMACHI (No. 11), SHINRIKI (No. 12) and AIKOKU (No. 13) was established because these varieties had better yield and higher quality than the others.

In 1925, pure line selection for the majority of varieties was completed and application of fertilizers was increased among the leading varieties, so not all the varieties could follow the modern environments. As an example, SHINRIKI and OMACHI could not increase their planted area because of their lower adaptability to higher fertilizer application. KAMENOO (No. 15) was a good variety with higher quality and its planted area had been increasing, but after this year the planted area was decreased because it was susceptible to blast disease. On the contrary, with their higher adaptability to unfavourable environments



Remarks : -

S - Seed and seedling
F - Fertilizers and manures
M - Materials
I - Irrigation and drainage
D - Disease and pests control
B - Buildings
Mc - Agricultural implements and machineries
A - Draft animals
L - Labor cost and wages
C - Charge and fee

Fig. 2. Structure of production cost for brown paddy field rice. 1922-1967.

and resistance to disease AIKOKU (No. 13) and GINBOZU (No. 17) increased their planted area despite their inferior quality. BOZU (No. 14) was released as the earliest modern variety and then the planted area of rice in Hokkaido, the northernmost district in Japan, was increased. These varieties were not only important as commercial varieties but also as important genetic stocks. The reason why the total planted area of leading varieties showed a decrease in this year was that the most of the previous leading varieties were not suitable to the modern environments. In 1928, the rice breeding network of the Government was started and this network consisted of one rice breeding centre in one ecotypic area, so there were nine breeding centres in this year. Numbers of breeding centres in this network at present are 15.

In 1932, because the milling quality of ASAHI (No. 16) was rather higher than SHINRIKI (No. 12) and ASAHI had better adaptability to modern rice culture, the planted area of ASAHI was increased rapidly until the end of World War II. And varieties released from farmers and prefectural experiment stations appeared are seen as 20B, 30A and 30B in Figure 1.

In 1939, RIKUWU 132 (No. 41) and NORIN 1 (No. 42) attained the maximum planted area and this was just before the abnormal conditions during the war time. The planted area of RIKUWU 132 in this year was 229, 000 ha and this record has never been broken up to now. Many rice varieties released from prefectural experiment stations and farmers, were adopted as the leading varieties, and indigenous and pure line selection varieties other than ASAHI and GINBOZU disappeared after this year. Rice breeding network of the Government came into effect after 10 years experience by this year.

In 1945, with the end of the World War II, every condition in Japan were the worst in this year and many local leading varieties were planted, but the planted area of predominant varieties decreased. Only NORIN 18 (No. 43) increased its planted area replacing SHINRIKI (No. 12) in western Japan.

In 1951, the planted area of NORIN 18 and NORIN 29 (No. 44), both were widely adaptable varieties, increased while that of ASAHI (No. 16) decreased considerably.

In 1955, the planted area of leading varieties showed the highest peak and many "A" and "B" class leading varieties occupied the majority, because the higher yield was the common target of rice growers in Japan. Lack of specially exceeding varieties increased the planted area of minor leading varieties which showed high yields in limited area but were not so widely adopted. Most of varieties released from farmers were heavy panicle type varieties that generally were not suitable to heavy application of fertilizer, and then disappeared as fertilizer application increased.

Since 1959 to present, old type leading varieties, RIKUWU 132 (No. 41), NORIN 1 (No. 42), NORIN 18 (No. 43) and NORIN 29 (No. 44) have been decreasing, while new leading varieties, HOUNENWASE (No. 45), KOSHIHIKARI (No. 46), FUJIMINORI (No. 47) and HOUYOKU (No. 48) have been increasing. KINMAZE (No. 31) has also been a leading variety. Among them, FUJIMINORI reached 214, 040 ha in 1968 and this is the first variety exceeding 200, 000 ha of planted area among the varieties released from Rice Breeding Network of the Government.

