THEORY AND PRACTICE OF GROWING RICE

EDITORIAL COMMITTEE

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Overseas Technical Cooperation Agency

Tokyo, Japan

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FOREWORD

Japan is geographically situated in Asian monsoon area and economically compelled to support a huge population crowded in the limited land area. As a result, it is quite natural that Japan has met with great success in achieving a unique intensive agriculture with rice culture as its mainstay.

With the problems of economic development in Asian countries coming to the forefront in the post-war period, food production increase has become increasingly important for the stabilization of needy people's livelihood. In this respect, agricultures in Japan has aroused a deeper interest of the United Nations, particularly FAO, etc., including rice-producing countries in general.

In consequence, a great many agricultural specialists have visited the country one after another, and many specialists in this sector have been sent from Japan as well. In such cases, however, a lack has been keenly felt of handy books written in English to introduce Japanese rice cultural techniques among overseas specialists. Earnest request for the publication of such helpful books has also been made from various parts. With a view to meeting such expectations, the Central Agricultural Experiment Station of the Ministry of Agriculture and Forestry, with the cooperation of the related staff members of the National Institute of Agricultural Sciences, has organized an editorial committee, and, with collaboration of the first-class rice experts, has attempted to prepare a book commenting on the rice cultural theory and techniques now prevalent in the country.

For want of time and space, the prepared book leaves much to be desired, but we have been encouraged in publishing it in our firm belief that this publication can meet the requirements on the part of overseas specialists who are much interested in rice culture in Japan.

It is hoped that this publication may contribute greatly toward the food production increase as well as toward the rice cultural techniques improvement in other rice-producing countries.

January, 1963.

KAWADA, Akira

CONTENTS

CHAPTER 1

CURRENT STATUS AND HISTORICAL DEVELOPMENT OF RICE CULTURE

Japan ranks seventh among the world's rice producing countries in rice planting area, and ranks third in rice production, but ranks first in rice yield, except Italy and Spain very small in rice planting area. The high rice yield is the salient feature of rice culture in Japan, i.e., highly intensive in culture with heavy fertilizer application and much labor input (Table 1–1).

1. Environmental Conditions for Rice Culture

1. Natural conditions

Rice is grown throughout the country (Fig. 1–1). In Japan, paddy rice acreage accounts for 95 per cent of the total rice area, and upland rice acreage comprises the remaining 5 per cent. Japan, lying in the North Pacific Ocean, stretches in a southwest-northeast direction off the east coast of Asia, is characterized by its local variation in climatic feature. The agricultural production is affected greatly by the local climatic conditions. Particularly, the climatic conditions during the rice cultural season have close bearing upon rice culture. Table 1–2 shows air temperatures and

Table 1-1. Population, Arable Land Area, Rice Planting Area, and Rice Production in the Leading Rice Producing Countries

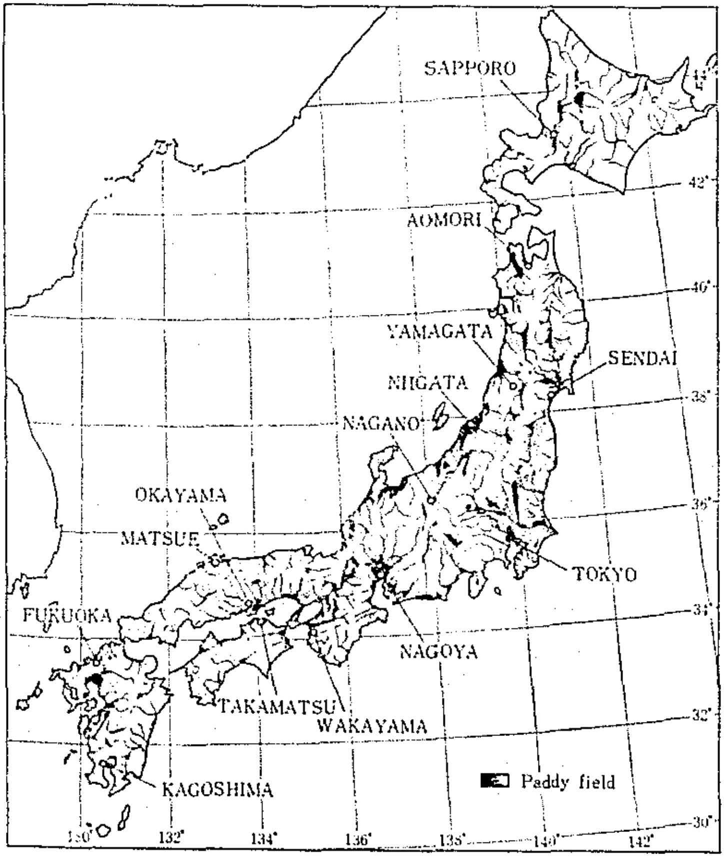
Country	*Population*	*Population density*	*Arable land area*	*Population density per arable land area*	*Rice planting area*	*Percentage of rice planting area to arable land area*
	1,000 prs.		1,000 ha.		1,000 ha.	
Denmark	4,500	106	2,764	163	—	—
France	44,071	80	21,325	207	27	0.1
W. Germany	53,692	217	8,699	619	—	—
Italy	48,483	161	15,781	307	126	0.8
U. K.	51,455	211	7,092	726	—	—
U. S. S. R.	200,000	9	221,366	90	—	—
U. S. A.	171,229	22	188,309	91	542	0.3
Burma	20,054	30	8,582	234	3,868	45.0
China (main)	640,000	66	109,354	585	32,100	29.3
India	392,440	119	158,341	248	31,981	20.2
Indonesia	85,100	57	17,681	481	6,830	38.6
Japan	90,900	246	5,048	1,801	3,232	64.0
Pakistan	84,450	89	24,726	342	9,292	37.6
Philippines	23,322	78	7,296	320	2,699	36.9
Thailand	21,076	41	7,793	270	4,576	58.7

(*Continued*)

Country	*No. of farm households*	*Rice area per farm household*	*Agricultural workers*	*Rice planting area per agr. worker*	*Rice production (paddy)*	*Rice production per farm household*	*Rice yield per hectare*
	1,000	ha.	1,000 prs.	ha.	1,000 tons	ton	ton
Denmark	211	—	518	—	—	—	—
France	3,974	0.01	7,484	0.004	114	0.029	4.3
W. Germany	1,253	—	5,113	—	—	—	—
Italy	2,537	0.05	8,468	0.002	597	0.235	4.7
U. K.	345	—	1,282	—	—	—	—
U. S. S. R.	—	—	—	—	—	—	—
U. S. A.	4,386	0.12	7,331	0.074	1,948	0.444	3.6
Burma	—	—	—	—	5,828	—	1.5
China (main)	—	—	—	—	86,600	—	2.7
India	—	—	71,809	0.445	37,829	—	1.2
Indonesia	—	—	—	—	11,611	—	1.7
Japan	5,667	0.57	17,224	0.188	14,328	2.528	4.4
Pakistan	15,055	0.62	17,125	0.542	12,935	0.855	1.4
Philippines	1,847	1.46	4,875	0.553	3,203	0.173	1.2
Thailand	—	—	7,674	0.600	5,724	—	1.3

Note: FAO, *Production Yearbook*, Figures for 1957 and around.

Fig. 1 – 1. Distribution of Paddy Field
(Ito)



precipitations during the rice cultural season (April–October) in the leading rice producing centers in Japan. These figures indicate that Japan is comparatively favored by temperatures and precipitations owing to the climate largely determined by the monsoons. The island country of Japan is a land of many volcanoes, traversed by north-south mountain ranges, forming as it were a backbone, and steep in its topography. The leaching loss of soil constituents is great because of excessive rainfall. The land is composed of weak acidic and sterile soils. Under such topography, soil structure, and varied climatic conditions, specifically great caretaking and protection are required to be taken of crop culture. During the winter months, the weather along the Japan Sea coast is cold and there is considerable snow, while the weather along the Pacific coast is warm owing to the Black Current. When the country is taken as a whole, changes in natural conditions are great and violent. As a result, Japan is frequently visited by natural disasters which inflict great damage upon rice

Table 1-2. Air Temperatures and Rainfall during Rice Cultural Season in the Leading Rice Producing Centers

		April			*May*			*June*			*July*		
		E 10	*M* 20	*L* 30	*E* 10	*M* 20	*L* 31	*E* 10	*M* 20	*L* 30	*E* 10	*M* 20	*L* 31
Air Temperature Average (°C)	1	3.0	5.4	7.4	9.3	10.6	11.8	13.6	15.0	16.6	18.4	20.9	22.2
	2	4.3	6.6	8.4	10.8	11.8	13.1	14.8	16.1	17.6	19.2	20.9	22.6
	3	6.7	8.7	10.5	12.6	13.6	14.7	16.2	17.8	19.1	20.8	22.2	23.4
	4	6.5	8.8	11.0	13.1	14.3	15.7	17.7	19.1	20.4	21.6	23.4	24.4
	5	10.5	12.7	14.4	15.6	16.7	17.8	19.4	20.5	21.8	23.0	24.6	25.6
	6	8.0	10.2	11.8	13.6	14.9	16.1	18.1	19.7	20.9	22.2	24.1	25.5
	7	7.2	9.6	11.6	13.4	14.5	15.9	17.7	19.4	20.6	21.9	23.6	24.5
	8	11.1	13.1	14.6	16.2	17.3	18.6	20.3	21.5	22.7	24.4	25.9	26.7
	9	11.7	13.6	15.3	16.6	17.7	18.9	20.5	21.9	23.2	24.7	26.3	27.0
	10	10.1	11.4	13.2	15.7	15.9	17.5	19.3	20.8	22.0	23.2	25.2	26.3
	11	10.9	12.9	14.5	16.1	17.3	18.8	20.3	21.7	22.9	24.5	26.2	27.1
	12	10.5	11.7	13.5	15.8	16.7	17.5	19.9	21.5	22.8	24.5	26.5	26.3
	13	11.4	13.1	14.8	16.2	17.2	18.4	20.0	21.5	22.6	24.5	26.2	26.8
	14	13.8	15.4	16.8	17.9	18.9	19.7	21.0	22.4	23.8	25.2	26.5	27.0
Rainfall (Total) (mm.)	1	19	15	19	19	20	23	20	20	22	31	27	35
	2	25	21	36	22	24	23	24	28	26	37	46	43
	3	39	30	38	25	39	37	47	36	60	59	59	38
	4	28	23	26	26	26	26	24	34	43	50	49	44
	5	49	41	43	46	50	50	50	58	64	55	37	49
	6	37	32	36	33	31	26	27	38	53	64	54	43
	7	23	20	26	26	25	26	27	34	46	50	49	47
	8	50	44	54	57	47	52	51	85	80	77	57	48
	9	36	39	51	47	37	38	49	71	80	72	51	35
	10	44	28	29	46	42	37	34	51	89	94	46	44
	11	29	30	40	37	31	33	42	51	67	68	35	36
	12	31	21	21	29	26	26	35	57	51	74	63	31
	13	39	35	50	39	43	31	47	80	119	103	70	60
	14	64	71	66	73	74	69	82	148	180	145	83	73

(Continued)

		August			*September*			*October*		
		E 10	*M* 20	*L* 31	*E* 10	*M* 20	*L* 30	*E* 10	*M* 20	*L* 31
Air Temperature Average (°C)	1	21.5	21.5	20.6	18.9	16.3	14.2	12.1	10.1	7.7
	2	23.1	23.2	22.4	20.4	18.2	15.9	13.9	11.9	9.9
	3	24.0	24.1	23.5	21.9	19.8	17.6	15.7	13.6	11.7
	4	24.6	24.5	23.6	22.1	19.4	16.8	14.7	12.7	10.4
	5	26.0	25.8	25.4	24.3	22.2	19.8	17.9	16.2	14.4
	6	26.0	26.0	25.3	23.8	21.5	19.0	17.2	15.5	13.5
	7	24.6	24.5	23.9	22.4	19.8	17.1	15.1	13.1	11.0
	8	26.8	26.8	26.2	25.1	22.9	20.2	18.4	16.6	14.5
	9	27.1	27.0	26.5	25.6	23.5	21.0	19.1	17.4	15.6
	10	26.2	26.8	25.7	24.0	21.8	19.4	17.5	15.9	13.7
	11	27.2	27.1	26.5	25.3	22.5	20.5	18.5	16.5	14.8
	12	27.3	26.7	25.6	24.8	23.0	20.1	18.1	16.6	14.2
	13	26.9	26.7	26.0	24.6	22.5	20.4	18.3	16.4	14.8
	14	27.1	26.9	26.4	25.9	24.4	22.4	20.8	19.1	17.2
Rainfall (Total) (mm.)	1	26	32	47	44	47	43	45	35	34
	2	34	36	49	55	55	38	32	39	41
	3	41	35	57	46	101	45	59	36	39
	4	45	40	53	47	48	45	44	29	37
	5	46	42	57	56	82	85	88	64	52
	6	39	31	41	54	67	59	57	48	60
	7	36	29	34	42	41	47	42	25	22
	8	53	43	52	74	74	82	71	45	39
	9	36	29	51	55	70	80	78	47	32
	10	34	30	79	81	174	57	87	61	40
	11	26	28	40	44	55	49	41	32	24
	12	36	20	48	33	72	40	91	26	24
	13	44	47	51	80	80	51	47	31	21
	14	55	77	72	73	76	68	55	54	35

Note: 1. Sapporo 2. Aomori 3. Sendai 4. Yamagata 5. Tokyo 6. Niigata 7. Nagano 8. Nagoya 9. Wakayama 10. Matsue 11. Okayama 12. Takamatsu 13. Fukuoka 14. Kagoshima (Refer Fig. 1–1)

harvest. Decreases in rice yield due to the natural disasters are shown in Fig. 1–2.

2. *Socio-economic background*

Weight of the rice production in agriculture from the socio-economic viewpoint:

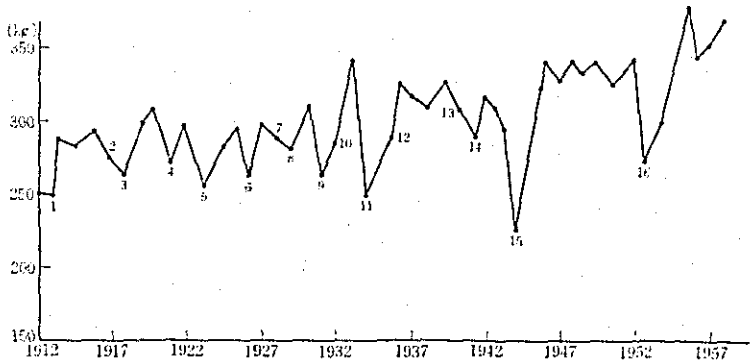
(1) From the national economic viewpoint:

In 1950, agricultural income accounted for 21.3 per cent of the total national income (12.3 per cent in 1959), and farm workers accounted for 48.4 per cent of the total number of workers (37.5 per cent in 1959). Those figures indicate a great disparity in income between agriculture and other industries. Production of rice amounting to 825,320 million *yen* in 1950 (866,496 million *yen* in 1959) accounts for 53 per cent of the total agricultural production of 1,557,459 million *yen* (1,686,608 million *yen* in 1959), reaching more than one-half of the total agricultural production.

(2) From the standpoint of farm household and farm household economy:

In 1955, about 90 per cent of the total of farm households were engaged in rice production (5,223,000 farm households or 86.4 per cent of the total were engaged in paddy rice production and 1,278,000 farm households or 21.2 per cent of the total in upland rice production). Smallness in size of holdings is shown in Table 1-3.

Fig. 1-2. Natural Disasters and Rice Yield Reduction
(*kg* per *10 ares*)



Note:
1. Unfavorable climate
2. — ditto —
3. — ditto —
4. Ditto, wind and flood damage
5. Damage by diseases and insect pests.
6. — ditto —
7. — ditto —
8. Unfavorable climate
9. Cool damage and disease damage
10. Damage by diseases and insect pests
11. Cool damage and disease damage
12. Unfavorable climate and disease damage
13. Insect pest damage
14. Disease damage and cool damage
15. Unfavorable climate (War damage)
16. Damage by disease, wind, flood and cold climate

Table 1-3. Number of Farm Housholds, by Size of Holdings, and Distribution of Agricultural Land Area (1950)

Size of holdings	*Number of farm households*	*Agricultural land area*
Class A		
Under 0.3 ha.	1.250,000	230,000 ha.
0.3-0.5	980,000	390,000
0.5-1.0	1,910,000	1,400,000
Total	4,140,000	2,020,000
Class B		
1.0-1.5	1,050,000	1,280,000
1.5-2.0	470,000	800,000
Total	1,520,000	2,080,000
Class C		
2.0-3.0	300,000	710,000
3.0-5.0	120,000	450,000
5.0 and over	90,000	980,000
Total	510,000	2,140,000
Total	6,170,000	6,240,000

To sum up, approximately six million hectares of agricultural land are held by around six million farm households, or one hectare per farm household. About two million hectares are held by each of the three farm household classes, but in the case of Class A, two million hectares are held by about four million farm households, while in the case of Class C, two million hectares are held by 500,000. Though the average holding of agricultural land area reaches one hectare per farm household, that of arable land area per farm household is 0.8 hectare. In reality, the number of farm households holding paddy fields of less than 0.5 hectare accounts for 56.7 per cent of the total. As a result, farmers in general can not depend upon the agricultural income alone. For instance, in 1959, full-time farm households accounted for 45.2 per cent (34.3 per cent in 1960), while part-time ones 54.8 per cent (65.7 per cent in 1960). The percentage of part-time farm households in suburban districts is further higher. Part-time farm households are on the increase in number year after year. The outline of farm household economy is as shown in Table 1-4.

Table 1-4. Farm Household Economy

Income	*1955*		*1960*	
	yen	%	yen	%
Farmer's gross income	505,000	100	603,000	100
Agricultural gross income	373,000	73.9	353,000	58.5
Gross income from rice crop	195,000	(52.3)	176,000	(49.9)
Farmer's income	358,000	100	411,000	100
Agricultural income	256,000	71.5	219,000	53.3
Non-agricultural income	102,000	28.5	192,000	46.7

Note: Figures in parentheses indicate ratios between gross income from rice and agricultural gross income.

As shown in Table 1-4, the percentage of gross income from rice to agricultural gross income in 1955 is 52.3 per cent (49.9 per cent in 1960), and agricultural income is on the decrease.

(3) From the viewpoint of land use:

(i) Land use by kinds of field: Arable land area, paddy field area, and upland area are as shown below.

Area	*1955*	*1960*
Arable land	5,091,000 ha.	5,324,000 ha.
Paddy field	2,876,000 (56.5%)	2,965,000 (55.7%)
Upland field	2,215,000 (43.5%)	2,359,000 (44.3%)

All the arable lands (except fruit, mulberry, and vegetable farms) have been brought under irrigation for using as rice fields as far as possible. Being steep in topography, the arable land area in Japan constitutes as low as 14 per cent of the total land area. Such percentage is extremely low, comparing with that in any country in the world, but the utilization of the land area for agricultural purposes has reached the maximum limit.

(ii) Land use by kinds of crop: In the phase of the arable land use, the percentage of the total area planted to rice in 1950 reached 39.3 per cent (40.9 per cent in 1960), far higher than that of the combined areas planted to wheat, barley, and naked barley, accounting for 24.5 per cent in 1950 and 18.8 per cent in 1960 (ranking second in the crop production in Japan). No appreciably great changes are found in the percentage of the total area planted to rice, constituting 38–40 per cent in the 1941–60 period.

As prescribed above, from the viewpoints of the national economy, farmers' own economy, and the use of national land, the rice cropping is evidently important. Japanese is the habitual rice-eating nation. In the prewar years, rice consumption per capita per year had been kept at a level of 150 kilograms for many years, but in the postwar days it showed a decrease to a level of 110 kilograms, on account of the increased consumption of animal protein food, wheat, and fruits commensulate with the changing national food pattern, reflecting the rise in the national income. Japan comprises a rice-eating population of 89,274,000 in 1955 (93,419,000 in 1960), crowded into its limited land area. This fact indicates that Japan is faced by a serious food problem. It is quite natural that the rice culture in Japan differs markedly from that in the USA or USSR, non-rice-eating nations, low in population density with vast land area. It is an inevitable consequence that the land saving device for rice culture has come to be developed, i.e., in order to raise the rice production to the highest possible extent and high-yielding varieties have come to be cultivated intensively on the limited field with intensified family labor and heavy fertilizer application. In this sense, the rice cultural techniques can be said the typical agricultural techniques in Japan.

2. Features of Rice Culture

1. Pre-eminence in rice culture and successive culture on the same field

Table 1－5. Main Rice Cultural Types in Japan

Type	Submergence and drainage		Name of crops	
	Summer cropping	Winter cropping	Summer crop	Winter crops
I	Submergence	Submergence or drainage	Paddy rice	Fallow
II	Submergence	Drainage	Paddy rice	Wheat, barley, beans, rape-seed, etc.
III	Alternation of submergence and drainage	Drainage	Paddy rice and grass or vegetables or other crops	Grass or other winter crops

(Continued)

Type	Duration of submergence	Remarks
I	Long	Mostly in single cropping fields in cold area, or in ill-drained fields
II	Medium	Typical type in Japan, found mostly in dried or semi-dried fields
III	Short	Mostly in dried fields, not so large in area (lowland and upland rotations)

Three rice cultural types shown in Table 1-5 are classified according to the climatic conditions, topography, soils, or farming conditions. Type I cultural practice is prevalent in the cold area (East Japan), and Type II in the warm area (West Japan). Winter crops in West Japan are mostly wheat and barley. The initiation of wheat or barley planting as the second crop dates back to the second half of the thirteenth century. It is reported that such practice had become prevalent in southwest Japan in the second half of the sixteenth century. The ratio between single-cropping fields and double-cropping ones in 1950 was 65.2 to 33.6

(68.8 to 30.5 in 1960).

(i) Spring and autumn labor peaks in double-cropping paddy field region: In the spring, on account of the harvesting operation of wheat or barley followed by the transplanting of rice seedlings, it is at the spring busy season, and in the autumn on account of the operations in succession of the harvesting of rice, the tillage of wheat or barley farms, and seeding of wheat and barley, it forms the autumn busy season. Thus the busy seasons and slack seasons alternate with each other. In most cases, rice culture being practised with family labor, it is hard to secure the labor sufficient to meet the labor requirements in the busy seasons, while in the slack seasons there is an excessive labor. In recent years, the problem of the excessive labor supply has come to be mitigated by the absorption of rural labor force by the secondary and tertiary industries on account of recent national economic growth, or by the planting of early-, medium-, and late-maturing rice varieties in combination, or by the practice of "early transplanting" or "early-seasonal cultivation". However, the cultural type sticking chiefly to rice, wheat, and barley cropping is still a predominant type. As a result, the problem remains still unsolved.

(ii) Importance of soil fertility conservation: Soils are depleted considerably because arable lands are planted mainly to cereal crops all the year round, aiming at attaining the high yields. As a result, the soil fertility conservation by means of heavy fertilizer application is at present a most important problem. Herein lies the reason for the development of techniques for maintaining soil fertility in Japan.

The very fact that Japan is surpassed by none in the world in the fertilizer consumption is indicative of the absolute necessity for soil fertility conservation.

2. Predominance of transplanting practice

Seeds are sown in the rice nurseries and the seedlings are grown with every possible care. When they have grown large, they are pulled out and transplanted to the paddy fields. Such cultural practice is prevalent throughout the country, except some parts in Hokkaido and Tohoku. The advantages of such practice are as follows:

(i) Advantage in weeding: When the seedlings are transplanted timely to the well-tilled and well-puddled paddy fields, rice plants can be kept away from troublesome weeds, comparing with the case of a direct-sowing practice;

(ii) Advantage in arable land use: Owing to the transplanting practice, the duration for the growth of the preceding crops can be prolonged more than in the case of the direct-sowing practice;

(iii) Advantage in production of healthy and uniform seedlings: Under the transplanting practice, it is possible for farmers to produce healthy and uniform seedlings with every care by using rice nurseries.