Figure 2 shows the changes in percentage of items composing the production cost of brown rice since 1922 to 1967. The actual production cost for one ton of brown rice was US$100 in 1952, $111 in 1957, $131 in 1962 and $194 in 1967. The cost in 1967 consisted 1.3% for seed and seedling, 12.4% for fertilizers and manures, 4.0% for materials, 2.9% for irrigation and drainage, 2.6% for diseases and pests control, 2.8% for buildings, 14.8 % for agricultural implements and machineries, 0.6% for drafting animals, 55.6% for labor cost and wages and 2.9% for charges or fees. The weight of fertilizers and manures was high in 1952, the post-war time, but this has been decreasing year by year. The actual cost of purchasing fertilizers per ton of brown rice production was about US$14 and has no big difference between 1952 and 1967, even the dosage of fertilizer application is increasing. This depends upon the decreasing of the unit cost of fertilizer production by the development of fertilizer industry.

Figure 3 shows the changes with years in the brown rice yield since 1881 to 1968. The yield of rice in Japan were rather low before 1955, but after 1955 total rice production

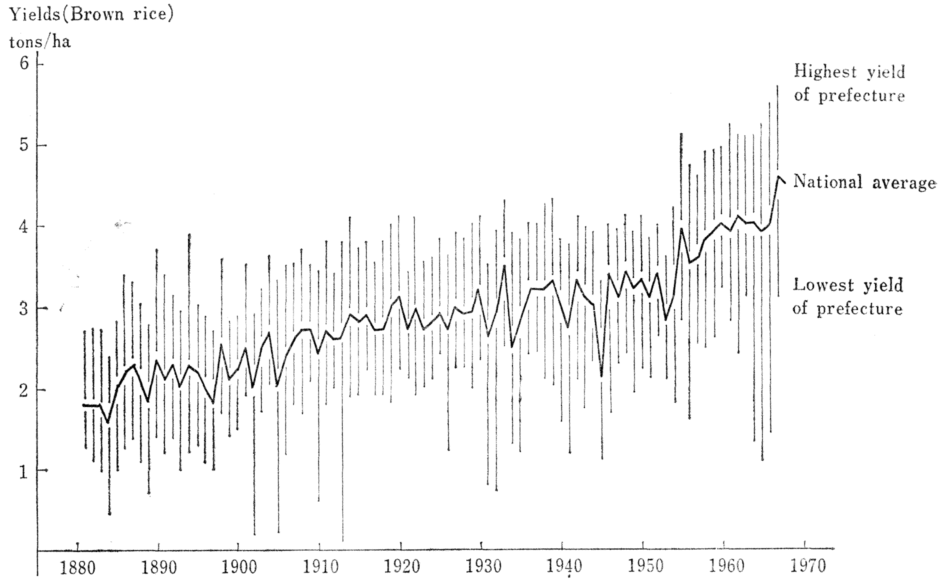


Fig. 3. Changes with years in the yield (brown rice) of paddy field rice. 1881-1968.

in Japan has been increasing. But even now the yield of prefectural lowest has been unstable recording very low yield during 1964 to 1966, because of cold damages in Kitami area, the north-eastern limit of rice culture in Japan. It will be an important future problem to reduce the prefectural differences in yield that are shown in the length of vertical lines in the diagram.

Changes in characteristics of growth with improvement in yield.