On the other hand, although much labor is required for the purpose of the transplanting practice, it is now practised widely throughout Southeast Asian countries as the main cultural practice. In some cases, however, highly intensive culture is practised, while in others, extensive cultural practice is observed. For instance, rice cultural type in Japan is a highly intensive culture, involving intensified labor (Tables 1–6 and 1–7).

In recent years, owing to the farm mechanization and the application of agricultural chemicals, the labor requirements for rice culture are on the decrease, but no appreciably great labor saving can be expected. The labor saving devices for the plowing and puddling of paddy fields and transplanting operation in the spring busy season as well as for the rice havesting operation in the autumn busy season are now in the pressing need. To sum up, the rice cultural system by means of transplanting method has the advantages and disadvantages described above, and is a typical intensive cultural system prevalent in a country like Japan where is crowded with a huge population to be supported by the limited arable land area.

Table 1 – 6. Labor Requirements for Rice Culture, per 0.1 Hectare by Kinds of Operation

Operation	*1954*	*1960*
Seed selection	0. 34 hrs	0. 32 hrs
Seed soaking	0. 39	0. 37
Rice nursery preparation	9. 03	9. 09
Paddy field plowing	14. 99	10. 04
Fertillizer application	7. 58	6. 79
Puddling	11. 46	6. 78
Transplanting	27. 45	26. 33
Split application of fertilizer	1. 88	1. 75
Weeding	31. 07	26. 55
Irrigation and drainage	6. 37	6. 47
Caretaking	12. 13	15. 41
Rice harvesting	37. 00	38. 14
Threshing	19. 75	18. 86
Husking	5. 78	5. 76
Total	185. 22	172. 67
Animal labor	12. 32	8. 46
Mechanical power	3. 89	7. 76

Table 1 – 7. Labor Requirements for Rice Culture, per 0.1 Hectare, by Months

Month	*1954*	*1960*
January	0. 52 hrs	0. 59 hrs
February	0. 54	0. 59
March	1. 22	2. 57
April	9. 42	11. 18
May	23. 84	27. 34
June	41. 77	33. 80
July	28. 69	22. 11
August	10. 49	9. 29
September	9. 77	17. 27
October	33. 01	30. 80
November	23. 19	14. 40
December	2. 76	2. 99
Total	185. 22	172. 67

3. Heavy fertilizer application is of prime necessity

The rice culture in Japan has attained its full development depending upon the two major programs: i.e., rice breeding and fertilizer application improvement. For instance, in order to fertilize paddy field soils, wild grasses were plowed-under or home-made manures were applied in former days, and then organic fertilizers (e.g., fish cakes, soybean cakes, etc.) came to be used, and finally chemical fertilizers have come to be applied. The forms of fertilizers have changed over from single fertilizers into compound fertilizers, and then into solid or granular ones. The fertilizer application has developed to the whole soil layer placement, split application and deep placement. High yielding being the primary aim, fertilizers are applied liberally and the amount of fertilizer application shows an increase year after year (Tables 1-8 and 1-9). On the other hand, due to the liberal application of nitrogenous fertilizers, stems and leaves of rice plants are weakened and damage is caused by frequent occurrence of diseases and insect pests or by lodging of stems. In order to increase the soil fertility, organic manures (composts and stable manures) are applied together with chemical fertilizers.

In some cases, the soil amelioration measures will have to be taken up prior to the improvement of fertilizer application. Among the cases in point are ill-drained paddy fields, habitual drought-stricken fields, salt-damaged fields, strong acid soils, *Akiochi* paddy fields, heavy clay soils, and peat soils. The fertilizer application improvement program, i.e., the planning of improved fertilizer application device basing

Table 1-8. Amount of Fertilizer Applications per Hectare in the Selected Countries

Country	*Nitrogen* (*N*)	*Phosphate* (P_2O_5)	*Potash* (K_2O)
Denmark	28.23 kg	32.15 kg	52.79 kg
France	16.40	31.35	24.77
W. Germany	51.65	53.37	97.56
Italy	15.08	26.41	2.54
U. K.	33.66	47.01	34.56
U. S. A.	9.45	10.72	8.64
India	0.78	0.10	0.07
Philippines	5.89	4.21	1.35
Thailand	0.53	0.42	0.02
Japan	99.25	47.46	72.62

Table 1－9. Amount of Chemical Fertilizer Applications to Paddy Field per 0.1 Hectare in Japan

Year	*Nitrogen* (*N*)	*Phosphate* (P_2O_5)	*Potash* (K_2O)
1954	5.84 kg	3.91 kg	4.63 kg
1955	6.72	4.50	5.26
1956	6.97	4.63	5.66
1957	7.08	5.03	6.16
1958	7.32	5.26	6.36

Note: Based on the crop statistics.

upon the soil survey results and the implementation thereof are now taken up throughout the country.

4. Low labor productivity

The intensive culture by means of transplanting practice is indicative of farmers' big dependence upon rice cropping as well as of farmers' great expectations for obtaining the highest possible yield of rice. However, any labor saving devices can not be attained readily as far as the major operations (e.g., transplanting, harvesting, etc.) depend largely upon the hand-labor. Table 1–10 indicates the disparity in labor productivity between the United States and Japan.

Table 1－10. Labor Requirements per 100 Kilograms for Agricultural Production in the U.S.A. and Japan

		Rice	*Wheat*	*White potato*	*Milk*
U. S. A.	1910	5.8 hrs	4.1 hrs	2.8 hrs	8.4 hrs
	1950	1.3	1.0	1.0	5.3
Japan	1954－56	49.0	54.0	7.0	17.1

Of course, in making a minute comparision of labor productivity, it will require to examine the various contributing factors. At any rate, Table 1–10 shows an awfully great disparity in labor productivity between the two countries. This is virtually a vital problem viewed from the standpoint of the international competition. At present, the necessity for raising the labor productivity in rice culture is pointedly emphasized. Considering that rice is the mainstay of agriculture in Japan, this is quite natural. Farmers will greatly be benefited by the improved labor productivity. At the same time, the saved labor and arable land can be destined for other crop production, e.g., animal production or fruit crops which are now in strong demand. Thus the agricultural income can also be increased more than ever before.

For the purpose of raising the labor and land productivity, the problem of a direct-sowing practice, particularly of the mechanized direct-sowing practice, is at present so much to the fore, and the study on the harvesting machines is now in progress. It is evident that the development of agriculture in Japan will greatly be actuated by the improvement in labor productivity in rice culture. The current low labor productivity can be ascribed to the conventional rice cultural techniques as well as to the groundworks for the rice production in the past. The main causative factors will be cited below.

Irrigation water-deficient fields	38.7%
Irrigation water-deficient fields after the irrigation improvement works	2.4
Ill-drained fields	23.0
Cool water irrigated fields	4.9
Deteriorated fields	16.4
Mine polluted, salt-damaged, and tidal damaged fields	2.5
Landslip (landslide)	1.0

Uplands to be improved 1,667,000 ha, or 70.5% of the total upland area

(i) Existence of many paddy fields in need of soil amelioration: The 1950 survey results show that such paddy fields reach as many as 2,721,000 hectares, or 88.1 per cent of the total paddy field area in Japan, made up as follows:

(ii) Smallness in size of each plot and scattering of fragmented plots: As shown in Table 1-11, the size of a plot of paddy field is 6 ares on an average. An arable land of 0.8 hectare consists of paddy fields and upland farms scattering in several places;

(iii) Existence of terraced ricefields on the sloping land or on the mountain of 1,000 meters above the sea: In either case, the land is utilized to the utmost extent, but the farm mechanization is interrupted due to the smallness in the size of paddy fields and the steepness in slopes.

Table 1-11. Scattering of Arable Lands

	No. of groups of plots operated per farm household	*No. of plots per group of plots*	*Area per group of plots*
Arable land	5.8	2.5	0.142 ha
Paddy fields	3.2	2.5	0.160
Upland fields	2.9	2.1	0.108

Notes: 1. Area per plot of paddy field: 0.06 ha.
2. Number of groups of plots of arable land shows no coincidence with the number of the groups of plots of paddy and upland fields combined, because paddy and upland fields are sometimes included in the same groups of plots.

3. Rice Production Increase since 1955

The 1955 rice production showed an all-time high record, reaching 1,207,180 tons (393 kilograms per 0.1 hectare). Since that year, the high production level has been upheld up to now. This can be ascribed to the smoothing-out of the prewar unevenness in productivity according to the regions and the farmers' strata. It can be understood that the rice cultural techniques have become stabilized both in East and West Japan. The increase in the acre-yield in East Japan (particularly in six prefectures in the Tohoku District) is striking (Fig. 1-3). The disparity in rice production according to the regions in the prewar and postwar years is shown in Fig. 1-4. The factors contributing to the increased rice production since 1955 will be taken up below.

Fig. 1-3. Changes in Paddy Rice Yield per 0.1 Hectare, by Prefectures

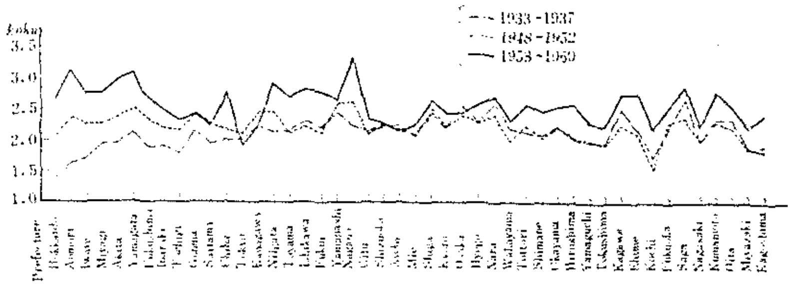
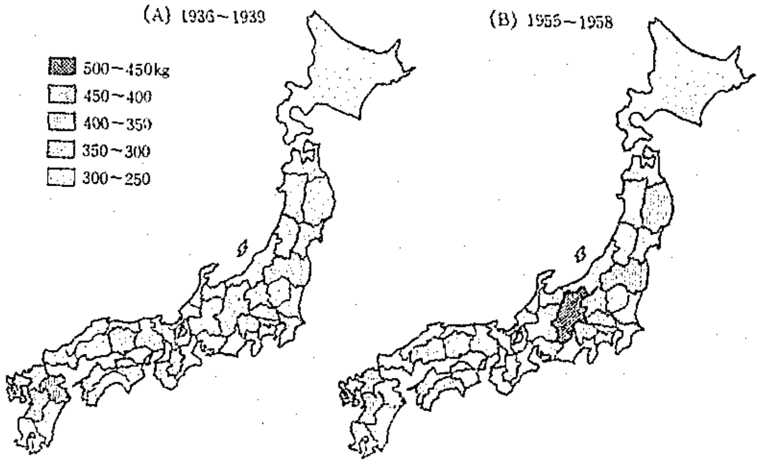


Fig. 1-4 Paddy Rice Yields per 0.1 Hectare according to the *Prefectures, Before and After World War II*



Stimulated by the postwar land reform, farmers were animated to increase the rice production through the improvement in the groundworks for rice production, the improved production means and ways, and the introduction of improved cultural practices. Thus the advent of the recent striking increase in rice production was hastened. The four major factors contributing directly to the recent rice production increase are: (i) land improvement, (ii) application of agricultural chemicals, (iii) use of agricultural machines, and (iv) improved production of seedlings in addition to the improvement of varieties and fertilizer application which are regarded as the characteristics of Japanese rice culture. A further description will be given below under the above four captions.

(i) Land improvement

The 1950 survey results reported that paddy fields of low productivity reached 2,721,000 hectares, or 88.1 per cent of the total paddy field area. In the past 10 years, paddy fields of approximately 1,500,000 hectares have been improved (Table 1-12). As shown in Table 1-12, the principal programs are the completion of irrigation and drainage facilities, land consolidation works, etc. The irrigation and drainage facilities have brought about the excellent effects such as timely planting, drought prevention, heavy fertilizer application to water-logged fields, and lodging control. The

Table 1-12. Area of Improved Paddy Fields

Project	*1949-53*	*1954-58*
	1,000 ha	1,000 ha
Government-operated irrigation and drainage works	79.6	94.4
Prefecture-operated irrigation and drainage works	253.6	152.3
Organization-operated irrigation and drainage works	174.0	261.5
Subtotal	507.2	508.2
Facilities for raising field water temperatures	13.0	6.2
Arable land consolidation works	106.7	260.4
Non-subsidized irrigation and drainage works	71.8	119.8
Total	698.7	894.6

effect of the soil improvement service has also brought about the excellent results.

(ii) Application of agricultural chemicals

Paddy field areas damaged by diseases and insect pests are shown Table 1–13.

Table 1–13. Area of Paddy Fields damaged by Diseases and Insect Pests

Year	Disease	Insect pest	Total
1949	587,460 ha	252,820 ha	840,280 ha
1951	495,480	626,160	1,121,640
1953	1,472,720	885,230	2,357,950
1955	1,501,570	943,950	2,445,460
1956	2,215,820	1,054,470	3,270,290
1958	2,135,000	1,144,000	3,279,000
1959	2,180,000	1,138,000	3,180,000
1960	2,604,000	1,448,000	4,052,000
	(539,500) tons	(233,300) tons	(772,800) tons

The weakening of the culms and leaves of rice plants caused by the liberal application of nitrogenous chemical fertilizers is remarkable. On the other hand, a rapid progress has been made in the disease or insect pest control measures. Agricultural chemicals (e.g., DDT, BHC, organophosphorus compound such as Parathion and mercury compounds, etc.) appeared one after another. Hand spraying or dusting has been replaced by power spraying or dusting. Individual spraying or dusting has been switched-over to cooperative operation with power sprayers or dusters. The decreased rice yield due to the disease or insect pest damage for the 1950-54 period reached 40 kilograms per 0.1 hectare on an average, while that for the 1955-59 period decreased to 20 kilograms per 0.1 hectare, or a 50 per cent decrease. Such decrease is ascribed to the application of herbicides, insecticides, and fungicides. The achievements of the disease and insect pest occurrence forecast service must be appreciated highly as well. Herbicides are now applied to the paddy fields constituting some 30 per cent of the total paddy field area.

(iii) Agricultural machinery

Threshing, husking, winnowing, and sorting operations have been mechanized in relatively early days, and now tillage, weeding, disease or insect pest control, and other caretaking operations are becoming mechanized step by step. Power tillers, power sprayers or dusters, etc., have come into general use and are contributing to the improvement both in the working efficiency and the labor productivity. At the same time, the operations have come to be carried out timely and exactly. At present, it requires the labor of as many as 20 man-days (about 170 man-hours) per 0.1 hectare per year, but there is a very fair possibility for affording a saving of 50 per cent in labor. For the purpose of deep plowing, larger type machines are expected to be introduced. However, the farm mechanization could not be realized without bringing about a satisfactory solution of fundamental problems such as smallness in size of farming, scattered fragmental plots, or lacking in farm roads. The progress in the farm mechanization is shown in Table 1–14.

Table 1–14. *Distribution of Agricultural Machinery and Implements (1927–60)*

(*in thousand*)

Year	*Motors*	*Engines*	*Power threshers*	*Power huskers*	*Power tillers*	*Power sprayers*	*Horses*	*Cows*
1927	12	39	30	39	—	—	1,495	1,474
1937	66	121	129	108	0.5	2	1,204	1,825
1949	538	345	764	348	10	11	1,072	2,091
1951	614	383	972	—	18	20	1,162	2,234
1953	810	642	1,269	540	35	43	1,090	2,503
1955	956	1,134	1,988	696	82	76	976	2,636
1956	1,025	1,264	2,210	737	141	120	888	2,719
1958	1,034	1,380	2,283	—	227	155	762	2,465
1959	1,042	1,525	2,343	711	338	168	728	2,365
1960	1,070	1,560	2,459	843	514	305	673	2,340

(iv) Techniques for production of superior seedlings

In Japan, it is said that "the good harvest depends upon the fine seedlings to the extent of 50 per cent". For this reason, the rice nursery is usually handled very carefully in order to produce healthy, firm, and uniform seedlings, and improved rice nursery beds are used, e.g., semi-irrigated nursery beds, dry nursery beds, etc. In the postwar years, protected nurseries (covered with oil paper or vinyl films) have become prevalent in Japan extensively. In the case of the protected nurseries, the temperature of a rice nursery bed can readily be raised. As a result, the protected rice nurseries are suitable for the cool region like East Japan where seedlings are transplanted earlier. Even in the warm region like West Japan, the use of the protected rice nurseries has made possible the moving-up of the cultural period by about 45-60 days. Namely, seeds are sown in the protected rice nurseries during the March-April months. Seedlings are transplanted in early April to mid-May, and rice is harvested in early August in Kyushu (West Japan) and early September in Kanto District. The early transplanting is of primary importance in the case of the cold region. In practice, the "early transplanting" is regarded as the principal factor in rapidly increased rice production in East Japan, because owing to this "early cultivation" the rice production has become stabilized and increased. The "early seasonal cultivation" makes possible the forestallement of typhoons which may visit frequently during the August-September months and serves in improving the low productivity of *Akiochi* fields, water-logged fields, etc., and it makes possible the introduction of succeeding other crops after rice has been harvested. However, it should not be overlooked that neither "early-transplanting" practice nor "early seasonal cultivation" by the use of protected rice nurseries could be developed *if the effective agricultural chemicals are not available.*

4. Historical Development of Rice Culture

As early as one century B.C., Japonica type rice planted in the south Yangtze River basin was imported from China into Kyushu (West Japan). After that the rice planting spread over the Honshu Island (the largest and the main island of Japan), and then to the Tohoku District in the eighth century, and in the thirteenth century it spread as far as to Aomori Prefecture, the northernmost prefecture of the Honshu Island. It was fairly late that rice planting came to be introduced into Hokkaido.

Table 1 – 15. Increase in Paddy Field Area
(NAGAI)

Period classification		Duration	Paddy field area	Increased area over that in the previous period
1st	one century B. C. – the 8th cent. A. D.	yrs 900	ha 1,050,000	
2nd	Middle of the 8th cent. – middle of the 18th cent.	1,000	1,650,000	ha 600,000
3rd	Middle of the 18th cent. – end of the 19th cent.	150	2,630,000	980,000
4th	End of the 19th cent. –late 20th cent.	80	2,900,000	270,000

As indicated in Table 1–15, it showed a marked increase in the paddy field area during the Edo era (1603~1867) and the Meiji era (1868–1911). In these periods, land development and reclamation projects and land consolidation or land improvement programs had been carried out in succession. Above all, Asaka irrigation project (in Fukushima Prefecture), Nasu irrigation project (in Tochigi Prefecture), and Meiji irrigation project (in Shizuoka Prefecture) are well-known projects carried out in the Meiji era. The Meiji Government noticed the growing demand for rice on account of the growing population and the rising level of living of the people commensurate with the national economic growth. Therefore, the rice export fell into abeyance after the 20's (1887–96) of Meiji. The rice production increasing plans in Taiwan and Korea were designed by the Japanese Government. The results of the plants were fundamental factors contributing to the subsequent economic development both in Taiwan and Korea, and the sufficient rice supply in Japan had been supported by Taiwan and Korean rice. Stimulated by the dire food shortage during and immediately after World War II, the rice production increasing program was actuated. The bumper harvest of rice in the years since 1955 can be regarded as the very results of the improved rice cultural techniques devised during the food shortage period, though it was partly due to the postwar land reform and the food control system.

Table 1–16. Planted Area, Production and Yield per 10 Ares, Upland and Lowland Rice Combined (1883–1960)

Year	*Planted area*	*Index number*	*Amount of production**	*Index number*	*Yield per 10 ares*	*Index number*
	ha		tons		tons	
1883-87	2,596,180	100	5,067,806	100	0.194	100
1888-92	2,714,940	105	5,829,061	115	0.213	110
1893-97	2,753,020	106	5,651,037	112	0.204	105
1898-1902	2,803,430	108	6,371,971	126	0.225	116
1903-07	2,853,250	110	6,942,920	137	0.241	124
1908-12	2,923,300	113	7,588,161	150	0.257	132
1913-17	3,920,500	117	8,286,323	164	0.271	140
1918-22	3,085,050	119	8,838,036	174	0.284	146
1923-27	3,120,010	121	8,700,410	172	0.276	142
1928-32	3,193,720	123	9,070,535	179	0.282	146
1933-37	3,159,360	122	9,383,557	185	0.294	152
1938-42	3,152,140	122	9,527,139	188	0.299	154
1943-47	2,905,370	112	8,418,975	166	0.271	140
1948-52	2,987,110	115	9,592,695	189	0.316	164
1953	3,014,465	116	8,238,570	165	0.273	141
1954	3,051,176	118	9,113,352	180	0.299	154
1955	3,221,806	124	12,384,737	244	0.384	198
1956	3,242,651	125	10,898,756	215	0.342	176
1957	3,238,607	125	11,464,258	226	0.354	182
1958	3,253,298	125	11,993,000	237	0.369	190
1959	3,288,237	127	12,501,000	247	0.380	196
1960	3,305,976	127	12,858,000	254	0.389	201

Note: * Metric tons in husked rice.

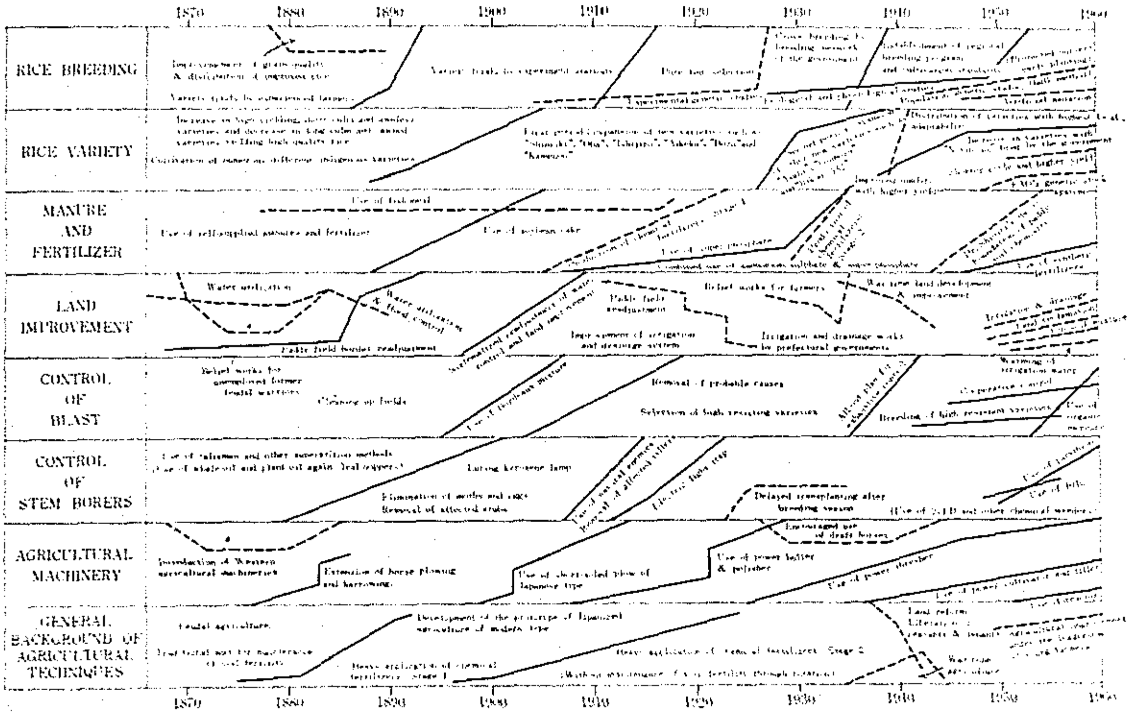
The development of rice production since 1883 is shown in Table 1–16. When the planted area, production, and yield per 10 ares in 1883–87 are indicated each by 100, those in 1960 will be represented by 127, 254 and 201 respectively. The reason that rice is selected as the main food in Japan with a huge population crowding into the limited land lies in the characteristics of rice crop superior to other food crops. Namely, (i) owing to its high productivity, larger number of population can be supported by the unit area of arable land; (ii) rice production can be stabilized by means of irrigation, and the fluctuations in the rice harvest are comparatively slight; (iii) rice can be stored longer and can be transported far away readily; and (iv) paddy field soils are eroded relatively slightly.

Rice is planted in every country in Southeast Asia. As high as 95 per cent of the total rice planting area in the world is concentrated in Southeast Asia. This fact indicates that from the socio-economic viewpoints there is many a point common to these nations. In this sense, rice crop can be said the crop most suitable to this region.

Owing to the recent marked economic growth in Japan, i.e., owing to the striking development of the secondary and tertiary industries, the rural population is absorbed thereby, thus resulting in a serious shortage of farm labor supply. Herein lies an absolute necessity for the agricultural modernization. In such critical situation, it is quite natural that the labor productivity improvement in the rice cropping enterprise is becoming increasingly important because rice is the mainstay of agriculture in Japan. Thus the labor-saving rice cultural techniques have become highlighted, without sticking to the conventional land saving device alone. In order to meet the requirements, it is necessary to actuate the systematic studies on the techniques and management (e.g., how to develop and operate the efficient farm machines, and how to raise farm labor efficiency). At the same time, it is also necessary to uncork any bottleneck (e.g., size of holdings, scattered fragmental plots, etc.) which may obstruct the modernization of the rice cropping enterprise. Great expectations are entertained for the full development of the rice production. In order to trace back the development of rice cultural techniques and to clarify its historical background, Fig. 1–5 will be given in the next page.

The relation of agriculture to industries: The effects of industries on agriculture in Japan, particularly on the development of rice production, are striking. Industries have

Fig. 1 – 5. Historical Development of Rice Cultural Techniques in Japan
(TOBATA and MORINAGA, data after 1940 supplement by ITO)



contributed to the formation of the rice cultural technical system peculiar to Japan by providing chemical fertilizers, agricultural chemicals, production materials, agricultural machinery, etc. In the future also, the relationship between rice culture and industries will become increasingly closer. Success in agriculture lies at the basis of progress in other industries, and industries will offer the important and stabilized home markets for agricultural and animal products as well as for rural labor.

CHAPTER 2

RICE BREEDING

1. History of Rice Breeding

1. Historical development of breeding organization and breeding methods

In Japan, the scientific breeding work was started in the year 1893 in which the National Agricultural Experiment Station came into existence. Owing to the success in the artificial crossing in 1904, the breeding of new crop varieties by a hybridization has been carried out actively. From that year up to now, a great number of new varieties have been bred and extended. Thus the rice yielding is becoming increased year after year.

The development progress in rice breeding can be divided into four stages from the viewpoints of the changes in the breeding organization and methods.

First stage: The age of comparison and selection of native varieties (from the time before artificial crossing to 1902);

Second stage: The age of a pure line selection (from 1904 in which artificial crossing met with success to 1926 in which rice breeding sub-centers were established);

Third stage: The age of rice breeding by hybridization (from 1927 to 1940 during which the pedigree method was mainly carried out);

Fourth stage: The age of rice breeding by bulk method, by the use of foreign rice varieties, and by artificial mutation (in and after 1945).

The chronological explanation of the progress in the establishment of the breeding organization will be given below.

1886: In the year 1886, the Main Cereal Crop Experiment Station of the Ministry of Agriculture was set up in the suburban of Tokyo, at which the native and foreign rice varieties were collected and the trial culture was carried out. Among the rice varieties cultivated for trial at that time were Sekitori and Homura Varieties, the names of which are noted still now.

1889: The Experiment Station was set up at Ebara, Tokyo.

1893: The National Agricultural Experiment Station (now known as "The National Institute of Agricultural Sciences") was set up at Nishigahara, Tokyo, and six branch stations came into existence (Kyushu, Tohoku, Hokuriku, and three others). Thus the experiments were started at a national level. For several years, the comparative tests on native rice varieties had been made. Shinriki, Aikoku, and Kamenoo Varieties were those selected by the comparative tests.

1903~13: At the Head Station and the Kinai and Rikuu Branch Stations, the pure line selection of rice varieties was carried out principally.

1916: Pure line selection tests were started at the respective prefectural agricultural experiment stations. As the results, almost all the rice varieties in Japan became pure line varieties. Among the leading varieties bred at that period were Rikuu No. 20, Aikoku No. 3, Kyushu No. 8, etc. (these are referred to "line"). By cultivating these varieties, the rice yields in the respective parts of Japan showed a 5–10 per cent incerase. New rice varieties obtained by the pure line selection at prefectural stations were named as Aikoku-Sai No. 1 (bred at the Saitama Prefectural Agr. Exp. Sta.), Aikoku-Ibaraki No. 2 (bred at the Ibaraki Prefectural Agr. Exp. Sta.), etc.

1904~25: The breeding by artificial crossing of native varieties was started at Nishigahara Main Station and the Kinai, Rikuu, and Kyushu Branch Stations. As a result, superior varieties such as Rikuu No. 132, Kairyo Aikoku, etc., were bred.

*1926: The whole of Japan was divided into eight ecolo*gical regions according to the climatic conditions and natural features, and the following prefectural agricultural experiment stations were designated as regional rice breeding experiment stations and the Konosu Experiment Farm of the National Agricultural Experiment Station was designated as the main station. Thus the rice breeding organization came to be established firmly.

Regional rice breeding stations:

Hokkaido,	at Kamikawa in Hokkaido,
Tohoku,	in Miyagi Prefecture,
Hokuriku,	in Niigata Prefecture,
Kanto,	in Saitama Prefecture,
Tosan,	in Gifu Prefecture,
Kinki,	in Hyogo Prefecture,
San-in,	in Shimane Prefecture,
Kyushu,	in Kumamoto Prefecture.

(i) The *primary process of the breeding procedure*, i.e., crossing and selection of F_1 and F_2 hybrid, was assigned to the main station, (ii) the secondary process from selection of F_3 and the subsequent generations up to the fixation was assigned *to the regional stations*, and (iii) the tertiary process, i.e., adaptability tests for promising lines and determination of recommendable varieties were assigned to the respective prefectural agricultural experiment stations. New rice varieties bred under the above breeding organization were determined to be registered with "Norin No." A majority of rice varieties cultivated at present are the varieties with "Norin No." which were bred under the above breeding organization.

1947~49: The designated breeding centers attached to the prefectural agricultural experiment stations were nationalized under the name of agricultural improvement experimental stations. At these breeding centers, the secondary process of F_3 and the subsequent generations had hitherto been carried out, but after the merger the entire breeding procedure from crossing to fixation came to be carried out under the integration in response to the breeding objectives in the respective regions.

1950: The naming of new varieties was subject to change and the varieties hitherto named "Norin No." came to be indicated by proper names (beginning with Norin No. 52) writing in squire type Japanese syllabary, e.g., Takachiho (instead of Norin No. 52), Tonewase (instead of Norin No. 55). As a result, the present "Norin No." is nothing but a "Registered No."

Present rice breeding centers under the supervision of the Government and the names of lines attributed to the respective centers are given in Table 2-1.

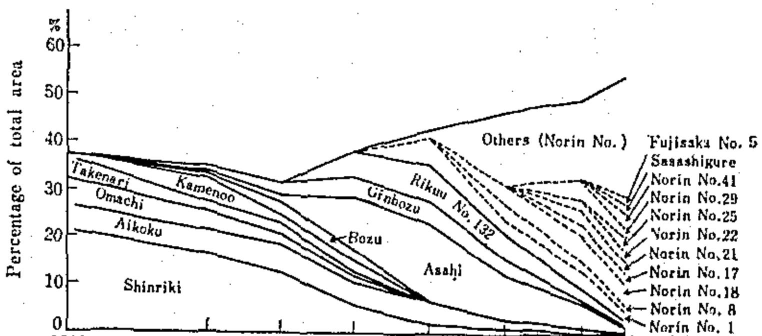
Table 2-1. National Rice Breeding Centers and Names of Bred Lines

Name of breeding center	*Names of lines*
Aomori Pref. Agr. Exp. Sta. (Fujisaka)	Fukei No.
Miyagi Pref. Agr. Exp. Sta.	Tohoku No.
National Tohoku Agr. Exp. Sta.	Ou No.
National Agr. Exp. Sta.	Kanto No.
National Tokai-Kinki Agr. Exp. Sta.	Tokai No.
National Hokuriku Agr. Exp. Sta.	Hokuriku No.
Fukui Pref. Agr. Exp. Sta.	Etsunan No.
National Chugoku Agr. Exp. Sta.	Chugoku No.
Shimane Pref. Agr. Exp. Sta.	San-in No.
National Kyushu Agr. Exp. Sta.	Saikai No.
Miyazaki Pref. Agr. Exp. Sta.	Nankai No.
Kagoshima Pref. Agr. Exp. Sta.	Seinan No.
Nara Pref. Agr. Exp. Sta.	Kansai No.

2. *Changes in rice varieties*

Changes in the kinds of fertilizers and the amounts of fertilizer applications according to the ages are the greatest contributing factors to the direction of improvement of paddy (lowland) rice varieties in Japan. For instances, in those days when wild grass or rice straw were chiefly applied, rice varieties with high fertilizer absorbing ability were adopted. With the increase in the amount of nitrogenous fertilizer application due to the import of Manchurian soybeans in and after 1910, rice plants suffered frequently from diseases and lodging. Thus disease resistant and strong-culmed varieties came to be required. To meet such requirements, changes took place in rice varieties. With the progress in the fertilizer manufacturing industry, the quick acting chemical fertilizer application practice was becoming popularized. Thus short-culmed, profusely tillering, and disease resistant varieties were in strong demand. On the other hand, in the prewar years, since Japan was a rice self-sufficient country owing to the ample supply of rice from Taiwan and Korea, rice quality was highly appreciated more than quantity. As a result, high-quality rice varieties were prevalent. Meanwhile, due to the dire food shortage during and after the war high yield-

Fig. 2－1. Changes in Area to Paddy Rice in Japan, by Varieties and Years



ing rice varieties have become welcome rather than high-quality varieties. Reflecting this, rice production in recent years is on the rapid increase. As a reaction, high-quality rice has become appreciated again, thus showing an upward trend in planting of high-quality varieties.

Fig. 2–1 indicates the changes in acreage planted to paddy rice in Japan, by the leading varieties and the selected years. Fig. 2–1 shows evidently that a number of native varieties had been selected during 1900-15, on a one-region one-variety basis, e.g., Shinriki in West Japan, Aikoku in Kanto, Kamenoo in Tohoku, and Bozu in Hokkaido. However, with the completion of regional agricultural experiment stations, a number of varieties suitable for the climatic conditions in the respective prefectures were bred out from these varieties by the pure line selection. After the opening of the 1930's, owing to the increase in the marketable rice and owing to the establishment of the rice inspection system, the standardized rice varieties with high marketability were in strong demand. Consequently, the breeding objective came to be changed to high-quality rice varieties. Thus Shinriki in West Japan came to be replaced by Asahi, a strong-culmed and disease-resistant variety with high quality, Kamenoo in the Tohoku District by cool-resistant and high yielding variety "Rikuu No. 132" and the variety prevalent in the Hokuriku District by strong-culmed and disease-resistant variety "Ginbozu", respectively. Moreover, owing to the improvement in the breeding organization designed by the Ministry of Agriculture and Forestry, a number of disease-resistant, strong-culmed, high yielding, and high-quality varieties with "Norin No." were selected one after another. Thus changes in rice varieties came to be brought about more quickly. In consequence, improved varieties have come to be planted widely, e.g., Norin No. 1 → Honenwase in the Hokuriku District, Norin No. 8 → Norin No. 29 and Norin No. 25 in the Kanto District, Norin No. 18 in the Kyushu District, and Norin No. 17 → Sasashigure in the Tohoku District.

2. Characteristics of Rice Varieties

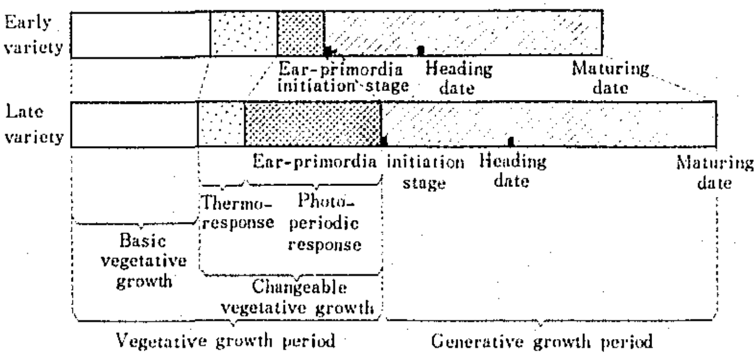
1. *Early- and late-maturity of rice varieties*

(1) Basic vegetative growth, thermo-response, and photoperiodic response

Life history of a rice plant can be divided into two growth periods (Fig. 2–2): (i) vegetative growth period and (ii) generative (reproductive) growth period. Vegetative growth period is the period for the growth of stems and leaves, i.e., the period from seeding to ear-primordia initiation in a stem (30 days before heading). Generative growth is the period from ear-primordia initiation stage to grain ripening date.

Vegetative growth can be subdivided into two stages: (i) basic vegetative growth stage and (ii) changeable vegetative growth stage.

Fig. 2–2. Life History of Rice Plants
(Early- and Late-Maturing Varieties)



Basic vegetative growth indicates the minimum necessary vegetative growth indispensable for entering into the generative growth. Originally speaking, when grown at high temperature, young panicle differentiation is accelerated and heading is hastened. The same phenomenon can be observed when grown in the short days. When rice plants are grown at high temperature in the short days, heading can be hastened further. However, even if rice plants are grown at high temperature or in the short days, without an ample period to form culms and leaves to some extent (the extent varies with varieties), rice plants could not enter into the generative period.

The vegetative growth during this period is known as "basic vegetative growth". The extent of basic vegetative growth of a given rice variety can approximately be judged from the vegetative growth up to the ear-primordia initiation stage attained when the plants have been grown at an artificially-raised temperature and artificial short days, i.e., when the plants are grown under the short-day treatment in a green house by using a short-day box.

Changeable vegetative growth denotes the vegetative growth which can be shortened by the external conditions, i.e., the vegetative growth which can be attained in a shorter period than under the natural culture, when the rice plants have been grown under the conditions stated above. The changeable vegetative growth can be represented by the following formula.

$$\underset{\text{(Number of days)}}{\begin{pmatrix}\text{Changeable}\\ \text{vegetative}\\ \text{growth}\end{pmatrix}} = \underset{\text{(Number of days)}}{\begin{pmatrix}\text{Vegetative}\\ \text{growth}\end{pmatrix}} - \underset{\text{(Number of days)}}{\begin{pmatrix}\text{Basic}\\ \text{vegetative}\\ \text{growth}\end{pmatrix}}$$

Changeable vegetative growth can, as illustrated in Fig. 2–2, be divided into two portions: the portion which can be shortened at higher temperature; and the portion in the short-days. The response of heading to the high temperature is known as "thermo-response", and the response to the short-day as "photoperiodic response".

Early- or late-maturity of rice varieties, as described above, varies with the three characteristics: (i) basic vegetative growth, (ii) thermo-response, and (iii) photoperiodic response of each rice variety. Three characteristics of the main rice varieties prevalent in the country are given in

Table 2-2. In general, early-maturing varieties distributed *in cold regions are high in thermo-response and low in photo*periodic response. In contrast to this, late-maturing varieties distributed in warm regions are low in thermo-response and high in photoperiodic response.

Fig. 2–3 indicates the changes in the heading dates of early- and late-maturing varieties according to the seeding dates. As shown in Fig. 2–3, the heading date of late-maturing varieties is not so hastened though seeded earlier, comparing with the case of early-maturing ones, and the heading date is not so delayed though seeded later.

ASAKUMA tested the heading dates of rice varieties seed-

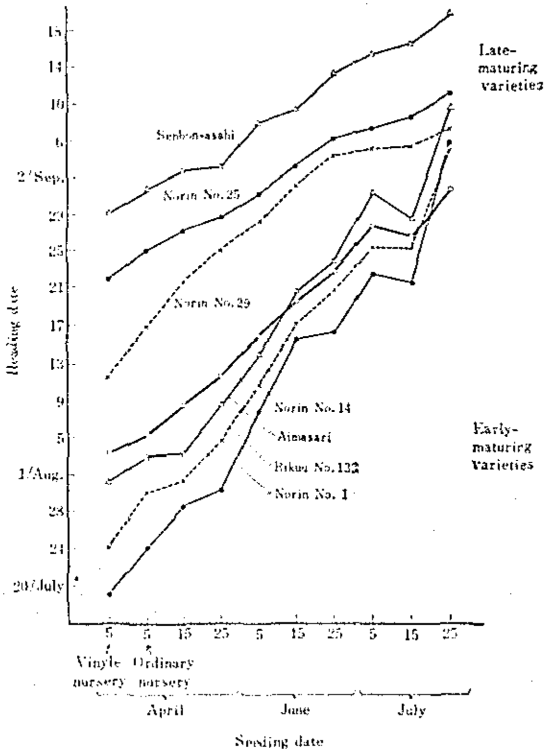
Table 2-2. Grade of Thermo-Response and Photoperiodic Response and Basic Vegetative Growth

(Kyushu Agricultural Experiment Station)

Varieties	*Cultivated regions*	*Photo-periodic response*	*Thermo-response*	*Basic vegetative growth*
Hayashio	Kochi (First crop)	0	3	3
Tomoemasari	Hokkaido	0	2	4
Kinugasawase	Kochi	2 a	3	2
Fujisaka No. 5	Tohoku	1 a	2	4
Norin No. 1	Hokuriku	0	2	6
Rikuu No. 132	Tohoku	1 b	2	6
Aimasari	Kanto-Tosan	1 b	3	5
Norin No. 17	Tohoku	1 a	2	5
Norin No. 32	Hokuriku, Kanto	2 b	1	4
Norin No. 29	Kanto	2 b	1	4
Norin No. 22	Tokai, Kinki, Chugoku	3 a	1	3
Ayanishiki	Ditto	3 a	1	4
Takachiho	Kyushu	3 a	0	4
Norin No. 37	Tokai, Kinki, Chugoku	4 a	0	3
Nakasengoku	Kyushu	3 b	0	4
Benisengoku	Kyushu	3 b	0	4
Hozakae	Kyushu	3 b	0	4
Asahi No. 1	Kyushu	3 b	0	4
Norin No. 12	Kyushu	3 b	0	4
Tsurugiba	Kyushu	3 b	0	4
Takara	Kyushu	4 a	0	4
Norin No. 18	Kyushu	3 b	0	5
Norin No. 39	Kyushu	3 b	0	5
Norin No. 40	Kyushu	4 a	0	5
Zuiho	Kyushu	4 b	0	4

Note: Figures for both responses show the degree of sensitivity.

Fig. 2 – 3. Changes in Heading Dates of the Respective Rice Varieties according to the Seeding Dates



ed early (on March 22) and late (on July 15) on the short-day plots and natural plots and disclosed recently the following new views.

The grades of thermo-response and photoperiodic response of rice varieties should not be indicated, as in the past, by the number of days for heading hastened by growing under the artificial conditions (at a high temperature or in the short days), as compared with rice grown under the natural conditions, but it is better to represent them by percentage for the acceleration of heading. As indicated in Table 2–3.

Table 2 – 3. Basic Vegetative Growth, Thermo-Response and Photoperiodic Response, by Varieties
(ASAKUMA)

Varieties	*Number of day until heading*				*Basic vege-tative growth*	*Photo-periodic response*		*Thermo response*	
	Short day treat	*Nat-ural*	*Short day treat*	*Nat-ural con-dition*		*Early sea-sonal culture*	*Late sea-sonal culture*	*Short culture*	*Natural con-dition*
Norin No. 20	74	75	44	38	2	1	−1	5	5
Norin No. 42	73	75	39	35	2	1	−1	5	6
Kinugasawase	72	76	35	39	2	1	2	6	5
Eiko	75	77	39	38	2	1	−1	5	6
Norin No. 34	75	79	40	37	2	1	−1	5	6
Nan-ei	83	83	47	40	3	1	−2	5	6
Hayanorin	80	83	50	42	3	1	−2	4	5
Hayashio	82	83	41	38	2	1	−2	5	6
Shin-ei	84	87	51	37	2	1	−4	4	6
Benihikari	86	89	44	43	3	1	−1	5	6
Shirohikari	86	90	45	43	3	1	−1	5	6
Tomoemasari	86	90	54	43	3	1	−1	4	6
Hatsunishiki	94	92	59	47	4	−1	−3	4	5
Mutsuhikari	89	94	60	50	5	1	−3	4	5
Fujisaka No. 5	94	95	50	51	5	1	1	5	5
Towada	96	95	53	53	5	−1	1	5	5
Sasashigure	92	96	54	50	5	1	−1	5	5
Hakkoda	95	97	55	55	6	1	1	5	5
Aimasari	89	97	55	60	6	1	1	4	4
Tedoriwase	92	98	56	53	5	1	−1	4	5
Norin No. 41	93	99	58	53	5	1	1	4	5
Hatsuminori	101	99	70	49	4	−1	−5	4	6
Norin No. 1	102	101	78	51	5	−1	−6	3	5
Norin No. 21	91	101	53	53	5	1	1	5	5
Norin No. 17	95	101	50	61	5	1	2	5	4
Kanto No. 44	92	101	56	56	6	1	1	4	5
Ginmasari	101	102	59	61	6	1	1	5	5
Tsugaruasahi	102	104	59	59	6	1	1	5	5
Yachikogane	91	105	46	60	6	2	3	5	5
Kinmaze	91	114	46	71	4	3	4	5	4
Norin No. 10	94	117	48	60	4	2	3	5	5
Norin No. 29	86	119	43	63	3	3	4	6	5
Norin No. 37	86	124	44	73	3	4	4	6	5
Aichiasahi	95	125	42	72	3	3	5	6	5
Wakaba No. 8	99	125	44	63	3	3	4	6	5
Norin No. 8	101	126	46	69	4	2	4	6	5
Yubae	101	129	48	73	4	3	4	6	5
Takara	97	130	44	77	3	3	5	6	5
Norin No. 18	88	132	45	77	4	4	5	5	5

Notes: (1) Seeding date: Early seasonal culture, March 22.
Late seasonal culture, July 15.
(2) Figures for both responses show the degree of sensitivity.

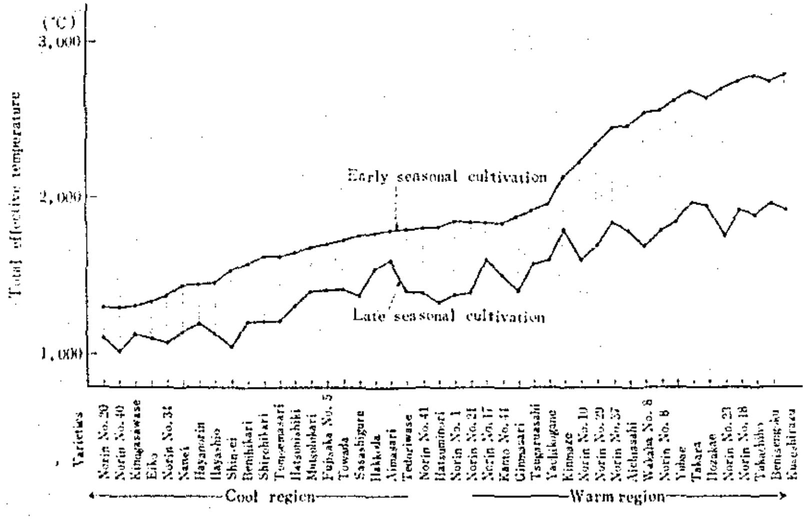
(i) Basic vegetative growth: High in the order of varieties in the Tohoku District, varieties in other districts, and those in Hokkaido;

(ii) Photoperiodic response: Varieties in South Japan are higher than those in North Japan;

(iii) Thermo-response: No appreciably great difference is observed among different varieties.