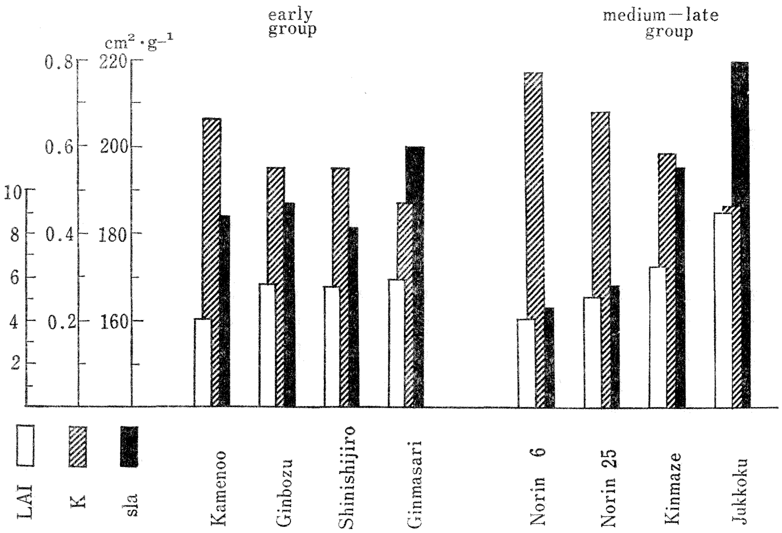
Rice breeders of Japan have continuously been breeding many varieties to meet the demands for higher yielding varieties with much more improved fertilizer response, and some of the recent varieties are quite excellent. General trends of changes in characteristics of variety are to have early-medium maturity, shorter stiff culm resistant to lodging, more number of panicles and spikelets per unit area of land. A typical example is shown in Table 1.

In this table, HOUYOKU, a new typical high yielding variety in Kyushu, the western-most district in Japan, with pronounced erect habit of leaves and fertilizer response, is compared with NORIN 18, an older predecessor with long drooping leaves and inferior response. Clearly HOUYOKU's higher yield depends on increasing the number of ripened grains per sq. meter, which is due entirely to more panicles. HOUYOKU also exceeds in total number of leaves despite its shorter growth duration and culm. These data suggest that HOUYOKU has been improved both in source and sink of photosynthete.

It will be interesting to examine characteristics of variety in relation to efficiency of solar energy conversion. Hayashi (1969) has reported higher efficiency of solar energy conversion particularly in ripening period in high yielding varieties that have a combination of higher leaf area index (LAI), smaller light extinction coefficient(K) and bigger specific leaf area (sla). This trend of combination is more clear when the varieties in past several

Table 1. Attributes of growth and yield in new (Houyoku) and old (Norin 18) rice variety.

Attributes	Houyoku	Norin 18
Growth duration after transplanting (days)	130	134
Total number of leaves on main stem	17.6	16.2
Length of culm (cm)	72	87
Length of panicle (cm)	19	22
Nos. of panicles per m^2	378	259
Nos. of ripened grains per panicle	86	95
Nos. of ripened grains per m^2	32500	24600
Weight of 1000 brown rice (g)	22.4	24.3
Yield of brown rice per m^2 (g)	584	516



Remark : Measurements were made 10 days after heading.

Fig. 4. Changes in leaf area index (LAI), light extinction coefficient (K) and specific leaf area (sla) of rice varieties. (Hayashi and Ito 1962)

decades are compared as in Figure 4.

In Figure 4, rice varieties are grouped into two, early and medium to late, and in each group varieties are arranged from left to right according to their yields in the experimental field in the Institute, Hiratsuka, Japan.

It will be noticed that an improvement in yield is almost always accompanied by an increase in LAI and sla, and by a decrease in K. In other words plant tends to have a higher LAI with thinner leaves in better form of plant. An adding explanation for JUKKOKU is that this is the mother variety of HOUYOKU and both are quite alike in form of plant.

It now is a widely accepted idea that a smaller K implies better form of plant, and K