Total effective temperature from seeding to heading of various rice varieties is given in Fig. 2–4. As shown in Fig. 2-4, the total effective temperature is lower in the earlier-maturing varieties. When early- and late-maturing varieties are grown both by early- and late-seasonal culture practices, in the case of early-maturing varieties the difference in the total effective temperature is slight, but the difference is great in the case of late-maturing varieties. This is due to the fact that in the case of early-maturing varieties, heading is not delayed so much by the early seasonal culture because the early-

Fig. 2–4. Total Effective Temperature from Seeding to Heading in the Natural Day-Length, by Varieties



maturing varieties begin to display the thermo-response even at a relatively low temperature, while in the case of late-maturing varieties, heading is not so hastened even when seeded earlier because late-maturing varieties do not begin to display the thermo-response unless the temperature is high to some extent.

(2) Early- or late-maturity of rice varieties and rice yield

Fig. 2–5 indicates the relationship between the "weight of straw" and "weight of grains" of early- and late-maturing varieties grown under the same cultural condition. From Fig. 2–5, it is observed that the weight of leaves and culms of late-maturing varieties is on the increase over that of early-maturing ones, while the grain weight of medium-maturing varieties is heaviest, and the grain weight of late-maturing varieties shows rather a decreasing trend in inverse proportion to the increase in the weight of leaves and culms. The reason for this can be found in the fact that as the weight of leaves and culms is resulted from carbon assimilation, it is quite natural that the weight of leaves and culms is becoming increased proportionately with the length of the growth period, but in the case of late-maturing varieties the consumption by respiration becomes larger due to the better plant growth, thus showing no heavy rice yield in comparison with the better plant growth. Moreover, in the case of late-maturing varieties as the temperature at the ripening period becomes lower, ripening is affected adversely, thus showing a decrease in the rice yield. Such phenomenon can be observed more markedly when the field condition or autumn weather is unfavorable. For instance, in the case of *Akiochi* area observed frequently in West Japan, the rice yield of late-maturing varieties shows a decreasing trend due to the decline in the function of roots caused by root-rot and due to the damage by *Helminthosporium* leaf spot. And in case of the Kanto District if not blessed with fine weather in autumn, late-maturing varieties will show every prospect of good harvest because of their luxuriant plant growth and a large number of spike-

Fig. 2 – 5. Relationship between the "Weight of Leaves and Culms" and the "Weight of Grains" of Early- and Late-Maturing Varieties Grown under the Same Conditions
(Ibaraki Prefectural Agricultural Experiment Station)

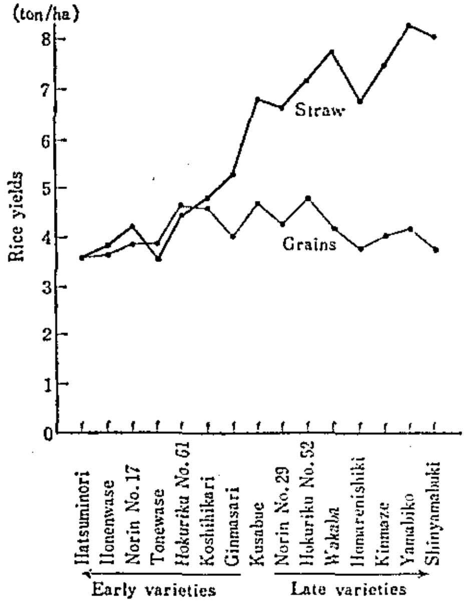
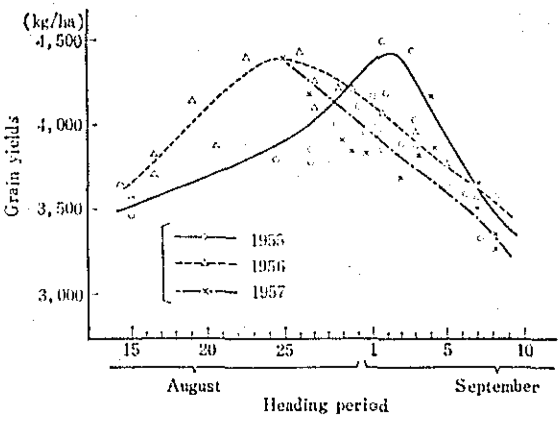


Fig. 2 – 6. Relationship between Climatic Conditions in the Heading Period and Rice Yields
(Kanto-Tosan Agricultural Experiment Station)



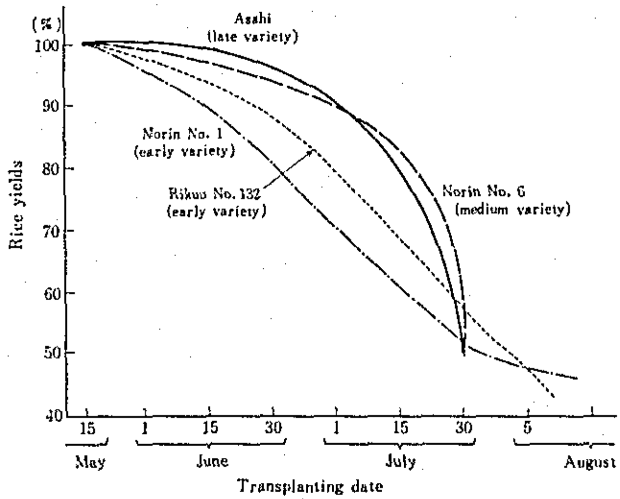
lets per hill, but due to the frequent cloudy or rainy weather, ripening is affected much and show decreases in rice yields (Fig. 2–6).

(3) Early- and late-maturing of rice varieties and hints on successful rice culture

In recent years, it shows a decreasing trend in the planting of late-maturing varieties throughout the country, while the planting of early- or medium-maturing varieties is on the increase. This is ascribed to the fact that, late-maturing varieties could show fairly heavy yields under favorable conditions, but due to the long duration of the plant growth period, rice plants are liable to suffer from various natural disasters and lacking in stability, and not a little disadvantageous from the standpoint of the utilization of paddy fields.

In planting early-maturing varieties, it is essential to grow big plants in order to obtain heavy rice yields because early-maturing varieties have poor plant growth. For this purpose, it is important to seed and transplant at earlier

Fig. 2 – 7. Relationship between Transplanting Date and Rice Yields of Early-, Medium- and Late-Maturing Varieties



season so far as cool-damage at the ear-primordia initiation stage can be avoided. As indicated in Fig. 2–7, in the case of early-maturing varieties, the earlier the transplanting date, the heavier the rice yields, while in the case of late-varieties, little or no effect of early-transplanting is observed.

Next, since the plant growth of early-maturing varieties is poor, it is better to transplant at a closer spacing. In the case of early-transplanting, the rice plants must grow at a relatively low temperature. As a result, in order to obtain heavier rice yield, a 20–30 per cent increase over the generally-accepted spacing is recommended. In order to accelerate the plant growth at the incipient growth stage, it is important to apply quick-acting fertilizers before transplanting as basic dressing.

2. *Plant types of rice varieties and fertilizer response*

(1) Plant types

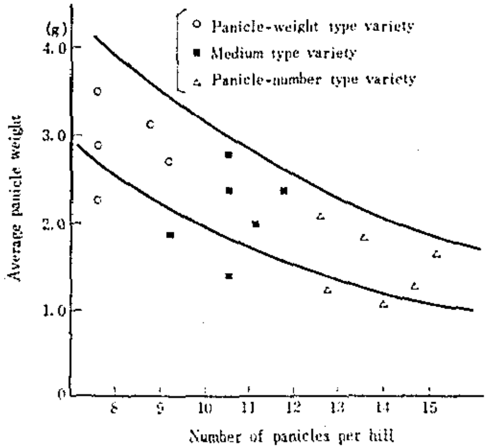
Rice yield per unit area is the product of "a total number of panicles per unit area" and "an average panicle weight". In general, varieties bearing many panicles are lighter in the panicle weight, while varieties of heavy panicle weight are less in the number of panicles. The former is known as "panicle-number type", and the latter as "panicle-weight type", and the medium as "medium type", respectively (Fig. 2–8). Panicle-weight type varieties have in general big and tall culms and the plant growth is vigorous. As a result, these are suitable for planting in sterile lands or with less amount of fertilizer application. Panicle-number type varieties have generally short culms and the plant growth is rather poor. As a result, these are suitable for planting in fertile lands or with heavy amount of fertilizer application.

(2) Fertilizer response

Rice plants absorb nitrogen by roots. On the other hand, sugar is formed by the photosynthesis (carbon assimilation) from carbon dioxide (CO_2) in the air and water in stems and leaves. From these materials, nitrogen and sugar, amino acids are produced at first, and then protein is synthesized

Fig. 2 – 8. Relationship between Panicle Weight and Panicle Number, by Types of Rice Varieties

(BABA)



from the amino-acids. However, some rice varieties perform their bodily functions actively in synthesizing protein, and others do not perform full functions, remaining much amount of ammonium nitrogen and amino-acids in the plant tissue. Amino acids contribute to the plant growth. As a result, in the case of rice varieties performing no full function in converting amino acids into protein if nitrogenous fertilizers are applied liberally, stems and leaves would grow too much and the rice plants would become feeble and liable to lodge or sensible to diseases. Accordingly, in the case of such varieties, rice yield would rather show an increase when nitrogenous fertilizers are applied moderately, while rice varieties of high protein-synthesizing ability are not affected like that by liberal fertilizer application. Such varieties are known as "varieties of high fertilizer response".

Relationship between plant types and fertilizer response is indicated in Table 2–4. It has been reported that panicle-number type varieties were of high fertilizer response and panicle-weight ones were of low fertilizer response, but it can not be asserted so. Connected with the relationship between grain-straw ratio (instead of plant type) and fertilizer response, the varieties at high grain-straw ratio are mostly of high fertilizer response and those at low ratio are mostly of low fertilizer response.

Table 2 – 4. Fertilizer Response of the Main Rice Varieties (BABA)

Varieties	*Plant type*	*Physiological fertilizer response*	*Resistance to blast*	*Resistance to lodging*	*Fertilizer response*
Kamenoo	P. L	C	C	C	C
Rikuu No. 132	M. L	A	B-A	B	B
Aikoku	T	A	B-A	B	B
Norin No. 1	T. S	B	B-C	A	A
Norin No. 7	P	A	A	B	A
Ginbozu	M	A	B	B	B
Norin No. 25	P. S	A	B-A	A	A
Norin No. 29	M	B	B	B-A	B-A
Norin No. 22	P. L	A	A	C	B
Norin No. 8	P	B-A	B	B	B
Asahi	M. L	C	C	B	C
Senbon-asahi	T. S	A	B	A	A
Kameji	P. L	B-A	B-A	B	B
Omachi	P. L	C	C	C	C
Shinriki	T	B	C	B	C

Note: P = Panicle-weight type B = Medium
T = Planicle-number type C = Low
M = Medium type L = Long stem
A = High S = Short stem

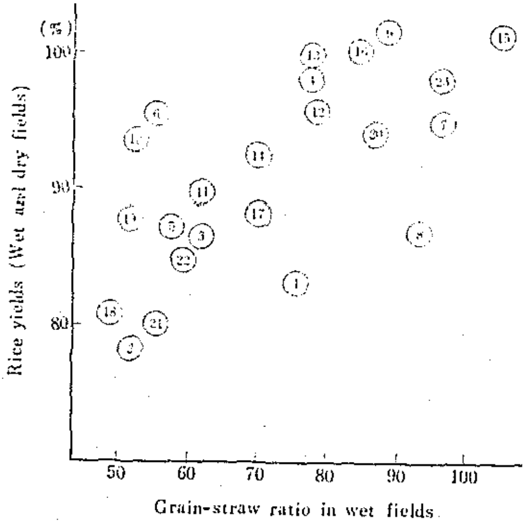
With the progress in rice breeding, all the panicle-weight type varieties now prevalent in Japan are not always long in *culm length* (e.g., *Norin No. 25* and *Fujisaka No. 5*), and panicles of panicle-number type varieties are not always small in size (e.g., Kinmaze). Many rice varieties of such plant *types as may be regarded as exceptions to the former plant-*type classification have come to be selected. As a result, even if a comparison be made between the above three plant *types and the fertilizer response, no relationship could actual-*

ly be observed.

Varieties of high fertilizer response would not readily overgrow even if fertilizers be applied heavily. Therefore, under the environmental conditions where rice plants are liable to overgrow or in case where such cultural method as may lead to the excessive plant growth is practised, the varieties of high fertilizer response (i.e., short-culm panicle-weight type or short-culm panicle-number type both high in

Fig. 2–9. Relationship between Adaptable Varieties for Wet Fields and Grain-Straw Ratio

(Kanto-Tosan Agricultural Experiment Station)



Notes: Number represents as follows:

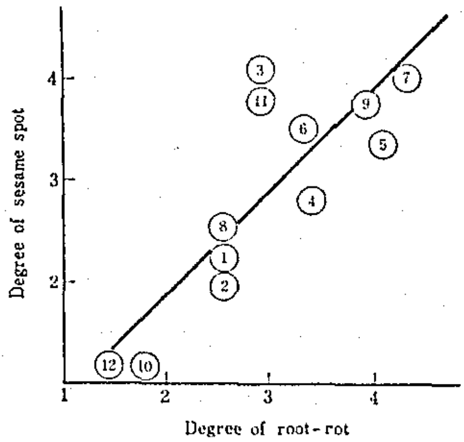
1. Norin No. 10
2. Norin No. 48
3. Hasseki
4. Norin No. 32
5. Kanto No. 55
6. Chibaasahi
7. Kiyosumi
8. Norin No. 29
9. Norin No. 25
10. Sensuji
11. Sen-ichi
12. Norin No. 35
13. Norin No. 22
14. Norin No. 23
15. Ginbozu
16. Norin No. 6
17. Norin No. 3
18. Sekitori
19. Tosan No. 38
20. Kinmaze
21. Fusakushirazu
22. Norin No. 8
23. Norin No. 31

the grain-straw ratio) are particularly recommended. For instance, as indicated in Fig. 2-9, in the case of wet fields in the Kanto District, varieties of high fertilizer response are particularly suitable, because the rice plants are liable to overgrow due to the effectiveness of nitrogen at the later plant growth period in such fields.

(3) *Akiochi* resistance

In the case of *Akiochi* paddy field, with the progress in soil reduction, hydrogen sulphide (H_2S) and other harmful substances (which may often cause root-rot) will present. As a result, the intensity of root-rot resistance of varieties will indicate the intensity of *Akiochi* resistance. Taking the country as a whole, the leading high root-rot resistant varie-

Fig. 2-10. Relationship between Root-Rot and *Helminthosporium* Leaf Spot (Sesame Spot) Occurrence, by Rice Varieties (12)
(BABA)



Note: *Number represents as follows:*

1. Norin No. 6
2. Norin No. 32
3. Chibaasahi
4. Norin No. 25
5. Norin No. 36
6. Norin No. 29
7. Norin No. 22
8. Norin No. 3
9. Norin No. 8
10. Norin No. 37
11. Aichiasahi
12. Kameji

ties are: Bandaiwase, Shin No. 2, Yachikogane, Shirogane, Sachiwatari, Norin No. 37 and the like. In general, in the case of degraded paddy fields, when root-rot occurs, *Helminthosporium* leaf spot will also occur frequently or the lower leaves will die-back. As illustrated in Fig. 2–10, root-rot resistant varieties are also resistant to *Helminthosporium* leaf spot, and the lower leaves will rarely die-back.

Since root-rot occurs due to the soil reduction at a high temperature in summer, in the case of *Akiochi* fields, it is important to avoid *Akiochi* by advancing or delaying the plant growth stage. Namely, it is recommended as *Akiochi* preventive measures to plant early-maturing varieties, and to practise early seasonal culture, or to plant extremely-late-maturing varieties in warm part of Japan (West Japan).

Table 2–5 indicates the *Helminthosporium* leaf spot resistance of the main rice varieties.

Table 2–5. Resistance to *Helminthosporium* Leaf Spot, by Varieties (BABA)

Varieties	*Sesame spot on 10cm leaf*	*Resistance*
Norin No. 32	3.9	A
Kameji	4.0	A
Norin No. 37	4.5	A
Senbon-asahi	4.8	B–A
Nakateginbozu	5.1	B–A
Norin No. 3	5.1	B–A
Norin No. 22	5.2	B
Norin No. 25	5.5	B
Norin No. 8	6.1	B
Harudaasahi	6.1	B
Omachi	6.5	B–C
Norin No. 36	6.7	B–C
Norin No. 29	7.7	B–C
Chibaasahi	8.3	C
Aichiasahi	9.3	C
Shinriki	9.9	C

Note: A, B and C indicate as follows:
A: High resistance
B: Medium resistance
C: Low resistance

(4) Lodging resistance

Rice plants are liable to lodging to a large extent due to the frequent visits of typhoons in autumn, as well as due to too heavy fertilizer application. In recent years, lodging resistant varieties are in strong demand increasingly in order to meet the mechanization of harvesting operation.

Lodging resistance of varieties is determined by three factors: stem strength, stem height, and panicle weight. Rice plants, in most cases, lodge from the basal part of each hill. When varieties are equal in stem strength, such varieties as may add heavy weight to the basal part of a hill would fall down readily. The weight added to the basal part will be equal to (stem-height) × (panicle-weight). The longer the stem and the heavier the panicle, the heavier the weight added to the basal part. On the other hand, when the weight added to the base of culms is equal, lodging depends upon the culm-strength. The culm-strength can be judged by the breaking load. Namely, a culm of a certain length is cut close to the ground surface and the cut culm is maintained horizontally by supporting its both ends with the supports. A weight is suspended from the central part of the cut culm and the weight is increased little by little until the culm may have been broken. The culm strength is measured by the total weight added to the culm. Of course, the greater the breaking load, the stronger the culm. Accordingly, when (Stem-height) × (panicle-weight) / (Breaking load) is small, rice plants do not lodge readily. Inversely, rice plants will lodge readily proportionately with the greater quotient (Fig. 2-11).

In order to obtain high rice yield, it is required to be varieties heavy in panicle weight as far as possible, but in order to minimize the lodging, when the panicles are large in size, the varieties must have short and strong culms as far as possible. Amongst the three factors, the stem-height has the closest bearing upon the lodging. Fig 2-12 indicates the relationship between the lodging degree and the stem-height of six rice varieties, showing that the higher the stem-height,

Fig. 2 – 11. Loding Degree and Lodging Index of Various Rice Varieties

(Tokai-Kinki Agricultural Experiment Station)

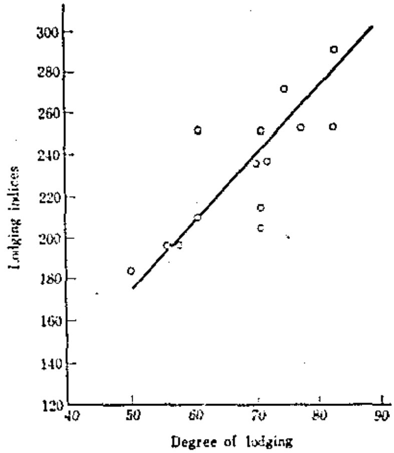
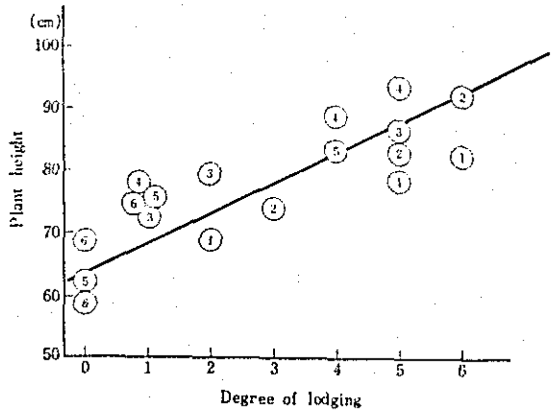


Fig. 2 – 12. Plant Height (Stem-Height) and Lodging Degree of Six Rice Varieties



Note: Number represents as follows:

1. Norin No. 41
2. Koshihikari
3. Hokuriku No. 58
4. Yachikogane
5. Hokuriku No. 52
6. Kinmaze

Table 2 – 6. Lodging Resistance of the Leading Rice Varieties in Japan

Region	*Higher*	*High*	*Medium*	*Low*
Tohoku	Fujisaka No. 5	Towada Otori Akibae Fujiminori	Mutsuhikari Yamatedori	Norin No. 41 Hatsunishiki Chokai Hakkoda Norin No. 17 Sasashigure Takanenishiki *Koganemochi*
Hokuriku		Tarehonami Manryo Koshihonami Shin No. 7 Fukuminori *Hokuriku* No. 52 Yachikogane Shirogane	Yomohikari Okumasari Tedoriwase Honenwase Ginmasari *Norin No. 30* Shinmasari Tarehonami Norin No. 43 Koshihonami	Yamakogane Koganenami Koshihikari Norin No. 1 Norin No. 21
Kanto	Kinmaze Nakate-shinsenbon Yamabiko Norin No. 25	Norin No. 31 *Tosan No. 38* Norin No. 32 Norin No. 29	Norin No. 35 *Chikuma* Tonewase Wakaba Norin No. 8 Kotobuki-mochi	Saitamamochi *Norin No. 10* Norin No. 48
Tokai Kinki Chugoku	Tokai Senbon Senbonmasari Shioji	Chukyoasahi Tokaiasahi Chiyohikari Aichiasahi Mihonishiki Koganenishiki Akebono Ayanishiki Hikari	*Hatsushimo* Norin No. 44 Yaeho Norin No. 23	*Norin No. 22* Norin No. 31 Asahi
Kyushu	Jukkoku	Asakaze Imari No. 2 Norin No. 39 Norin No. 27 Nakasengoku Benisengoku	Norin No. 18 Hamayu Tsurugiba Hozakae Takara Norin No. 12 Shimotsuki Zuiho Norin No. 40	Kuseshirazu

the higher the lodging degree. Moreover, varieties with tough stems are heavy in the breaking load and those with soft stems are light. As a result, the former do not lodge readily. However, varieties with stems which are stiff but lacking in elasticity (e.g., Tarehonami or Wakaba) are liable to be broken from the basal part when struck by typhoons. Elasticity is indispensable to firmness of the stems. Table 2–6 indicates the lodging resistance of the leading rice varities in various parts of the country.

(5) Disease and insect pest resistance

Degrees of damage to rice plants caused by diseases and insect pests of various descriptions vary according to the rice varieties. The difference in degrees of damage by disease and insect pests is ascribed to the two cases: (i) a case where it is confirmed that the difference is ascribed to the resistant factor of rice varieties and (ii) a case where it is ascribable to a mere "escaping" due to differences in growth stage or in plant types instead of to the resistant factor. The difference among varieties in resistance to blast (*Piricularia Oryzae* CAVARA), bacterial leaf blight (*Xamthomonas Oryzae* DOWSON), *Helminthosporium* leaf spot (*Cochliobalus* MIYABE), stem maggot (*Chlorops Oryzae* MATSUMURA), etc., is ascribable to the former, and the difference among varieties in resistance to sheath blight (*Corticium Sasakii*), dwarf (*Fractilinea Oryzae* HOLMES), stripe, rice borer (*Chilo suppressalis* WAKER), etc., is ascribable to the latter. As a result, the selection of varieties is of great significance as the control measures against the diseases and insect pests falling under the former, while in the case of the latter, the selection of varieties is of little significance.

(a) Resistance to blast disease (*Piricularia Oryzae* CAVARA)

Taken the country as a whole, the damage by blast disease is pre-eminently serious above the rest. For instance, until about 1953 the annual decrease in rice yields due to the blast damage amounted to around 300,000 tons. In recent years, however, due to the advanced control techniques by the use of mercury compounds and due to the early-seasonal rice cultural practices in the southwest part of Japan, the disease damage has decreased to some extent, but affected once, it is usual to result in the decrease in production of 20–30 per cent. If taken into consideration that the rice culture in future Japan will tend to the culture with heavier fertilizer application, the role of the varieties of high blast resistance is still important.