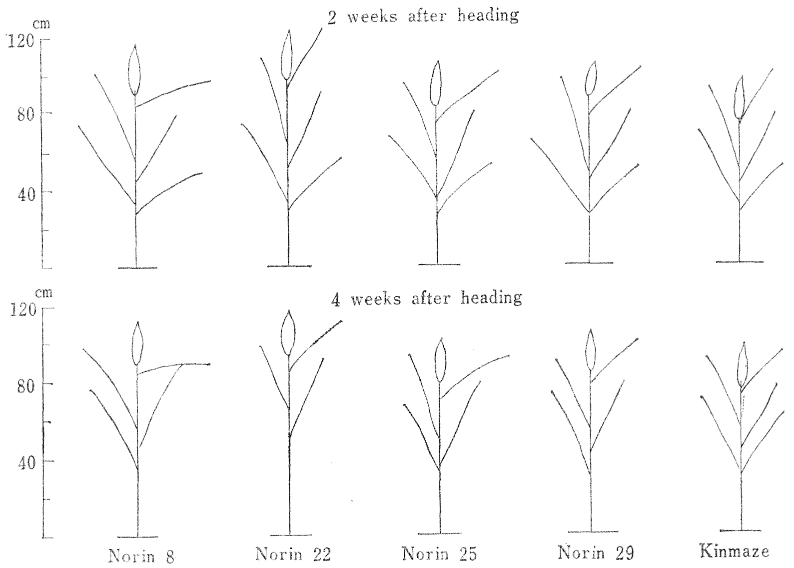


Fig. 5. Trend in improvement of form of plant in rice varieties.

is smaller as leaves are more erect and thinner. Trends in improvement of form of plant is demonstrated in Figure 5.

In Figure 5, leftward three inferior varieties have taller statue and longer more horizontal leaves that easily bend. Rightward two superior varieties have shorter statue and slightly, not extremely, shorter more erect leaves that hardly bend. The difference becomes more clear as maturing advances, and also senescence of lowermost leaves occurs in all varieties except KINMAZE. Tsunoda (1959) already showed similar trends in the improvement of form of plant for better fertilizer response.

Since yield is determined in the balance between source and sink of photosynthate the changes in characteristics should be examined also from both sides of the source and sink. Osada and Murata (1965) have reported less decreases in the ratio of photosynthesis to respiration and of panicle to straw weight at a higher dose of nitrogen in the varieties adaptable to heavy application of fertilizer. Tanaka, Yamaguchi, Shimazaki and Shibata (1968) have reported no varietal difference in photosynthetic rate per unit leaf area of the leading varieties in past five decades in Hokkaido. And also, the general trends detected were to have higher LAI, more panicles and spikelets per sq. meters and smaller K.

Table 2 gives another example in which the source and sink at heading period and their subsequent balance estimated either by efficiency of solar energy conversion (Ec) or by panicle weight ratio are presented. In Table 2, varieties are arranged from old to new according to their released year in each group. In the source at heading period with FUJIMINORI and ASAHI as exceptions LAI and sla tends to increase, while leaf area per stem (A) decrease. In the sink, though the trends is less clear in the early group, numbers of spikelets per sq. meter (N) and numbers of spikelets per unit dry weight of plant (N/W) tends to increase, while leaf area per one spikelet (L/N) decrease, indicating an improved efficiency of forming spikelets relative to dry weight or LAI and also a reduction in sink other than spikelets. The decrease in (A) and (L/N) might act to reduce

Table 2. Changes in characteristics of growth and in efficiencies of solar energy conversion of rice varieties.

Varieties	Heading period						Ec			Maturity
	LAI	A	sla	N	N/W	L/N	P_1	P_2	P_3	HI
		cm	$cm^2.g^{-1}$	×100	g^{-1}	cm	%	%	%	%
early group										
Kamenoo	4. 51	180	221	344	46	1. 31	1. 19	1. 47	1. 27	44. 4
Sasashigure	4. 65	150	236	325	43	1. 43	1. 22	1. 46	1. 29	49. 4
Hounenwase	4. 42	113	235	297	43	1. 49	1. 16	1. 99	1. 40	48. 7
Fujiminori	3. 87	163	229	257	40	1. 50	1. 09	2. 31	1. 45	46. 0
Sasanishiki	4. 87	126	240	374	53	1. 28	1. 26	1. 94	1. 46	53. 0
medium group										
Asahi	8. 64	234	231	517	41	1. 67	1. 54	2. 09	1. 65	35. 0
Ginbozu	6. 99	220	225	476	40	1. 47	1. 47	2. 02	1. 58	40. 6
Norin 6	6. 42	188	219	421	37	1. 52	1. 50	1. 44	1. 39	38. 6
Norin 8	6. 97	212	226	417	39	1. 67	1. 33	1. 78	1. 42	39. 3
Norin 22	5. 57	209	215	343	46	1. 62	1. 25	2. 01	1. 41	41. 7
Norin 29	6. 12	181	239	437	46	1. 40	1. 27	2. 19	1. 57	44. 4
Kinmaze	7. 56	173	245	491	46	1. 54	1. 48	2. 28	1. 68	40. 9
Nakate Shinsembon	7. 62	172	250	507	43	1. 50	1. 51	2. 23	1. 67	43. 0
late group										
Norin 18	8. 71	265	230	374	28	2. 33	1. 42	1. 17	1. 39	26. 7
Houyoku	9. 01	204	262	442	37	2. 04	1. 33	2. 20	1. 47	35. 0