Rice varieties of high resistance to blast disease in Japan can be classified into the following four categories.

(i) Varieties bred by crossing among Japanese varieties

Among the pure Japanese varieties, Norin No. 22 and Norin No. 23 are the varieties of the highest resistance to leaf blast and neck-rot (blast). Both of the two have been bred by crossing between Norin No. 8 (leaf blast resistant variety, but low in resistance to neck-rot) and Norin No. 6 (low in leaf blast resistance, but high in neck-rot resistance). Those disease resistant varieties are also used as parent varieties. For instance, Hatsunishiki and Chokai (in Tohoku), Yaeho (in Kanto), and Yamabiko and Chiyohikari (in Tokai) are the varieties bred by using Norin No. 22 as a parent, and superior ones of high blast disease resistance and widely planted in the respective districts.

(ii) Varieties bred by crossing between upland rice varieties and paddy rice varieties

It is well known that upland rice varieties are resistant to blast disease. Late S. Iwatsuki, famous rice breeder of the Aichi Prefectural Agricultural Experiment Station, with a view to combining the blast disease resistant factor of upland rice with paddy rice varieties, crossed Sensho (upland rice variety) with a paddy rice variety and crossed the progeny again with the paddy rice variety. Repeating such crossing he could breed blast disease resistant paddy rice varieties: Futaba and Shinju. By carrying out further improvement, he obtained many blast disease resistant varieties, e.g., Wakaba, Koganenishiki, Ginga, Ayanishiki, Senbonmasari, and Yutakasenbon. Those varieties are not so high yielding ones, except the last two varieties which belong to the Senbon-asahi Group. Nevertheless, those are particularly useful varieties in the intermountain areas in the Tokai and Chugoku Districts where blast diseases break out frequently.

(iii) Varieties bred by crossing between Chinese rice varieties and Japanese ones

The National Agricultural Experiment Station of the Ministry of Agriculture and Forestry (in the time when it was named "the Konosu Experiment Farm") carried out the tests for several hundred foreign rice varieties collected from various foreign countries, and confirmed that Reishiko and Toto Varieties introduced from Central China were blast disease resistant ones and comparatively resembled Japanese rice varieties in characteristics, and bred Kanto No. 51–55 (lines of high blast disease resistance) by crossing Reishiko and Toto with Japanese rice varieties. By repeated crossing between Kanto No. 53 and Norin No. 29, a new variety of high blast resistance named "Kusabue" has come to be bred recently. The variety bred by crossing by the use of the Chinese varieties as a parent is blast disease resistant, high yielding, and superior in quality, but very susceptible to bacterial leaf blight.

(iv) Varieties bred by crossing between Philippine rice varieties and Japanese ones

Some paddy rice varieties among those distributed in Southeast Asian countries are very high in blast disease resistance, but differ greatly from Japanese ones in characteristics. As a result, it has been reported to be very hard to combine their resistant character with that of Japanese ones, while at the Chugoku Agricultural Experiment Station, Ministry of Agriculture and Forestry, hybrid was obtained by crossing between Philippine variety (Tadukan) and Japanese one (Senbon-asahi), and then obtained the lines (Pi No. 1 and Pi No. 2) by backcrossing at two times between the above hybrid and Senbon-asahi. Pi No. 3 and Pi No. 4 were also obtained by carrying out the same backcrossing method by the use of Norin No. 8, and likewise Pi No. 5 was bred by the use of Tosan No. 38. These new lines are very high in blast disease resistance because the resistant character of Tadukan has been combined with their characters. These new lines are now used widely as the intermediate parent varieties.

Of the above four classes, two classes: varieties bred by crossing between upland rice varieties and paddy ones (ii) and varieties bred by crossing between Central Chinese rice varieties and Japanese ones (iii) may sometimes differ greatly in the degree of blast disease resistance according to the

Table 2-7. *Blast Disease Fungus Races and Resistance of Rice Variety-Groups to the Respective Blast Fungus Races*

(GOTO and YAMANAKA)

Rice variety group	*Varieties*	*Types of disease fungus race*					
		T	A	B	C	D	E
a	Tetep, Zenith	R	R	R	R	R	R
b	Tadukan, Pi No. 1, No. 2	R (S)	R	R	R	R	R
c	Chokoto (Toto)	R	S	R	R	S-R	R
d	Reishiko, Yakeiko, Kanto No. 51, Kanto No. 52 (No. 53) No. 54, No. 55	R	S	R	R	R	R
e	Ishikarishiroge, Norin No. 34	S	S	S	R	R	R
f	Homarenishiki, Ayanishiki, Sensho, Ginga (Fujisaka No. 5)	S	S	S	R	R	R
g	Norin No. 22 (Norin No. 37)	S	S	S	S-R	S	R
h	Aichiasahi, Asahi No. 1 Asahi No. 4, Senbon-asahi, Eiko, Hashiribozu No. 1, Hakkoda, Norin No. 7, No. 21	S	S	S	S	R	R
i	Norin No. 20, No. 1, No. 6, No. 8, Ginbozu, Kamenoo, Rikuu No. 132, Kinaiwase No. 22	S	S	S	S	S	R

Notes: R = Resistant. R (S) = Slightly susceptible.
S = Susceptible. S - R = Medium.

Table 2 – 8-(1). Resistance to Leaf Blast of the Main Rice Varieties

Region	*High*	*Medium*	*Low*
Tohoku	Towada Fujisaka No. 5 Fukusuke Fujiminori Toyochikara	Hatsunishiki Chokai Akibae Otori Hakkoda	Sasashigure Norin No. 41 Oirase Yamatedori Takanenishiki Koganemochi Norin No. 17 Mutsuhikari
Hokuriku	Honenwase Koshijiwase Yamakogane Koganenami	Okumasari Yomohikari Tarehonami Megumiwase Koshihikari Fukuminori Manryo	Nihonkai Yoneyama Shinmasari Norin No. 1, No. 30
Kanto	Kanto No. 53 Yaeho Wakaba Kotobukimochi Kusabue	Norin No. 25 Kinmaze Norin No. 8 Norin No. 48 Ginmasari Tosan No. 38 Nakate-shinsenbon	Norin No. 35 Norin No. 29 Norin No. 32 Norin No. 10 Saitamamochi No. 10
Tokai Kinki Chugoku	Ginga Norin No. 22 Chiyohikari Yamabiko Koganenishiki Ayanishiki Norin No. 37 Shuho	Shioji Yutakasenbon Nagiho Senbonmasari	Aichiasahi Hatsushimo Yubae Tokaiasahi Akebono Mihonishiki Chukyoasahi Asahimochi Senbon-asahi Tokaisenbon
Kyushu	Norin No. 37	Shimotsuki Tsurugiba Hamayu Norin No. 12 Kuseshirazu Nakasengoku Benisengoku	Jukkoku Norin No. 40 Zuiho Imari No. 1 Takara Hozakae Asakaze Norin No. 18 Norin No. 39

Table 2-8-(2). Resistance to Neck-rot (blast) of the Main Rice Varieties

Region	*Hgih*	*Medium*	*Low*
Tohoku	Hatsunishiki Chokai	Towada Hakkoda Otori Norin No. 17 Akibae	Sasashigure Norin No. 41 Takanenishiki Koganemochi *Fujisaka* No. 5
Hokuriku	Koshijiwase *Honenwase* Koganenami Yamakogane Hokuriku No. 41 San-in No. 17	Megumiwase *Yomohikari* Manryo	Yoneyama *Nihonkai* Tarehonami Norin No. 43 Yachikogane Shirogane Tedoriwase Shin No. 6 Shinmasari Fukuminori
Kanto	Kanto No. 53 Yaeho, Wakaba Kotobukimochi *Kinmaze* Nakateshinsenbon Norin No. 6 Kusabue	Norin No. 35 Tosan No. 38 Norin No. 25	Norin No. 32 Norin No. 10 Norin No. 8 *Ginmasari* Norin No. 48 Norin No. 29 Norin No. 31 Saitamamochi
Tokai Kinki Chugoku	Norin No. 22 Norin No. 23 Koganenishiki Ayanishiki Shuho Chiyohikari, Yamabiko Ginga, Yutakasenbon, Norin No. 37, Nijimochi	Mihonishiki Senbonmasari Shioji, Nagiho Shimotsuki	Senbon-asahi Hikari, Aichiasahi Asahi No. 1, Yubae Akebono, Hatsushimo, Tokaiasahi Chukyoasahi Tokaisenbon Kyoasahi, Asahimochi
Kyushu	Kuseshirazu	Norin No. 17 Asakaze Hamayu Norin No. 18 Tsurugiba Norin No. 39 Shimotsuki Zuiho Nakasengoku	Norin No. 40 Benisengoku Hozakae, Takara Imari No. 1 Jukkoku

areas. For instance, Kanto No. 51–55 (iii) are very high in blast disease resistance in the Kanto Plain Area, but very susceptible in the intermountain areas in Aichi or Nagano Prefecture. This is due to the fact that Kanto lines are resistant to most of the various blast fungi, but are very susceptible to a certain kind of fungi. Table 2–7 indicates the races of blast disease fungi and the resistance of various rice variety-groups to the respective races of blast disease fungi. Table 2–8 indicates resistance to leaf blast and neck-rot of the leading rice varieties in the various parts of the country.

(b) Resistance to bacterial leaf blight (*Xanthomonas Oryzae* DOWSON)

Bacterial leaf blight occurred mostly over the areas from South Kanto to West Japan, particularly in the areas visited by frequent typhoons. In recent years, however, it has spread as far to the Tohoku and Hokuriku Districts and the damage by bacterial leaf blight is becoming increasingly outstanding. Consequently, the degree of resistance to bacterial leaf blight of the rice varieties distributed in West Japan has become clarified to a fairly great extent, but that of the rice varieties prevalent in North Japan has not been clarified as yet.

The relationship between bacterial leaf blight resistance and plant types of rice varieties is not fully clear as yet, but it is generally accepted that varieties having small flag leaves or light-colored leaves are mostly high in bacterial leaf blight resistance, while varieties having long flag leaves or dark-colored leaves are mostly susceptible to this disease. And varieties resistant to blast are, in most cases, susceptible to bacterial leaf blight. The varieties resistant to both blight and bacterial leaf blight are confined to such varieties as Tosan No. 38, Chikarasenbon, Norin No. 23, and Yaeho. Table 2–9 indicates the bacterial leaf blight resistance of the leading rice varieties in various parts of Japan.

(c) Resistance to rice stem borer (*Chilo suppressalis* WALKER)

Resistance of rice plants to rice stem borers varies greatly because many complicated factors are involved therein, e.g.,

Table 2-9. Resistance to Bacterial Leaf Blight of the Main Rice Varieties

Region	*High*	*Slightly high*	*Medium*	*Low*
Hokuriku	Yachikogane Shirogane	Manryo Koganenami Honenwase Norin No. 30 Yamakogane Koshisakae	Okumasari Koshihikari Megumiwase Norin No. 43 Nihonkai	Hokuriku No. 52 Fukuminori Koshijiwase
Kanto	Norin No. 35 Yaeho	Norin No. 48 Norin No. 8	Norin No. 32 Norin No. 29 Wakaba Yamabiko	Chibaasahi Nakateshin-senbon Norin No. 25, Kinmaze Saitama-mochi No. 10
Tokai Kinki Chugoku	Norin No. 23 Nagiho Tozan No. 38 Kidama Kaori Taishoakaho Koganemaru	Norin No. 22 Koganenami Norin No. 44 Tokaiasahi Shioji Chiyohikari Yubae Chukyoasahi	Hatsushimo Mihonishiki Ayanishiki Tokaisenbon Akebono Koganenishiki	Senbon-asahi Asahi No. 1 Asahi Aichiasahi Yutakasenbon Norin No. 37
Kyushu	Norin No. 27 Zensho No. 17 Zensho No. 26 Kono No. 35 Akashinriki Asakaze	Benisengoku Norin No. 7 Hamayu	Kuseshirazu Nakasengoku Norin No. 18 Shinai Takachiho Shimotsuki Zuiho Norin No. 39	Tsurugiba Hozakae Jukkoku Takara Imari No. 1 Shinzan Asahi

spawning condition, resistance of stems to the invasion of larvae, inside condition of plant stems under which larvae live, difficulty in moving of larvae from one stem to another, and the extent of worm-eaten damage to plant stems. The extent of rice stem borer damage to rice varieties varies according to these factors combined. In general, however, rice varieties of higher tillering ability are lower at the damaging rate and less in the number of the damaged stems per unit area than those of lower tillering ability. This is partly due to the fact that rice varieties of higher tillering ability possess many charcteristics unsuitable for the living of larvae and partly due to the greater number of tillers not injured by larvae bacause they have many tillers.

In recent years, the rice stem borer control by the use of Parathion compounds has come to be practised throughout the country. As a result, the demand for rice stem borer resistant varieties is becoming decreased.

(d) Resistance to stem maggot (*Chlorops Oryzae* MATSUMURA)

Stem maggot generates twice a year in Hokkaido and Tohoku, but generates thrice a year in the region west to Kanto. The imago lays eggs on the leaves of seedlings. The larvae which emerged from eggs bore into stems from the space between the leaf sheaths and the stems and eat new leaves or young panicles inside the stems. When leaves are eaten by stem maggots, holes will be bored on the leaves or the leaves will be injured. When young panicles are eaten by stem maggots, the grains will be deformed or a part of the grain will be injured.

The extent of stem maggot damage varies markedly according to the rice varieties. For instance, the comparison between Yomohikari (resistant variety) and Yachikogane (susceptible variety) shows that little or no difference is observed in the number of eggs laid on the leaves, but a great difference in damage is found. It has become evident that in the case of the former, the death rate of larvae which bored into the stems is very high and quite a few ones survived.

In general, medium-maturing varieties suffer great damage from stem maggots. This can be accounted for by the relationship between a peak larval emergence period and heading stage of rice. Namely, early-maturing varieties free from stem maggot damage owing to the early panicle formation, and late-maturing varieties suffer from the damage to the leaves, but not to the panicles owing to the late panicle formation stage. The leading stem maggot resistant varieties in various regions are given in Table 2–10.

(6) *Rice quality*

With the increase in quantity of rice shipped to the mar-

Table 2-10. Resistance to Rice Stem Maggots of the Main Rice Varieties, by Regions

Regions	*High*	*Medium*	*Low*
Tohoku	Ou No. 30, No. 188, Kuhei No. 2, Fukusuke	Norin No. 17, Sasashigure, Kamenoo, Shinnigo, Ojiro, Okuniwase, Obakowase, Sekiminori, Hatsunishiki, Norin No. 41	Norin No. 16 Rikuu No. 132 Ou No. 23, Sekiyama, Fujisaka No. 5, Towada
Hokuriku	Hayanorin, Hokuriku No. 11, Norin No. 43, Koshihikari, Shin No. 5, Manryo, Fukuminori, Yomohikari, Koganenami	Norin No. 1, No. 21, No. 30, Honenwase, Koshijiwase, Hatsuminori, Bandaiwase No. 7	Shin No. 2, Yachikogane, Shirogane, Tarehonami, Imochishirazu, Megumiwase, Koshihonami
Kanto Tosan	Norin No. 6, No. 25, No. 31, No. 29, No. 32, Kinmaze, Nakateshinsenbon, Wakaba, Yaeho, Yamabiko, Kiyosumi, Kotobukimochi	Norin No. 10, Aimasari, Tonewase, Ginmasari	Akibae, Chikuma, Norin No. 48, 8, 36, 23, Tosan No. 38 Takanenishiki, Norinmochi No. 45, Saitamamochi No. 10
Tokai Kinki Chugoku	Norin No. 22, 44, Shuho, Mihonishiki, Koganenishiki, Ayanishiki, Aichiasahi, Kameji, Kidama, Senbon-asahi, Tokaisenbon, Yutakasenbon, Chiyohikari, Shioji, Yaeho, Asahimochi, Akebono, Chukyoasahi, Tokaiasahi	Yubae, Futaba	Sachiwatari, Norin No. 37 Hatsushimo Homasari, Asahi Kyoasahi, Nagiho Norinmochi No. 5 Tsubasa
Kyushu	Norin No. 18, 12, 26, 27, 39, Nakasengoku, Asakaze, Hozakae, Takara, Benisengoku	Zensho No. 17, Zuiho, Tsurugiba Norin No. 40 Kuseshirazu,	Akashinriki Banseiasahi Kono No. 35

ket, rice quality problem is now so much to the fore. What on earth is the meaning of quality of rice? In a broad sense, it will indicate the four characteristics: (i) degree of milling rate; (ii) palatability; (iii) imperishability; and (iv) nutritive value. However, the importance placed on these four factors varies according to the standpoints of the respective persons. It is not easy to set up an objective criterion. For instance, from the standpoint of consumers in general, an importance will be placed on the palatability, rice retailers will place an importance on the milling rate, and the Food Agency in charge of rice control and rice storage will place an importance on the imperishability.

Under the present rice inspection system, milling rate (i) and imperishability (iii) are taken up, and the rice is graded basing upon these two items. Palatability of rice (ii) is now under study and the nutritive value (iv) does not differ appreciably according to the rice varieties and the producing areas. The present rice inspection standards are given in Table 2-11.

Table 2-11. Inspection Standards of Husked (Brown) Rice

Grade	*Lower limit*			*Upper limit*				
					Mix of bad grains and other matters			
	Volume weight	*Percentage of perfect grain*	*Character*	*Moisture content*	*Non-ripened grain*	*Paddy*	*Other*	*Other matters*
	g	%		%	%	%	%	%
1st	840	90	1st class	14.0	3.0	0.1	0.0	0.0
2nd	830	80	2nd 〃	14.5	5.0	0.2	0.1	0.1
3rd	810	70	3rd 〃	15.0	7.0	0.3	0.3	0.2
4th	790	60	4th 〃	15.0	10.0	0.3	0.5	0.4
5th	770	45	5th 〃	15.0	20.0	0.3	1.0	0.6
Other	below 770	—	—	15.0	100.0	5.0	5.0	1.0

(a) Milling rate and characteristics of rice varieties

Milling rate indicates the ratio of weight of milled rice to the weight of original husked rice (brown rice). Factors affecting the milling rate are the rate of perfect grain (husked rice), grain weight (per liter), characteristics of rice varieties (thickness of seed-vessel, grain-shape, and grain size uniformity), moisture-content, types of milling machines, etc. Above all, the rate of perfect grain has the closest bearing upon the milling rate and is the most important factor in determining the grades of rice. Volume weight of grain has also a close bearing upon the grading.

The rate of perfect grain is the ratio of weight of perfect grains in a definite quantity of husked rice to the total weight of husked rice. Perfect grains indicate the fully ripened grains, i.e., out of the total quantity of husked rice are excluded damaged grains, dead grains, non-ripened grains, grains of other varieties, and foreign matters (sand or dust). Some grains other than perfect grains may become rice bran by milling operation and may decrease the milling rate, and others may become broken rice which may degrade the quality of milled rice. As a result, in the case of rice inspection, rice bran and broken rice are regarded as serious items in grading. With respect to these items, the maximum allowable mixing rates are regulated for each grade of rice.

As stated above, the milling rate is affected by characteristics peculiar to rice varieties such as thickness of grain, amount of opaque grains or white-belly grains, grain uniformity, and grain shapes. Moreover, these characteristics are the important factors in determining the external appearance of rice as commodity. Grain quality of rice varieties in a narrow sense indicates mostly the integrated characteristics of those peculiar to rice varieties. "Characteristics," as used in the inspection standards, can be taken as the meaning similar to the quality referred to here, and indicate the external appearance of the rice representing the respective grades. The standard samples are prepared according to the respective grades. Table 2–12 indicates the rice quality of the leading rice varieties in the respective regions.

Connected with the rice quality of various varieties, adding to the quality of husked rice itself, it should be taken into consideration that ripening time, disease resistance, and lodging resistance exert influences on the grain quality.

(b) Rice varieties and palatability

Palatability of rice varies according to the rice cultural methods and areas, but the characteristics peculiar to rice varieties have the closest bearing upon the palatability of rice. The superiority in grain characteristics of varieties and the superiority in palatability do not always coincide with each other. Lustrous grains with thin seed-vessel and excellent external appearance are usually palatable. Palatability varies depending upon the consumers' own judgment. Namely, it varies greatly according to the areas in which consumers live, and their ages or occupations. Even in the case of consumers under the same conditions, individual variations are observed. As a result, the criteria for judgment of palatability can not

Table. 2-12. Quality of Rice of the Main Rice Varieties

Quality / *Regions*	*High*		*Medium*
	High	*Low*	*High*
Tohoku	Hatsunishiki Norin No. 16	Rikuu No. 132	Sasashigure
Hokuriku	Koshihikari Honenwase Norin No. 1 Koshijiwase Koshisakae	Manryo Norin No. 30 Yamakogane	Shirogane Megumiwase Nihonkai Koganenami Fukuminori Tedoriwase
Kanto	Norin No. 6 Yamabiko	Norin No. 35 Chibaasahi Norin No. 8 Yaeho Norin No. 10	Norin No. 29 Norin No. 48 Chikuma Tosan No. 38 Wakaba
Tokai Kinki Chugoku	Chiyohikari Norin No. 44 Asahi Kinki No. 33 Asahi No. 1	Norin No. 22 Norin No. 23 Norin No. 37 Syuho Koganenishiki Hikari Hatsushimo Aichiasahi Nagiho	Mihonishiki Tokaiasahi Tokaisenbon Senbonmasari Yubae Yutakasenbon Akebono
Kyushu	Norin No. 12	Kuseshirazu Norin No. 18 Shimotsuki Zuiho	Nakasengoku Imari No. 1 Asakaze Hamayu Tsurugiba Norin No. 39 Benisengoku Jukkoku

(Continued)

Quality / Regions	Medium	Low	
	Low	High	Low
Tohoku	Yamatedori Norin No. 17	Chokai Towada Fujisaka No. 5 Otori	Norin No. 41 Hakkoda
Hokuriku	Ginmasari Yachikogane	Ginbozunakate	Aikoku
Kanto	Norin No. 32 Norin No. 25	Kinmaze Nakatesenbon	Fukusuke
Tokai Kinki Chugoku	Senbon-asahi Ayanishiki Shioji	Ginga	
Kyushu	Hozakae Takara	Norin No. 40	

readily be set up. However, rice as commodity must be suitable to the taste of a great number of consumers instead of specific consumers.

(c) Imperishability and quality

Moisture-content in rice has the closest bearing upon the storage of rice. During the storage, moisture-rich rice will lose in weight, or will become moldly, or sometimes may rot. In this sense, in times of free marketing, rice low in moisture-content was known as "hard rice", and rice relatively high in moisture-content as "soft rice." Rice was thus classified according to the producing centers. Such classification is still now observed among rice dealers. For instance, rice produced in the regions west to Kanto is called "hard rice", and rice produced in Hokkaido, Tohoku, and in areas on the Japan Sea side is called "soft rice". However, moisture-content in rice can be reduced by drying methods after harvesting. In the future, with the popularization of drying machines, rice with poor imperishability due to the excessive moisture-content will become decreased.

Imperishability of rice according to the rice varieties remains still unknown.

3. Outline of Rice Breeding Methods

Breeding methods by hybridization and artificial mutation are the paddy rice breeding methods now practised in Japan. The latter has been practised since several years ago and has not been established firmly as yet. Therefore, the breeding by hybridization only will be dealt with in this Chapter. The first step in breeding by hybridization is to develop hybrid between two rice varieties in order to combine the desirable characters in one pedigree, and then to select the desirable plants from among the segregating progenies. Rice breeding method by hybridization is the mainstay of the main self-fertilized crop (rice, wheat or barley) improvement methods in present Japan. The method of breeding by hybridization is subdivided into various methods, but pedigree method and bulk method are the two major methods applied mostly. In the case of the pedigree method, the individual selection is started from F_2 generation, and with respect to F_3 and the subsequent generations, the line breeding is practised. In the case of the bulk method, the early generation is grown in a segregating population, exercising no individual selection, and the line breeding is practised at the stages of the advanced generations (F_5-F_6). The former has an advantage in that the breeding period is relatively short, but has a disadvantage in that excessive labor and enough experience are required, while the latter has the reverse advantage and disadvantage.