Remarks. A: leaf area per stem, N: nos. of spikelets per m^2, N/W: nos. of spikelets per unit dry weight of plant, L/N: leaf area per one spikelet, Ec: efficiencies of solar energy conversion assuming that 1 g dry weight is equivalent to 4000 cal, P_1: growing period from transplanting to heading, P_2: growing period from heading to maturity, P_3: P_1+P_2, HI: dry weight ratio of panicle to whole plant.

mutual shading of leaves when more spikelets are formed mainly by increasing the number of panicles. Efficiency of solar energy conversion (Ec) of vegetative period (P_1) differs not much among the varieties, but that of ripening period (P_2) is apparently higher for the improved varieties than for the older ones, indicating an increased dry matter production. Increasing the efficiency of solar energy conversion of the whole period (P_3) and the panicle weight ratio (HI) in the improved varieties indicates a favourable combination of higher percent of yield and bigger plant weight. The maturing periods of late varieties in this experiment were too late to give proper value of panicle weight ratio, so only the relative magnitude is informative.

FUJIMINORI of which yield depends much more on weight of panicles than on number of panicles has changed in rather opposite trends, but its efficiency of solar energy conversion in ripening period was the highest. ASAHI and GINBOZU, from their crossing many good varieties have subsequently been derived, show defects only in the A and HI. As a rule, the early group is more efficient in many respects than the late group with the medium group in-between, this could probably be attributable to the difference in growth duration.

A close possitive correlation between LAI and sla implies a difficulty to increase simultaneously both LAI and photosynthetic rate of unit leaf area, because the leaves of bigger sla, namely thinner leaves, tend to photosynthesize less. But this is very well compensated by having K smaller, with which the improved varieties perform a greater dry matter production at a higher LAI. The advantage of thicker leaves will directly be reflected on increasing the yield when intense light falls upon the leaves as in the case of lower LAI or ample radiation. Less sink other than spikelets at heading period in the improved varieties might indicate an increased dependency of yield on dry matter production after heading and hence on more favourable weather particularly in radiation. In short, most of the newer leading varieties have been improved both in size and efficiency of the source and sink of photosynthate per unit area of land by increasing the number of spikes and by shortening the culm.

Conclusion

Factors affecting the changes in rice varieties are not few, but the increase of fertilizer application is one of the predominant factors up to now. Most of the newer leading varieties have so far been improved both in size and efficiency of the source and sink of photosynthate per unit area of land by increasing the number of spikes and by shortening the culm. Considering that the main target of future rice production in Japan is to reduce the cost of production as low as the international cost, the direction of changes in rice varieties might be slightly changed.

Because the genic constitution of plant materials for experimental use are sometimes not same even their names are completely same, it will be difficult to have precise repeat or comparison of the experiments unless enough consideration is given to this point. To solve these problems, it is important to provide the international network of genic resources centres and supply centres of plant materials. By the close cooperation of all the scientists of the world, the authors expect that these organizations are established in near future.

Discussion

Chee, S. P., Malaysia : What is actually meant by the term thinner leaves? Does this mean the width or the depth of a leaf? I would be grateful if the speaker could elaborate this.