In Japan, rice breeding had been achieved until several years ago almost exclusively by the pedigree method, but in recent years, the breeding by bulk method has come to be adopted rapidly in most breeding centers. The procedure in breeding will briefly be described below.

1. Establishment of breeding objectives

The first step in breeding is to set up the breeding objectives. In order to set up the breeding objectives firmly, it is needed to review and study the following factors to the fullest extent.

(i) Soil-climatic conditions in the respective areas;

(ii) Future direction of rice cultural methods;

(iii) Merits and demerits of rice varieties now prevailing in the country.

The characters of the desirable varieties are determined basing upon the above factors. For instance, in the case of level areas in the Kanto District, the principal breeding objectives can be set up to breed the rice varieties characterized by the superior-quality, medium- or late-maturing, strong culms and high resistance to bacterial leaf blight.

2. Selection of parent varieties

After the breeding objectives have been set up, parent varieties to be combined are required to be selected. In selecting the parent varieties, the selection must be made from among the varieties now prevailing in various parts of the country, and native varieties or foreign varieties will be used, if need be. For this purpose, characteristics of many varieties in stock are required to be made clear. As described in Section 2 on the utilization of foreign rice varieties for breeding the blast resistant varieties, in the case of a wide-crossing it is very hard to breed a practical variety straightforwardly. As a result, a stepwise method is adopted, i.e., to begin with, an intermediate parent variety is produced and then the practical variety is bred by making use of the intermediate parent.

3. Procedure in rice breeding

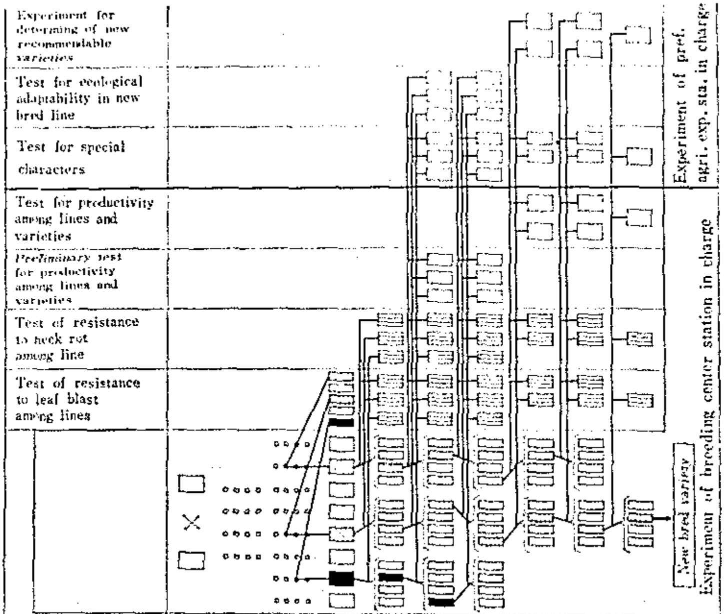
(1) Pedigree Method

The procedure in rice breeding is illustrated in Fig. 2-13. It is divided into three processes: (i) crossing; (ii) selection of desirable individual plants or lines up to F_5 generation; and (iii) yielding test, local adaptability test, and fixation of superior lines of F_6 and the subsequent generations.

(a) Crossing

In order to make sure the crossing, it is necessary to give treatment so that the two parents may flower simultaneously.

Fig. 2 – 13. The Outline of Process of Rice Breeding



Process of Breeding

Generation	Crossing	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9
Number of selected plants per line				5	5	5	5	5	5	
Number of selected lines (individuals)			100~150	10~20	5~15	2~5	2~5	2~4	2~4	1
Area for each generation (m^2)		1.1	33~66	250~375	125~250	63~187	33~83	33~83	33~66	33~66
Unit area of each line (m^2)				2.5	2.5	2.5	3.3	3.3	3.3	3.3
Number of individuals per line				45	45	45	60	60	60	60
Number of planted lines and individuals		20	600~1200	100~150	50~100	25~75	10~25	10~20	10~20	10~20

Note: Test for special characters as follows:
1. Leaf blast 2. Bacterial leaf blight 3. Sclerotial diseases 4. Helminthosporium leaf spot 5. *Akiochi* 6. Cold resistance 7. Lodging resistance

Table 2-13. The Beginning Date of Short-Day Treatments

Normal blooming date	*Number of days desired to be quickened*							
	3 days	*5 days*	*7 days*	*10 days*	*15 days*	*20 days*	*25 days*	*30 days*
Aug. 16	July 23	July 17	July 14	July 9	July 4			
17	24	18	15	10	5			
18	25	19	16	11	6			
19	26	20	17	12	7			
20	27	21	18	13	8	July 4		
21	28	22	19	14	9	5		
22	29	23	20	15	10	6		
23	30	24	21	16	11	7	July 3	
24	31	25	22	17	12	8	4	
25	Aug. 1	26	23	18	13	9	5	July 1
26	2	27	24	19	14	10	6	2
27	3	28	25	20	15	11	7	3
28	4	29	26	21	16	12	8	4
29	5	30	27	22	17	13	9	5
30	6	31	28	23	18	14	10	6
31	7	Aug. 1	29	24	19	15	11	7
Sept. 1	8	2	30	25	20	16	12	8
2	9	3	31	26	21	17	13	9
3	10	4	Aug. 1	27	22	18	14	10
4	11	5	2	28	23	19	15	11
5	12	6	3	29	24	20	16	12
6	13	7	4	30	25	21	17	13
7	14	8	5	31	26	22	18	14
8	15	9	6	Aug. 1	27	23	19	15
9	16	10	7	2	28	24	20	16
10	17	11	8	3	29	25	21	17
11	18	12	9	4	30	26	22	18
12	19	13	10	5	31	27	23	19
13	20	14	11	6	Aug. 1	28	24	20
14	21	15	12	7	2	29	25	21

For this purpose, the short-day treatment is given to a parent of the delayed flowering time. Thus, heading time is quickened by the short-day treatment. The commencement of the short-day treatment is required to be adjusted timely according to the heading time of the variety under the natural condition and the number of days desired to be quickened, but it has been determined by the experiment, as given in Table 2-13.

Crossing is usually attempted in a sunny and wind-free room. In crossing self-fertilized crops, the flowers of the female parent are first emasculated. Before crossing, the panicles of such male parent as may flower on that day must be pulled out from the field early in the morning and ready at the rate of 10–20 panicles per cross. The emasculation is practised by using the hot water method, i.e., the female parent's panicles are soaked in hot water (43°C) for 5 minutes. By this treatment, pollens become impotent but pistils remain healthy. When the flowers of female parent open, the pollens of the male parent are sprinkled slowly over the flowers of the female parent. (See Photo. 2–1.) After that, the female parent's spikelets which have finished to flower before emasculation and the spikelets which do not flower as yet even after emasculation are cut away because there is a fear that they might be self-pollinated. After crossing, the female parent's panicles are covered with paraffin paper on which the name of the parent varieties and the crossing date are indicated.

(b) Growing of F_1 generation

F_1 is usually cultured by transplanting in the paddy field at the rate of 10–20 plants placing them by the side of the parent varieties. F_1 is transplanted on a one-seedling per-hill basis. Thus the success or failure of crossing is judged by observing the various characters and 5–10 individual plants per crossing are selected. Because the degree of heterosis varies with the combinations, it is recorded in some cases.

(c) Growing and selection of F_2 generation

About 500–2,000 individual plants of F_2 generation in various combinations are transplanted on a one-seedling per-hill basis. Various characters of these population segregate according to the characters of the two parents. From among them are selected such individuals as may meet the breeding objectives. The number of the selected individuals differs according to the combinations, and the total number is restricted by the acreage of the line breeding farms for the next generation plants, but in the case of superior combination, about 100–200 plants are selected. Of course, the combinations extremely poor in disease or lodging resistance are discarded. In the case of combination in which the segrega-

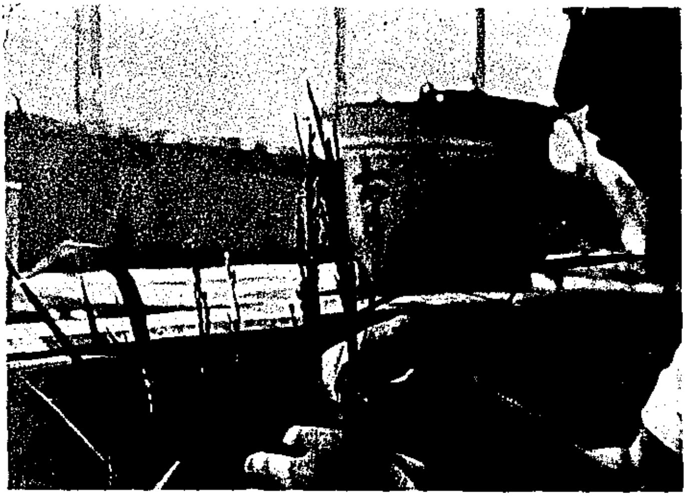


Photo. 2-1. Pollinating

tion of maturing character is great, various colored vinyl strings must be attached to the plants according to each heading date so that the maturing date of each plant can be distinguished at the time of selection. The main characters to be selected are those of high heritability, e.g., heading date, culm height, and disease resistance.

(d) *Growing and selection of F_3 generation*

F_3 generation of the selected F_2 plant is handled as F_3-line. Each line consists of 40-50 plants. At the stage of F_3 generation, the line selection is carried out. Two major criteria for the line selection are: (i) segregation of various characters is not so much, and (ii) plants possess ample desirable characters. Besides, the respective lines are subjected to the test for resistance against blast and other diseases on the character test fields in order to clarify the disease resistance. Of the superior lines thus selected, several plants are further put to the individual selection according to the lines. Furthermore, the respective lines are put to the indoor test of quality in order to select 3–5 plants for each line.

(e) Growing and selection of F_4 and the subsequent generations

In the stage of F_4 generation, the respective lines selected at the stage of F_3 generation are grown in line-groups consisting of 3-5 lines each. In the selection of F_4 and the subsequent generations, the selection among the line-groups is first made and then the most desirable lines are selected from the selected line-groups. The same treatment is repeated in the cases of F_5 and the subsequent generations.

(f) Yielding test and character test

Superior lines of F_5 and the subsequent generations are put to the yielding test or the character test. The yielding tests are carried out commonly on the plots (early-maturing variety plot, medium-maturing variety plot, and late-maturing plot) together with check variety, respectively. The tests are carried out on two or three replicated plots. Plants are cultured by the usual cultural method (on a 3-seedlings-per-hill basis). Several yielding tests are sometimes carried out under the different cultural conditions (e.g., culture with heavy fertilizer application, early-transplanting culture, or late-transplanting culture). The character tests are carried out on various test fields at various locations. The various characters of superior lines can be clarified further by these tests.

(g) Adaptability test for the bred lines

Those lines regarded as desirable by the above tests are forwarded in the year following to the respective prefectural agricultural experiment stations at which trial culture is carried out for one or two years. This is known as "adaptability test for the bred lines," by which the adaptability of the bred lines for the respective regions are clarified. When it has been confirmed that a certain line is very high in adaptability for a certain region and superior to the line on the check plot, a "Local Number" is assigned to the line and the line is put mainly to the yielding test in various parts of the region for 2 or 3 years. This test is known as "recommendable variety determining test". At the same time, the trial culture of the line with "Local Number" is assigned to the farmers at some ten places in the prefecture in order to test its adaptability for each part of the prefecture. In response to the prefecture's request for taking up the said line as the recommendable variety, the said line is registered as a new variety and the variety name is applied thereto. Thus this recommendable variety is extended widely among general farmers.

(2) Bulk method

In case where gene compositions between two parents differ greatly or in the case of a combination for obtaining the characters consisting of polygene, almost all the plants at the early generation of hybrid being heterogenous, the marked segregation is observed, and owing to the heterosis (hybrid vigor) the individual selection at the stage of the early generation becomes less effective. Particularly, it is impossible to select the quantitative character like yielding character. However, in the case of self-fertilized crops, homogeneous plants increase according as the generation advances. At the stages of F_5–F_6, the fixation advances to a fair extent. Therefore, it is quite rational and effective to exercise the individual selection after almost the fixation has been attained by growing the hybrid population as a mass without giving selection at the stages from F_2 to F_5–F_6. This is known as "bulk method".

In breeding by bulk method, two major points are pointed out: (i) a large number of plants for the respective generations are necessary to be retained because it is necessary to advance the generations without losing the plants (small in the number) which possess the objective character; and (ii) there is a fear that the objective character of the plants will be lost in the long period course of growing population due to the competition among individual plants or natural selection.

The following are the important hints on the successful breeding by bulk method.

(i) To shorten the breeding cycle by means of the acceleration of the early generation;

(ii) In harvesting the seeds of population, seeds must be harvested from the respective individual plants equally in quantity as far as possible, and attention must be paid so as not to give a bias to the population;

(iii) To carry out the combining ability test in early period in order to discover and discard the undesirable combinations at the earliest possible time;

(iv) As to the characters high in heritability (e.g., ripening date, culm height, and disease resistance), the mass selection must be carried out at the stage of mass growing, or it is sometimes better to make natural selection by growing the population in mass in such areas where diseases and insect pests occur frequently.

The above are the features of the bulk method. After the time when the line breeding of the advanced generations has been started, the treatment similar to the case with the pedigree method is applicable (Table 2–14).

In practice, either of the above two breeding methods are applied according to the combinations of parent varieties and the desirable characters. In some cases, at the generation of F_2 or F_3, a comparatively small number of plants are selected and the pedigree method is applied, and the bulk method is applied to the remaining plants. When such combined method is applied, the period required for breeding work can be saved much, and at the same time the failure, if it happens, in selection of superior type varieties can be saved.

4. Seed Multiplication System

In order to distribute the newly-bred varieties widely

Table 2-14. An Example Illustrating Rice Breeding by Bulk Method

Generations	*Method of treatment*	*Number of strains*	*Number of plants*	*Selection*
F_2	Breeding in main paddy, one plant per hill		2000	Mass selection concerning to heading date and plant height
F_3	1. Breeding in nursery for reduction of plant area (direct sowing)		1500	No selection
	2. Breeding in test field of diseases or insects		5000	Mass selection concerning to diseases or insect pests
F_4	Breeding in main paddy one plant per hill		2000	Individual selection
F_5	Breeding of line in main paddy	150	6750	Line selection
F_6	Preliminary test for productivity (2 replications)	30	5400	Line selection concerning to productivity and others
F_7	Breeding of derived line	5	225	Line selection concerning to productivity and others, individual selection
	Test for productivity (3 replications)	5	1350	
F_8	Breeding of line	15	675	Line selection concerning to productivity and others, individual selection
	Test for productivity	3	810	
Total		208	18455	

among general farmers, the systematic multiplication and distribution of seeds are required. In the case of self-fertilized crops (such as rice, wheat or barley), the following four steps are taken.

(i) A new crop variety must be grown on the breeder's stock farm in order to obtain pure seeds bearing the characters peculiar to the new crop variety;

(ii) The pure seeds obtained are multiplied on a foundation stock farm. Impure plants are removed in the course of the culture on foundation stock farm;

(iii) The seeds multiplied on the foundation stock farm are multiplied further on seed farms;

(iv) The seeds multiplied on the seeds farms are distributed among general farmers.

In Japan, with respect to the important crops (such as rice, wheat or barley), the seeds of those crop varieties which have already been distributed among farmers are renewed at several-year intervals, namely, those seeds that have become genetically-mixed ones (owing to the individual farmers' own seed harvesting) can be exchanged with the pure seeds multiplied on the foundation stock farms. Therefore, not only with newly-bred varieties, but also with old varieties, already distributed among farmers, seeds are multiplied by the above system.

(1) Breeder's stock farm

Breeder's stock farm is the farm by which the characters of such new crop varieties as bred by breeders are preserved. The seeds which are used as original ones for seed multiplication are known as "breeder's stock seeds".

Breeder's stock farms are kept under the careful management of the respective prefectural agricultural experiment stations. When a new variety, as the result of recommendable variety determining test, has been adopted as recommendable variety in prefecture, some ten plants of that line are provided immediately from the breeding center of the said new variety, and they are grown on the breeder's stock farm by the line-culture method. The number of lines grown is usually 20–50 lines for each variety (5–10 line-groups including 4–5 lines each).

(2) Foundation stock farm

Foundation stock farm is the farm on which the seeds to be used for seed farm are produced by using the seeds produced in breeder's stock farms. The seeds produced here are known as "foundation stock seeds". In the foundation stock farm, seedlings are commonly planted on a one-seedling-per-hill basis in order to make possible the easy discovery of mixture of other seeds. Foundation stock farms are usually kept under the management of prefectures or prefectural agricultural experiment stations. The total acreage of paddy rice foundation stock farms throughout the country amounts approximately to 2,000 hectares, and the production amounts, in the aggregate, to around 750 tons.

(3) Seed farm

Seed farm is the farm to multiply the foundation stock seeds for the purpose of distributing them among general farmers. Seed farms are generally kept under the management of seed producers' associations at towns or villages or hamlets (*Buraku*, or units of a village or sub-communities). In the case of paddy rice seed farms, the farms are brought under the management of skillful farmer designated by the Ministry of Agriculture and Forestry, on a contract with towns or villages. In this case, a part of the required expenses are sometimes subsidized from the Central Government. Seed farms managed with the Government subsidy are known as "designated seed production farms". The farms and the products are put to the prefectural inspection under the Main Crop Seed Law. The total area of paddy rice seed farms throughout the country reached 13,000 hectares in 1952, and the total seed production in the same year reached around 60,000 tons which are sufficient to supply the required amount of seeds for planting in around 1,000,000 hectares of paddy fields.

CHAPTER 3

THEORY OF PLANT GROWTH

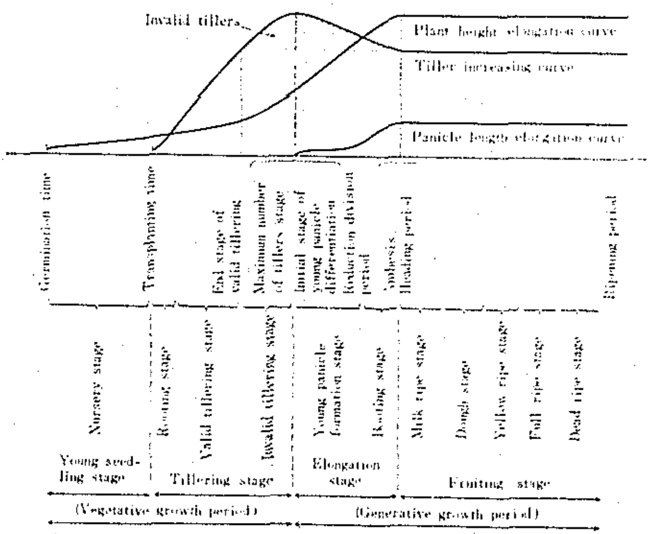
I. LIFE HISTORY OF RICE PLANT

1. Outline of the Life History of Rice Plant

Under the climatic conditions in Japan, the life history of rice plant from the germination of seeds to the ripening lasts generally for 120 to 180 days, except for specific cases. The life history of rice plant can be divided into two periods: vegetative growth period and generative growth period (Fig. 3-1). The vegetative growth period is the period during which the rice plant itself grows. The increase in the number of tillers is the most salient feature of this period. The generative growth period is the period during which the growth of rice plant is completed to reproduce rice plants of next generation. This period is characterized by the panicle formation and its growth. The two growth periods are demarcated by the initiation of the young panicle formation. Namely, after the seed germination a rice plant grows and puts forth tillers. By and by leaves, roots, and culms grow up, but when the increase in number of tillers begins to slow down, young panicles are formed at the base of stalks. Until this period is called the vegetative growth period. Afterward, young panicles grow gradually and plant begins to develop ears and the ears ripen. This period is called the generative growth period.

The vegetative growth period is subdivided into two stages: nursery stage and tillering stage. The tillering stage is subdivided again into rooting stage, valid-tillering stage, and invalid-tillering stage. Though tillers develop at the nursery stage, most of them will usually die after the transplanting of seedlings, except strong ones. The rooting stage generally lasts for several days after the transplanting of

Fig. 3-1. Life History of Rice Plant



seedlings. No tillers develop during this period, but when the plant has once rooted, many tillers develop rapidly. The increase in the number of tillers comes to a state of abeyance at the advent of a certain period. Subsequently to that period, weak tillers begin to die, thus showing a decrease in the number of tillers. However, by the time when the heading stage has come and the number of panicles has come to be fixed, the number of tillers has come to be fixed. The stage when the number of tillers reaches a maximum is called the maximum number of tillers stage. The stage when the number of tillers has come to coincide with the final number of panicles is known as end stage of valid-tillering period, and the period ranging from the rooting to the end stage of valid-tillering period is known as valid-tillering period. And the subsequent vegetative growth period is known as invalid-tillering period, viz., it means that only those tillers produced by the time of the end stage of valid-tillering period bear panicles, and that those tillers developed subsequently die and bear no panicles (speaking rigidly, however, it cannot always be said that every tiller developed before the end stage of valid-tillering period will bear panicle, while every tiller developed subsequently will die).

Next, the generative growth period lasts for the period from the young panicle differentiation to ripening, and is subdivided by the heading stage into two periods: young panicle developing period and ripening period. In case of the former, internodes at the base of a culm begin to elongate, and elongate markedly up to the heading period, and four or six internodes from the top will complete the elongation. And in this period, changes take place in the leaf-emerging velocity, viz., the leaf-emerging interval in the tillering period is usually four or five days, while that in the generative growth period takes a little longer, lasting for eight or nine days. The elongation of internodes, changes in leaf-emerging velocity, as well as the differentiation and development of young panicles are the outstanding characteristics of the pre-heading generative growth period. The young panicle developing period can be subdivided again into young panicle formation stage and booting stage. Generally speaking, the young panicle formation stage lasts from the initiation of the young panicle formation stage till the time just prior to the booting stage. The booting stage denotes the period in and about the reduction division stage (or meiosis stage). The young panicle formation begins from "about 30–34 days prior to the heading period" known as "primary bract primordium differentiation stage" (or neck-node differentiation stage), but it can not be seen with the naked-eye before the time of the secondary rachis-branch primordium differentiation. The secondary rachis-branch primordium differentiation stage sets in generally about 24–27 days prior to the heading period, when the young panicle measures about 0.5–1.0 millimeter in length. After that the young panicle grows slowly and sets in the spikelet primordium differentiation stage. When the young panicle grows larger than 1 millimeter long, the spikelet primordium differentiation begins at the tip of a young panicle. The differentiation stage lasts fairly long, usually lasting for 7–10 days. At the late differentiating stage of spikelets, a young panicle will generally grow to the extent of 1 centimeter in length. At this time the intercellular spaces begin to develop in the anthers and then the reproductive cells develop. By this time, the young panicle will grow to the extent of 3–5 centimeters long. From this period, the young panicle will grow markedly, reaching 20 centimeters long or more in about one week. At the time of its peak elongation, the reduction division of the pollen mother cells and the embryo-sac mother cells will take place. In the normal year, the reduction division begins to take place from 14 or 15 days before the heading period and arrives at the peak about 10 days before the heading period and will end usually about 5 days before the heading period. By the telophase of the reduction division, the elongation of the young panicle is nearly completed. Both the palea and lemma will reach almost full length and width, and the number of spikelet primordia per panicle has come to be fixed. When rice plant shoots out the ear, the anthesis will begin from that day or from the day following. Two or three hours after the anthesis, the fertilization will have been completed. The anthesis begins generally from the tip rachis branch of a panicle and then shifts to the lower ones. The anthesis lasts generally for 7–10 days. The fertilized embryos will grow gradually and the endosperm also will develop. It shows increases in length, width, and thickness of caryopsis (rice kernel) in the order. The fruiting stage after the heading can, according to the maturity of rice kernel or the paddy color, be divided into milk ripe stage, dough stage, yellow ripe stage, full ripe stage, and dead ripe stage. Generally speaking, short-term varieties will ripen about 35–40 days after the anthesis, and long-term ones about 60–65 days after the anthesis.