Answer : Thinner leaves in this presentation mean the leaves of higher specific leaf area(sla). The sla is a term in growth analysis showing that to how many cm^2 the lamina of one gram dry weight is expanded, so the higher the sla the thinner the leaves. We already confirmed a very close negative correlation between sla and leaf thickness actually measured by a micro-caliper.

Y. Murata, Japan : Concerning the comparison of productivity between Houyoku and Norin 18, which characteristics is most responsible for the difference ? Please explain the problem from the point of formation of "yield container" and of production of "yield content".

Answer : Apparently the increase in number of spikelets that is "yield container" is the one reason for HOUYOKU's higher yield. We have an experimental evidence, not with HOUYOKU unfortunately, but with the varieties of similar habit of erect leaves, that the lower leaves of the varieties with smaller K can survive longer probably due to improved light penetration. This will certainly act to maintain photosynthetic rate of leaves, and this could be considered as an increase in "yield content". Thus, HOUYOKU's higher yield is attributable to the increase both in "container" and "content".

Y. Murata, Japan : Do you think it necessary to have thinner leaves in order to improve light receiving habit of rice variety ?

Answer : For receiving light alone I don't think it necessary, but for improving the efficiency of solar energy conversion per unit land area of a dense crop thinner leaves would be more advantageous because thinner leaves can form high LAI with minimum light extinction coefficient (K) while thicker leaves have an adverse effect to increase K. But I don't think that the leaves should so extremely be thin that they easily bend.

S. **Yoshida**, IRRI : How much more in terms of grain or total dry weight do you believe you can improve the existing Japanese varieties by changing plant morphology ?

Answer : We can't answer any accurate magnitude because the attributes you asked depend to a greater extent on amount of radiation which is so variable through years and places. The evidence that an improvement in form of plant as in the case of IR 8 might give you an idea of the magnitude.

(Comment) S. **Tsunoda**, Japan : I would like to make a short comment on the cultivation on *indica* varieties in Japan. Besides *japonica* varieties dealt with by Dr. Hayashi, varieties occupied a fairly large proportion to the total rice cultivation in Japan at least about 500-600 years ago. Such *indicas* completely disappeared from Japan about 50-60 years ago just after the farmers began the application of ammonium sulphate.

Answer : Thank you, Dr. Tsunoda for making such an interesting comment, though we have no appropriate data on *indica* at the moment.

References for Paper 1

1. Hayashi, K. and H. Ito (1962) : Studies on the form of plant in rice varieties with particular reference to the efficiency of utilizing sunlight.
   1. The significance of extinction coefficient in rice plant communities. Proc. Crop Sci. Soc. Japan 30 : 329-333.
2. Hayashi, K. (1969) : Efficiencies of solar energy conversion and relating characteristics in rice varieties. ibid. 38 : 495-500
3. Ito, H. (1960) : Rice culture in Japan - A diagramatic introduction to its physical, economic and social backgrounds. Japan FAO Association.
4. Ito, H., H. Uchiyamada and M. Minoshima (1961) : A genealogical consideration on the transition of leading paddy field rice varieties in Japan during 1908 to 1955. Japanese J. Breeding 11 : 285-290.
5. Osada, A. and Y. Murata (1965) : Studies on the relationship between photosynthesis

and varietal adaptability for heavy manuring.

3. Effects of photosynthetic characteristics on dry-matter-production and ripening of rice varieties. Proc. Crop Sci. Soc. Japan 33 : 460-446.

6. Tanaka, A., J. Yamaguchi, Y. Shimazaki and K. Shibata (1968) : Historical changes viewed from form of plant in paddy rice varieties in Hokkaido. J. Sci. Soil & Manure, Japan 39 : 526-534.

7. Tsunoda, S. (1959) : A developmental analysis of yielding ability in varieties of field crops.

2. The assimilation-system of plants as affected by the form, direction and arrangement of single leaves. Japanese J. Breeding 9 : 237-244.

8. Out of the above various statistical tables issued by Ministry of Agriculture and Forestry, were used.