2. Process in Determination of Grain Yields during the Life History of Rice Plant

The final objective of rice cropping is to increase the yields. Fertilizer application and caretaking must always be done from the standpoint of rice yielding increase. For this purpose, it is required to know when and how the rice yield be determined during the life history of rice plant. Grain (kernel) yield is determined by the following formula:

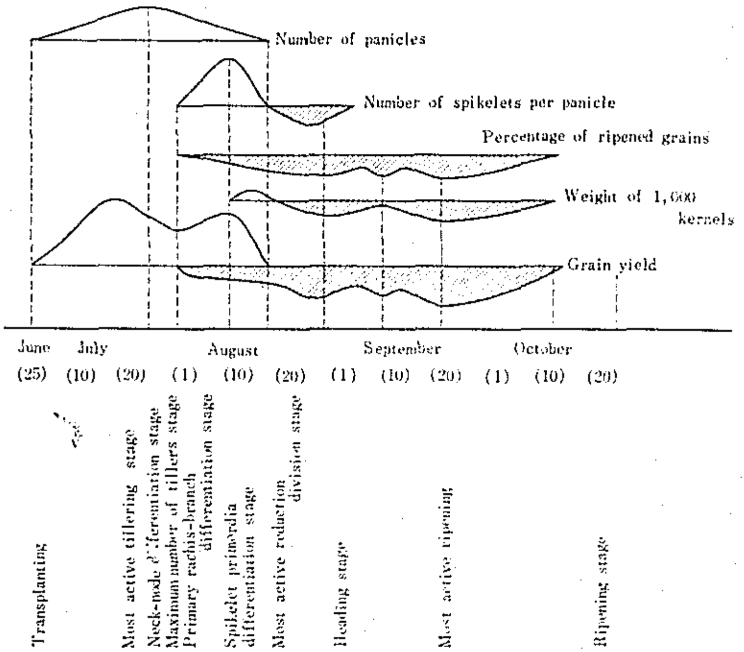
$$\begin{pmatrix}\text{Grain}\\ \text{yield}\end{pmatrix}=\begin{pmatrix}\text{Number of}\\ \text{panicles}\end{pmatrix}\times\begin{pmatrix}\text{Number of}\\ \text{spikelets}\\ \text{per panicle}\end{pmatrix}\times\begin{pmatrix}\text{Percentage}\\ \text{of ripened}\\ \text{grains}\end{pmatrix}\times\begin{pmatrix}\text{Weight}\\ \text{of 1,000}\\ \text{kernels}\end{pmatrix}$$

Accordingly, in order to know how and when the rice yield is determined, it is needed to make clear how the above four contributing components are determined during the life history of rice plant (Fig. 3–2).

(i) The main stage at which the number of panicles is determined is the most active tillering stage ranging over the period lasting for 20 days before the maximum number of tillers stage. The number of panicles is affected most strongly by the environmental conditions during this period. In general, the number of panicles is finally determined on or about the 10th day after the maximum number of tillers stage.

(ii) The number of spikelets per panicle is determined by the difference between the number of differentiated spikelets and the number of degenerated ones. The number of differentiated spikelets begins to be affected chiefly by the

Fig. 3 – 2. Process in Determination of Grain Yields (MATSUSHIMA 1959)



Note: The larger the unshaded portion, the more favorable for yield increase, while the larger the shaded portion, the less favorable for yield increase.

environmental conditions from the neck-node differentiation stage, and is affected most adversely at the secondary rachis-branch primordium differentiation stage, and little or no adverse effect is brought about by the environmental conditions after the spikelet primordium differentiation stage. In or about the reduction division stage, there is a time at which spikelet primordia are most readily degenerated, and the number of degenerated spikelet primordia will have been determined finally by about "the 5th day before the heading date" (i.e., the end stage of the reduction division).

(iii) Percentage of ripened grains: This indicates the percentage ratio of fully-ripened kernels to the total number of grains produced. In non-ripened grains (paddy) are included non-fertilized grains (paddy), and imperfectly ripened ones. It begins to have an adverse effect on the percentage of ripened grains chiefly from the neck-node differentiation stage. In the stages of reduction division, heading, and the *most active ripening stage, there is a time at which the percentage* of ripened grains is most readily affected, but the percentage of ripened grains will be fixed almost finally by the time about 35 days after the heading.

(iv) Weight of 1,000 kernels (husked rice): The weight of 1,000 kernels depends primarily upon the size of hulls which is determined before the heading, and secondarily depends upon the rate of *filling up of hulls with caryopsis.* As a result, if small-sized paddy has once been formed, kernels could no longer grow larger due to the mechanical restrictions by the size of hulls, whatever favorable the environmental conditions after the heading may be. In view of this, the weight of 1,000 kernels has direct bearing upon the two periods: (i) the period from the spikelet primordium differentiation stage to the reduction division stage and (ii) the most active ripening stage about 10–25 days after the heading.

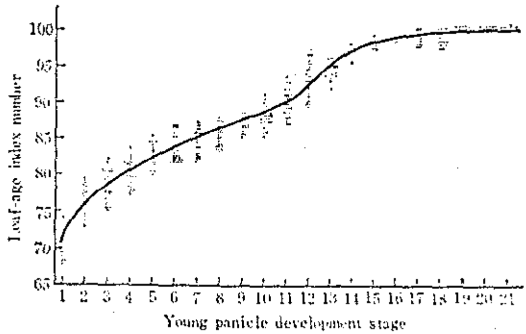
3. Age of Rice Plant (Plant-age as expressed by leaf number) and Plant Development

As is the case with human life history, it is very convenient to observe the life history of rice plant according to the plant-age as expressed by number of leaves, because the development stage of rice plant can generally be judged from the plant-age as expressed by leaves. The plant-age by leaves is represented by the number of leaves born on the main culm after the germination of seed of rice. The leaves developing from the main culm during the period from the germination to the heading are generally less in number in the case of short-term varieties, while more numerous in the case of long-term ones. The total number of leaves arising from the main culm up to the heading stage is called the "total number of leaves on the main culm". When the same variety is cultivated under the same cultural condition, the total number of leaves on the main culm is almost the same from year to year, except abnormal years, showing the total number of leaves peculiar to the variety. The leaves (excluding coleoptyle) are named as the first leaf, second leaf, third leaf, and so on, respectively, in the order of the leaf emergence. When each leaf has grown fully, it is called the first leaf stage, second leaf stage, third leaf stage, and so on, respectively. When a leaf has not grown to the fullest extent, e.g., when the sixth leaf has emerged only to the extent of 30 per cent of the full-grown sixth leaf, it is called the 5.3 leaf stage, and when it has grown up to the extent of 70 per cent, it is called the 5.7 leaf stage. In such case, the length of the full-developed sixth leaf is deduced from the length of the fifth or fourth leaf. From the standpoint of the plant-age by leaves stated above, it can safely be said that, in the case of rice varieties bearing the similar total number of leaves on the main culm, if these are similar in plant-age by leaves, these varieties would almost be at the same inner physiological development stage. However, in the case of rice varieties bearing the different total number of leaves on the main culm, it is usual that even if the plant-age by leaves be similar, these varieties are not always at the same development stage. In order to compare the inner development stages between the varieties bearing the different total number of leaves on the main culm, the "leaf-age index number" is used. The leaf-age index number is the figure obtained by

$$\frac{\text{(Present plant-age by leaves)}}{\text{(Total number of leaves on the main culm)}} \times 100.$$

By using this figure, the inner development stage of rice plant can be made clear to a fairly extent. Between the leaf-age index and the inner development stage being found the relationship as given in Fig. 3-3, the status of development of young panicle could be made clear by the use of leaf-age index number without attempting any analysis or microscopic examination. Determination of plant-age by leaves can not be made without counting the number of leaves from the beginning of plant growth. However, the reduction division

Fig. 3-3. Relationship between Leaf-Age Index Number and Young Panicle Developmental Stage
(MATSUSHIMA and MANAKA, 1956)



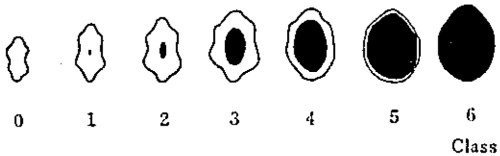
No.	*Young panicle developmental stage*	*Leaf-age index number*
I	Flag-leaf primordium differentiation	71
II	First bract primordium differentiation	76
III	Bract primordium increase	78
IV	Primary rachis branch primordium differentiation (Early stage)	80
V	Ditto (Medium stage)	82
VI	Ditto (Late stage)	83
VII	Secondary rachis branch primordium differentiation (Early stage)	85
VIII	Ditto (Late stage)	86
IX	Spikelet primordium differentiation (initial stage)	87
X	Ditto (Early)	88
XI	Ditto (Medium)	90
XII	Ditto (Late)	92
XIII	Pollen mother cell development	95
XIV	Pollen mother cell reduction division (Early)	97
XV	Ditto (First stage)	98
XVI	Ditto (Second stage)	98
XVII	Ditto (Tetrad stage)	99
XVIII	Extine formation (Early stage)	100
XIX	Extine formation	100
XX	Pollen ripening (Beginning)	100
XXI	Pollen ripening (Completion)	100

stage which is regarded as most important throughout the life history of rice plant can be judged exactly by the other method. In this case, the judgment is formed by measuring the distance in-between two auricles (ear-shaped appendages to leaves). The distance in-between auricles indicates the distance between the auricle of flag-leaf and that of the immediately lower leaf, and when the flag-leaf blade projected partly and its auricle was still remaining in the sheath of the next leaf, it is represented by minus sign (−); when the auricles of both leaves coincide with each other, it is represented by zero (0); and the state in case where the flag-leaf auricle has projected partly is indicated by plus sign (+). Hence it can be said that the reduction division stage will begin nearly from the time of (−) 10 centimeters in the distance in-between the auricles, and will reach nearly its most active stage at the time of (0), and will close at the time of (+) 10 centimeters or so. Nor can be applicable the leaf-age index number to the judgment of the development stage of rice plant after the heading. The development stage of rice plant after the heading is subdivided into milk ripe stage, dough stage, yellow ripe stage, full ripe stage, and dead ripe stage, or, in most cases, it is represented by the number of days after the heading. However, when expressed in such parlances, the development of rice kernels, though similar in ripeness, would often be taken differently according to the years, varieties or areas, and it is also unreliable in preciseness. In contrast to this, the judgment formed from the "specific gravity of grain (rough rice)", "kernel-hull (weight) ratio", or "proportion of the translucent area to its whole area in cross-section of a grain" is more recommendable, because when judged by such criteria, the same result can always be obtained from the same test samples, irrespective of the time or place of test and of tester. Namely, the specific gravity of dried grain (rough rice) indicates the size of the space between the hull and the kernel which is developing in the hull, and indicates exactly the degree of plumpness of a kernel in the hull. "Kernel-hull weight ratio" indicates the ratio between the volume of a hull and the size of the kernel which is developing therein. The judgment by this ratio is highly precise and reliable. However, these two methods can not be easily applicable because there are in reality fairly much complicated. In contrast to these methods, the judging method by the "proportion of the translucent area to its whole area in the cross-section of a grain" is the most convenient method. Speaking generally, the transversal section of a kernel reveals the increase in its translucent area step by step from the central part, with the progress in the ripening of a kernel, and this translucent area can be seen distinctly. Consequently, the ripening degree can be judged by the measure with the eye based upon the criteria established for the respective grades of transparency (Fig. 3–4). The ripening degree of a panicle as a whole can be made clear by measuring the transparency of the first two kernels from the tip of the central rachis-branch.

4. Regularity in the Plant Growth Behavior

The growth of the respective organs of rice plant is completed orderly, but not disorderly. Regularity in the production of tillers and in plant growth is found in the vegetative growth period. The tiller produced directly from the main culm is called the primary tiller, the tiller from the primary tiller is called the secondary tiller, and the tiller from the secondary one is known as the tertiary one, respectively. The following relationship is found between the appearance of each tiller and the emergence of leaf on main culm. Namely, simultaneously with the appearance of the fourth leaf (4/0) from the main culm, the "first leaf of the primary tiller No. 1" (1/1) emerges. Simultaneously with the appearance of the fifth leaf, sixth leaf, ... (5/0, 6/0 ......) on the main culm, the second leaf, third leaf, ... (2/1, 3/1 ......) emerges from the primary tiller No. 1. Leaves represented by (2/1, 3/1 ......) and (5/0, 6/0 ......) are called the synchronously-emerged leaves. In

Fig. 3–4. Transversal Section of Kernel Indicating the Proportion of Width of Translucent Area to its Whole Area
(MATSUSHIMA and TANAKA, 1961)



Note: Translucent area is indicated by dark spot.

case of the primary tiller No. 2, its first leaf (1/2) appears simultaneously with the appearance of the fifth main culm leaf (5/0), and its leaves (2/2, 3/2 ......) emerge simultaneously with the main culm leaves (6/0, 7/0 ......). The same can be said of the primary tiller No. 3 and downward. Next, the "first leaf of the secondary tiller No. 1" (1/1.1) emerges simultaneously with the "fourth leaf of the primary tiller" (4/1). Accordingly, this period just falls on the emergence of the seventh main culm leaf (7/0). Table 3–1 will give help in understanding the above relationship.

As stated above, each of the respective leaves both on the main culm and tillers develops at a definite interval, and all the leaves from tillers develop in parallel with the development of leaves on the main culm. Accordingly, tillers and leaves from one hill as a whole can be divided into groups: groups of synchronously developed leaves and groups of synchronously developed tillers. And since the synchronously developed tillers not only develop simultaneously but also each of all leaves (including leaves from the first leaf to the flag-leaf) develops simultaneously, these tillers always have each own corresponding leaf. This is known as synchronous homologue of the main culm and tillers. This regularity is observed exactly until immediately before the maximum number of tillers stage, while in and after this stage, it is usual that the emerging velocity of leaves from some tillers is slowed down and the relative growth is disturbed to a considerable extent (these tillers become invalid-tillers.)

In the generative growth period, a definite regularity can also be found among (i) the elongation of internodes, (ii) growth of young panicle, leaf blade, and leaf sheath, (iii) time of leaf emergence, (iv) rooting nodes, and (v) the increase in root number.

Table 3-1. Relationship of Synchronously Developed Leaves and Tillers in Rice of a "Standard Plant"
(KATAYAMA, 1951)

4/0	*5/0*	*6/0*	*7/0*	*8/0*	*9/0*	*10/0*	*11/0*	*12/0*	*13/0*	*14/0*	*15/0*
1/1	2/1	3/1	4/1	5/1	6/1	7/1	8/1	9/1	10/1	11/1	12/1
—	1/2	2/2	3/2	4/2	5/2	6/2	7/2	8/2	9/2	10/2	11/2
—	—	1/3	2/3	3/3	4/3	5/3	6/3	7/3	8/3	9/3	10/3
—	—	—	1/4	2/4	3/4	4/4	5/4	6/4	7/4	8/4	9/4
—	—	—	—	1/5	2/5	3/5	4/5	5/5	6/5	7/5	8/5
—	—	—	—	—	1/6	2/6	3/6	4/6	5/6	6/6	7/6
—	—	—	—	—	—	1/7	2/7	3/7	4/7	5/7	6/7
—	—	—	—	—	—	—	1/8	2/8	3/8	4/8	5/8
—	—	—	—	—	—	—	—	1/9	2/9	3/9	4/9
—	—	1/1 P	2/1 P	3/1 P	4/1 P	5/1 P	6/1 P	7/1 P	8/1 P	9/1 P	10/1 P
—	—	—	1/11	2/11	3/11	4/11	5/11	6/11	7/11	8/11	9/11
—	—	—	—	1/12	2/12	3/12	4/12	5/12	6/12	7/12	8/12
—	—	—	—	—	1/13	2/13	3/13	4/13	5/13	6/13	7/13
—	—	—	—	—	—	1/14	2/14	3/14	4/14	5/14	6/14
—	—	—	—	—	—	—	1/15	2/15	3/15	4/15	5/15
—	—	—	—	—	—	—	—	1/16	2/16	3/16	4/16

5. Inter-Relationship between Vegetative Growth Period and Generative Growth Period

The life history of rice plant is, as stated before, divided into two periods: the vegetative growth period which is characterized by the increase in the number of tillers, and the generative growth period in which the development of young panicle constitutes the principal feature. However, there are not a few cases where a clear line of demarcation can not be drawn between these two growth periods. In most cases, as shown in Fig. 3-1, young panicle differentiation begins from the time when the increase in the number of tillers begins to stop, while in the cases of (i) short-term varieties, (ii) late transplanting of seedlings, or (iii) colder areas, it is usual that, even after the young panicle differentiation, rice plant still continues to put forth tillers. Namely, the vegetative growth period and the generative growth period often overlap each other. However, in the cases contrary to the above, the two growth periods can, in most cases, be clearly demarcated. As the period in which tillering begins to be slowed down coincides with the maximum number of tillers stage, the latter can be regarded as the close of the vegetative growth period. Since the beginning of the generative growth period is the young panicle differentiation stage, the problem of the overlapping or separation of the two growth periods can after all be attributed to the relationship between the maximum number of tillers stage and the young panicle differentiation stage. The relationship can be summarized in three phases: (i) young panicle differentiation takes place before the maximum number of tillers stage (overlapping of both growth periods); (ii) the maximum number of tillers stage just coincides with the young panicle differentiation stage (continuation of the two growth periods); and (iii) the young panicle differentiation takes place after the maximum number of tillers stage (segregation of two periods). Needless to say, Fig. 3–1 represents only one of these three cases. Connected with this, it is worth while to notice that in the case of rice plants transplanted simultaneously under the same cultural condition, their maximum number of tillers stage reach almost simultaneously, irrespective of varieties of different maturity, i.e., it cannot be recognized that the stage of short-term varieties always reaches earlier than that of long-term ones. From such fact, it can be inferred that the relationship between the maximum number of tillers stage and the young panicle differentiation stage varies according to the varieties of different maturity. This is due to the fact that in a normal year, no marked difference according to the varieties is found in the number of days from the young panicle differentiation stage to the heading period.

To sum up, the relationship between the maximum number of tillers stage and the beginning of young panicle differentiation can be summarized in the three cases: overlapping of both periods; clear separation between the two periods; and the intermediate state. However, the relationship between the two periods varies according to the cultivating areas as well as according to the cultural methods and the varieties of different maturity even in the same cultivating area. This is an important point from the viewpoint of rice cultivation, particularly important in judging the right time for the top dressing of fertilizer at the panicle formation stage, herbicides application, mid-summer drainage practice, and final weeding operation. In view of this, it is needed for rice grower to make clear in advance the relationship between the beginning of young panicle differentiation and the maximum number of tillers stage with respect to each of his own rice fields.

II. CARBON ASSIMILATION AND RESPIRATION

1. Meaning of Assimilation

A great part of substances (dry matter) composing a plant body consists of various organic compounds containing carbon. These organic compounds are all produced by carbon assimilation. The energy required by a plant to grow and propagate is provided through the respiration by decomposing part of the organic compounds produced by assimilation.

Exactly speaking, assimilation is called the "carbon assimilation" or "photosynthesis", i.e., formation of carbohydrates (sugars and starches) from water and carbon dioxide in the chlorophyll-containing tissues of a green plant exposed to light, and during the photosynthesis the oxygen is released. The over-all equation given for photosynthesis is as follows:

$$6CO_2+6H_2O+690\ \text{Kcal} \rightarrow \underset{\text{(glucose)}}{C_6H_{12}O_6}+6O_2$$

This reaction is, in terms of chemistry, a sort of oxidation-reduction reaction. Photosynthesis is characterized by the fact that the photochemical reaction, known as "photolysis of water" by the action of radiant energy, is comprised in the process of photosynthesis. The part of the photochemical reaction is called "light reaction" and other part "dark reaction".

2. Photosynthetic Activity per Unit Leaf Area

Under the natural conditions, the amount of dry matter produced by the rice plant grown in a paddy field is determined by the photosynthesis of rice population. The photosynthesis of rice population is the sum total of the photosynthesis of unit leaf area of individual leaves. To begin with, the characteristics of photosynthetic activity per unit leaf area will be explained. Next, the problem of photosynthesis in rice population will be taken up, and then the dry matter production will be described.

Photosynthetic activity per unit leaf area is influenced by the various internal and external factors. The principal contributing factors will be clarified below.

1. Light

As indicated in Fig. 3-5, when light is low in intensity, photosynthetic activity increases nearly proportionately with the light intensity up to a certain point, but when the intensity becomes further higher, the rate of increase in photosynthetic activity is lowered, and when reaches to 40-50 K lux (about 50 per cent of the full sunlight) or more, it will no longer show any increase. The light intensity at which the photosynthetic activity attains its maximum is called the "saturation light intensity", and the phenomenon itself is called the "light saturation". The fact that the light saturation exists in the photosynthesis of an individual leaf is closely connected with the efficiency of the light utilization by the whole rice population on a field, as described later.

This relationship between light and photosynthetic activity is similar, in principle, with leaves at any position. However, a leaf at the lower position is adapted to the low light intensity and characterized as a shade leaf. Under a high light intensity, a lower position leaf shows a lower photosynthetic activity than an upper position leaf which is characterized as a sun leaf, but little or no difference is found under

Fig. 3-5. Relationship between Light Intensity and Photosynthetic Activity per Unit Leaf Area (MURATA and OSADA)

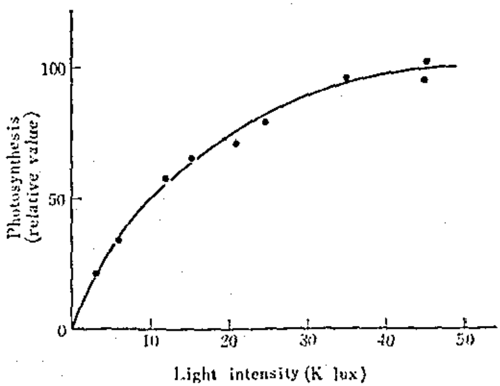
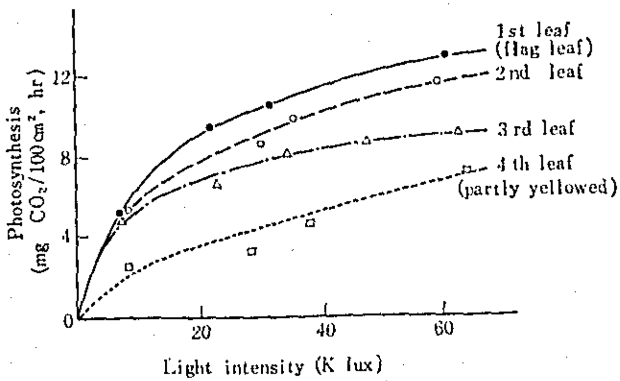


Fig. 3-6. Relationship between Light Intensity and Photosynthetic Activity, by Position of Leaves (MURATA and OSADA)

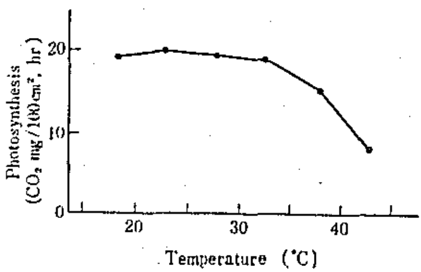


a low light intensity between upper and lower leaves (Fig. 3-6).

2. Temperature

At the temperature of 18–33°C, little or no difference is found in photosynthetic activity, but if the temperature exceeds 33°C, the activity will become lowered (Fig. 3-7). The process of photosynthesis can be divided into three stages: (i) diffusion of CO_2 into chloroplast; (ii) light reaction; and (iii) dark reaction. Among these, dark reaction is considered to be influenced pre-eminently by the temperature. The temperature coefficient is nearly equivalent to 2. Consequently, it can be said that the temperature has a fundamental connection with the photosynthesis. As the light supply is relatively ample under the natural condition, the photosynthesis is readily to be influenced by the factors other than the light reaction. Moreover, under the natural condition, due to the low concentration of CO_2, the diffusion of CO_2 (which is deemed not affected appreciably by temperature) acts as a limiting factor more effectively than dark reaction. Thus the temperature seems to come to have nothing to do with photosynthesis.

Fig. 3-7. Relationship between Temperature and Photosynthetic Activity per Unit Leaf Area
(YAMADA et al.)



3. Fertilizer elements

(1) Nitrogen

The total assimilation per plant is increased by the two functions of nitrogen: promotion of photosynthetic activity per unit leaf area and expansion of leaf surface. As indicated in Table 3–2, the photosynthetic activity per unit leaf area is becoming increased by the top-dressing of nitrogen, showing a maximum 10–16 days after the nitrogen application. Afterwards it tends to decrease day by day to the level of check plot to which no nitrogen top-dressing has been applied. But by that time, the leaf area will enlarge considerably, and the dry weight per hill will also show an increase.

Nitrogen forms protoplasmic proteins of living cells and participates in the dark reaction and various other chemical reactions as enzymatic proteins.

On the other hand, nitrogen participates, as a component of chlorophyll, in the light reaction also. However, the presence of chlorophyll in a plant is fairly greater in amount than the required amount. As a result, as stated later, it is considered very rare that the chlorophyll acts directly as a limiting factor in photosynthesis, except under a low light intensity.

(2) Phosphorus

Table 3 - 2. Effect of Nitrogen Top-dressing on Photosynthesis of Unit Leaf Area, Dry Matter Weight, and Leaf Area (MITSUI and NISHIGAKI)

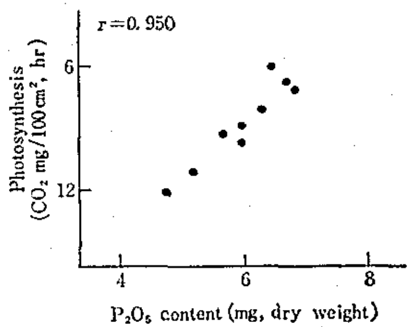
Days after nitrogen application	*Photosynthesis per leaf area, CO_2 mg*		*Dry weight gram per plant*	
	Check plot	*N-plot*	*Check plot*	*N-plot*
3 days	4.21	7.16	5.04	4.81
6	5.53	7.08	5.81	6.61
10	10.93	15.76	6.13	6.78
16	9.40	13.93	8.27	10 31
23	9.03	8.36	9.95	13.64
30	11.19	11.25	10.40	12.94
37	9.09	8.83	9.72	15.10
33	Leaf area per plant:	Check plot, 349 cm^2 N-plot, 576 cm^2		

Phosphoglyceric acid, a compound of phosphate, is the first CO_2-fixation product of photosynthesis. Thus phosphorus participates directly in the synthesis of hexose or starch, in the form of various sugar phosphates, playing an important role in the photosynthesis. Though the required amount is considered comparatively small, phosphorus will sometimes limit photosynthesis, especially nitrogen supply is ample and phosphorus supply is relatively insufficient (Fig. 3-8).

(3) *Potassium*

When nitrogen or phosphorus is supplied sufficiently, potassium will become relatively insufficient and will sometimes limit photosynthesis. It is said that potassium promotes photosynthesis or makes up a sunlight shortage (NOGUCHI and SUGAWARA) and that it has a bearing upon the aging of photosynthetic activity (described later). However, the process of action of potassium on the photosynthesis still remains unclarified.

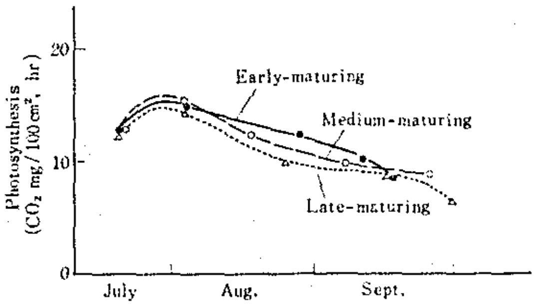
Fig. 3-8. **Relationship between Phosphorus Content of Leaf and Photosynthetic Activity per Unit Leaf Area**
(MURATA and OSADA, 1959)



4. Growth stage

At the very beginning of the growth stage, the photosynthetic activity is somewhat low, but it will soon reach a peak point, and then continues to decrease gradually (Fig. 3-9). This change is almost similar, irrespective of early-maturing varity, medium-maturing one, or late-maturing one. Therefore, this change is regarded as a phenomenon associated with the lapse of days of growth, i.e., aging phenomenon. However, a slight increase in photosynthetic activity was sometimes observed at heading stage, a remarkable increase was recognized by NOGHCHI (1938) and more clearly by DASTUR et al (1932).

Fig. 3-9. **Changes in Photosynthetic Activity in Rice Plants according to the Growth**
(MURATA and OSADA, 1958)



The same can be said of a leaf, viz., the photosynthetic activity in a young leaf not unfolded fully yet is somewhat low, but at the time when a leaf has come to fully unfold, the activity reaches a peak point, and then slows down proportionately with the progress of maturity of the leaf.

Potassium content in the leaf tissue has a bearing upon the aging phenomenon. There is a possibility that the richness of protoplasm and activity of the leaf tissue also have bearings upon it (MURATA, 1961).

5. Varietal difference

At the stage of maximum number of tillers of rice plants (same in the number of days from sowing), the varietal difference of 10-20 per cent is found in the photosynthetic activity (Table 3-3), while at the heading stage the photosynthetic activity of late-maturing variety (which takes longer period to the heading stage) has a tendency to become low because of the aging phenomenon. The relationship between photosynthetic activity at heading stage and the number of days from sowing to heading is as indicated in Fig. 3–10. Fig. 3–10 reveals a general tendency that the photosynthetic activity is becoming lower proportionately

Table 3 – 3. Photosynthetic Activity per Unit Leaf Area, by Rice Varieties (30°C, 50 K lux)
(MURATA and OSADA)

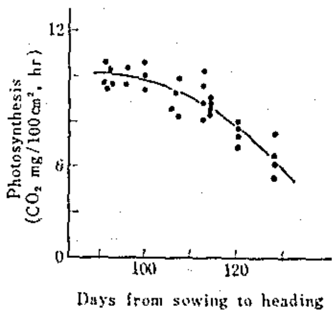
	Rice variety	*Photosynthesis, CO_2 mg/100 cm²/hr*		
		Maximum tillering stage	*Heading stage*	*Days from sowing to heading*
1	Norin No. 1	10.49	12.28	92
2	Fujisaka No. 5	11.92	10.45	92
3	Rikuu No. 132	11.55	9.60	92
4	Sasashigure	11.01	9.53	92
5	Norin No. 17	10.59	9.65	92
6	Norin No. 21	10.05	10.31	96
7	Kamenoo	10.97	9.63	96
8	Shinnigo	10.48	9.46	100
9	Muboaikoku	12.20	10.71	100
10	Saitamamochi No. 1	11.12	9.90	100
11	Reishiko	9.72	9.94	107
12	Tetep	10.14	8.18	107
13	Danahara	9.95	9.26	107
14	Norin No. 29	10.82	8.37	106
15	Norin No. 25	11.39	8.01	113
16	Norin No. 36	11.53	9.49	113
17	Tangin	12.64	10.31	113
18	Murasakiine	—	8.80	113
19	Norin No. 8	11.37	8.54	114
20	Kiyosumi	11.47	8.47	114
21	Kotobukimochi	10.47	9.02	114
22	Kinmaze	8.87	8.93	114
23	Fusakushirazu	9.67	7.46	120
24	Kameji	11.88	6.78	120
25	Shinriki	9.78	7.52	120
26	Senbon-asahi	9.98	7.99	120
27	Norin No. 18	9.10	6.28	128
28	Yubae	9.01	6.12	128
29	Takara	7.87	7.46	128
30	Benisengoku	9.20	5.48	128
	Mean	10.83	8.73	109.3

with the number of days from sowing to heading. As a result, the portion excluding such general tendency (i.e., the distance from the curve to each point in Fig. 3-10) indicates the varietal difference, in its truest sense, free from the effect of the number of growing days.

Such varietal difference has been considered to be ascribed to the facts that the photosynthetic activity at the younger stage depends upon the richness of protoplasm and the general activity of the leaf tissue, and that at the stage after the maximum number of tillers stage depends upon such activity of the leaf tissue as may be represented by water-content or respiration rate (MURATA, 1961).

Fig. 3-10. Relationship between Photosynthetic Activity per Unit Leaf Area of Paddy Rice Plant and Number of Days from Sowing to Heading

(MURATA, 1957)



6. *Chlorophyll*

Chlorophyll-content has, needless to say, an important effect on the photosynthetic activity. However, under a high light intensity due to the ample supply of light, it is deemed rare that the chlorophyll-content (contributing factor in the light reaction) acts as a limiting factor on the whole process of photosynthesis. In contrast to this, the activity under a low intensity of light, due to deficiency of light, chlorophyll-content is considered liable to act as a limiting factor on the photosynthetic activity. In reality, in the case of low intensity of light, there are instances indicating the close correlation between the photosynthetic activity and the chlorophyll-content.

3. Photosynthesis of Rice Population

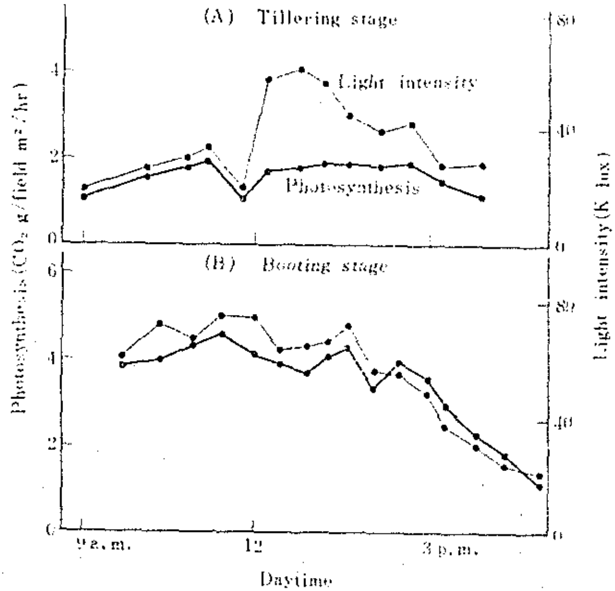
Photosynthesis of a rice population is the summation of photosynthesis of individual leaves which bear such characteristics as stated above. Then what are its characteristics and by what factors will it be affected?

1. Light and photosynthesis in rice population

Fig. 3-11 indicates the changes in the photosynthesis in rice population under the daytime natural condition. Fig. 3-11 (A) indicates that under a low intensity of sunlight (30-40 K lux and under) the photosynthesis shows an increase, in general, proportionately with the light intensity, while with a high sunlight intensity exceeding 30-40 K lux, it remains nearly unchanged. On the contrary, Fig. 3-11 (B) indicates that throughout low light intensities to high light intensities (70-80 K lux), the photosynthesis coincides well with the change in the light intensity.

When the data of photosynthesis given in Fig. 3-11 is plotted against the light intensity, by neglecting the time factor, the photosynthesis as a function of light intensity is obtained as shown in Fig. 3-12. From Fig. 3-12, it is observed that the population photosynthesis under the natural condition is also affected by the light intensity, and that the effect of light intensity varies according to the growth stage. At the early growth stage when the foliage is less luxurious (A), owing to the ample supply of light to the individual leaves of the population, the photosynthesis as a whole are saturated with light approximating to the saturation points for the respective leaves, thus describing a gentle sloping curve. While at the later growth stage when the foliage is more luxuriant (B), due to the low intensity of light on the individual leaves overlapping each other, the saturation

Fig. 3 – 11. Changes in Population Photosynthesis in the Course of Daytime
(MURATA and OSADA)

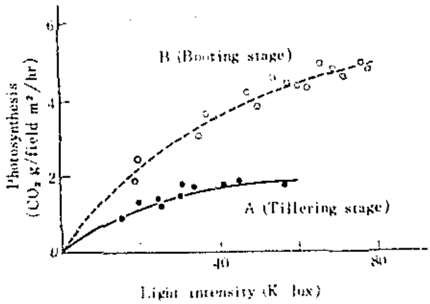


point as a whole rises, thus describing a sharp sloping curve.

2. Leaf area and population photosynthesis

The degree of luxuriance in foliage can be represented best by the total leaf area per unit ground surface area. As a result, it is concluded that the changes in the shape of a light-photosynthesis curve have taken place chiefly due to the differences in the leaf area. The effect of the leaf area on the photosynthesis is given in Fig. 3–13. As shown in the model graph, in case where the leaf area is still relatively small, a rectilineal relation is maintained between the leaf area and the photosynthesis, but with the increase in leaf area, the increasing rate of photosynthesis is becoming lower and the proportional relation will cease to exist. This phenomenon is caused by the following two opposite actions:

Fig. 3 – 12. Relationship between Light Intensity and Population Photosynthesis



(i) the increase in the leaf area causes the increase in the total photosynthetic capacity, due to the increased photosynthetic organs; and (ii) the increase in the leaf area also causes the decrease in the individual leaf photosynthesis due to the lowered light intensity in the inner part of the leaf layer. From the very balance of effects between the two actions, comes out the above-described pattern of population photosynthesis.

The lowered light intensity in the inner part of the population due to the increased leaf area is represented by the following inverse exponential relation (MONSI and SAEKI, 1953).

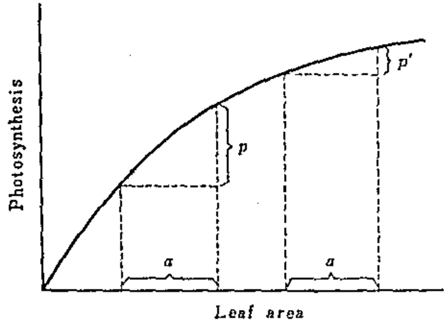
$$I = I_0 \, e^{-KF}$$

where

- I_0: incident light intensity
- I : light intensity after passing through the leaf layer (F)
- K: light transmission coefficient
- e : base of natural logarithm

The results of measurement of light intensity between hills of rice varieties which differ much in leaf areas coincide well with the above relation. In the case of the rice population at the booting stage (at which the rice plant is in full

Fig. 3 – 13. Relationship between Leaf Area and Population Photosynthesis (Model graph)



luxuriancy), the leaf exposed to the light stronger than the saturating light intensity is confined to a flag leaf, even on a fine day. The rest are exposed to the light of far lower intensity (Table 3–4).

Table 3 – 4. Actual Light Intensity at the Leaf Surface of a Rice Population (MURATA and OSADA)

Position from the top	*Light intensity*
	K lux
1st leaf	30.6
2nd leaf	18.2
3rd leaf	15.3
4th leaf	9.6
Mean	18.4

3. *Composition of population photosynthetic capacity and light-receiving coefficient*

MURATA et al. (1957) represented the decreased light intensity in the inner part of a rice population caused by its luxuriance, as follows:

Namely, supposing that all the leaves in a population be exposed fully to the light up to the saturating point, the population photosynthesis (P) can be taken approximately equal to the product (Ap_0) obtained by multiplying the leaf area (A) by photosynthetic capacity per unit leaf area (p_0).

However since the light intensity in the inner part of a population will be lowered owing to the luxuriance of the population, if the mean lowering rate of the light intensity is indicated by f, P would be represented by fAp_0, where f is called "light-receiving coefficient". The formula "$P=fAp_0$" is recognized as applicable to every rice population, though varied in cultural season, fertilizer application amount, spacing, or in rice varieties.

4. Light-receiving coefficient and plant form

The relationship between light-receiving coefficient and leaf area can be represented by the formula (MURATA et al., 1957),

$$f=ae^{-bA}$$

where

a and b: constant,
e : base of natural logarithm

With the expansion of leaf area, the light-receiving coefficient will show a decrease in terms of the inverse exponential function. In the case of the same rice variety, a and b (constants) are almost the same throughout the plant growth period, but vary with rice varieties. Though even in a leaf area, the light-receiving coefficient varies practically to some extent with rice varieties. This is due to the varietal difference in the value of a and b, and the value of them is considered to be determined depending upon the light-transmitting ability or uniformity in spatial distribution of leaves of the population. Formal factors such as angle or thickness of a leaf, plant height, and tiller number have also close bearings.

It can be said that the light-receiving coefficient at the early growth stage of rice variety of profuse tillering is generally low. Rice variety of profuse tillering is generally short in a leaf blade and the tillers are tended to develop densely. As a result, panicle-number type varieties are lacking uniformity in the spatial distribution of light, comparing with panicle-weight type varieties. This is deemed as the principal reason for the smallness in the light-receiving coefficient of panicle-number type varieties. On the other hand, tall plant height makes vertical distribution of leaves deep. This results in an uniform distribution of light within the plant population, giving an increased light-receiving coefficient.

At the advanced plant growth stage, the thickness of a leaf also brings about the effect on the light-receiving coefficient to a certain extent. When the thickness of a leaf is low, though even in a leaf area, the inner part of the population is brighter. As a result, there is a possibility of raising the light-receiving coefficient. It is reported that it is low in light-transmitting ability of the leaf layer of a plant which bears a leaf having a nearly horizontal angle (MONSI and SAEKI).

From the viewpoint of the light-receiving coefficient, the desirable type of rice variety is as follows:

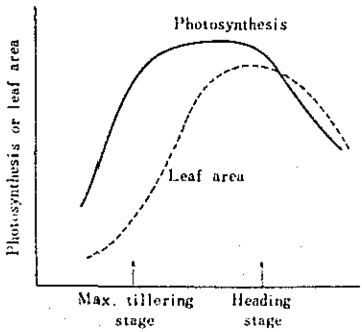
Plant height:	Not too low
Leaf:	Erect type and not too thick
Luxuriance:	Fairly spread, not too dense
Spatial distribution of leaves:	Uniform and deep

5. Plant growth period and population photosynthesis

A "light-photosynthesis curve" at the growth stages other than tillering and booting stages will after all describe a curve in the intermediate form between the curves shown in Fig. 3–11, depending upon the degree of luxuriance. Namely, from the time immediately after the tillering stage, it shows an increase in the luxuriance and the curve is becoming increasingly sharp, and the saturating point will rise or disappear. After the heading stage, due to the decrease in the leaf area, the curve becomes increasingly gently, thus approaching to a horizontal form.

When the numerical value of photosynthesis at a certain light intensity (e.g., 60 K lux), which is obtainable from the respective light-photosynthesis curves at the major plant growth stages, is combined with each growth stage in the order, the curve indicating the changes in the population photosynthetic capacity for the light throughout the whole plant growth period can be obtained (Fig. 3–14). The form of this curve is almost similar to the form of the curve indicating the changes in the leaf area, but for the reason that the photosynthetic activity of an individual leaf and the light-receiving coefficient are higher during the earlier growth period, the photosynthesis at the earlier period is higher, considering the size of the leaf area, and its peak point is observed to reach earlier than in the case of the leaf area.

Fig. 3–14. Changes in Population Photosynthetic Activity, with Progress in Plant Growth



4. Dry Matter Production

A part of the dry matter consists of the inorganic compounds absorbed by plant roots, but the amount accounts for only 10–20 per cent of the total, and a great part of the dry matter consists of the carbohydrates produced in the process of photosynthesis and the derivatives of carbohydrates. Dry matter production can, in principle, be represented in the form of the balance between the total assimilation and the total respiration. Accordingly, two fundamental factors in the photosynthesis (i.e., photosynthetic activity per unit leaf area and leaf area) are the fundamental factors in determining the dry matter production as well. As the population photosynthesis is regulated by the light intensity to which individual leaves are exposed, the light-receiving coefficient is also a determining factor in the dry matter production. From the viewpoint of these three factors, the dry matter production of rice plants will be discussed below.

1. *Photosynthetic activity per unit leaf area*

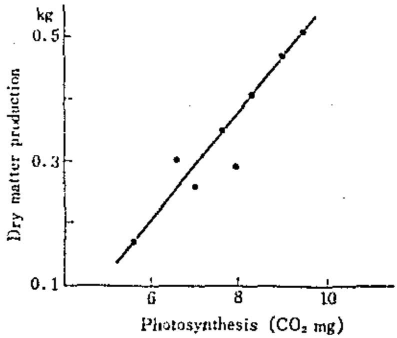
Photosynthetic activity per unit leaf area has, needless to say, a positive effect on the dry matter production, but the effect varies with the plant growth stages. At the very earliest growth stage in which every leaf is exposed fully to the light, the photosynthetic activity must have a direct effect on the dry matter production. However, with the expansion of a leaf area, the light intensity at the very surface of the individual leaf becomes lower, and the light-receiving coefficient will become more dominant. At the ripening stage when the leaf area begins to lessen, the photosynthetic activity is restored again in its importance.

The photosynthetic activity per unit leaf area has, in principle, the above-mentioned characteristics, but the range of its variation according to the rice varieties and cultural conditions is less, comparing with that in the leaf area or light-receiving coefficient, it is rare to have its effect directly on the dry matter production. However, if, owing to the shifted cultural period, a fairly great change has taken place in the photosynthetic activity at the heading stage, a nearly rectilineal relation will be found between the dry matter production and the photosynthetic activity during the ripening stage (Fig. 3-15).

2. *Leaf area*

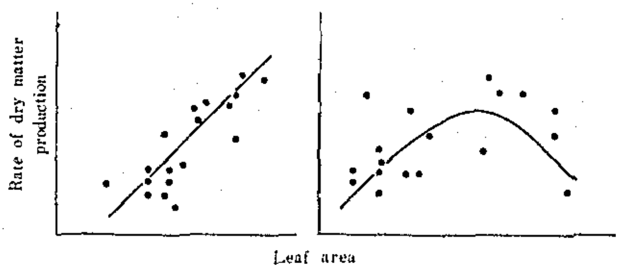
At the stage when the leaf area is small, the leaf being exposed fully to the light, the leaf area has completely a positive effect on the dry matter production, as is the case with the photosynthetic activity. However, when the leaf area has been expanded with the advance in the plant growth, the photosynthesis will not come to increase proportionately with the increase in the leaf area. As indicated in Fig. 3-16,

Fig. 3 – 15. Relationship between Dry Matter Production and Photosynthetic Activity per Unit Leaf Area at Ripening Stage
(MURATA and OSADA, 1959)



in which different varieties are compared, at the earlier growth stage at which the leaf area is still small, a positive relation is observed between the leaf area and the rate of dry matter production. Even when the leaf area has become fairly larger with the advance of plant growth, a positive relation is still observed to a certain extent, but in the case of rice variety showing too large leaf area, the rate of dry

Fig. 3 – 16. Relationship between Leaf Area and Dry Matter Production in Paddy Rice Varieties
(MURATA and OSADA, 1959)



matter production tends to decrease. Rice variety showing the leaf area approximating to some 2.5 sq. meters gives a maximum rate of dry matter production in this example. This is called "optimum leaf area for dry matter production". If exceeded this limit, the influence of the leaf area on the dry matter production would show a negative trend.

The reason for the existence of the "optimum leaf area" can be explained as follows (Fig. 3–17) : As stated before, the relation between the leaf area and photosynthesis is represented by curve (A), while the respiration shows a rectilineal increase with the increase in the leaf area (B). As a result, the net amount of CO_2 fixation (equivalent to the dry matter production) can be represented by curve (C) which has a maximum.

Fig. 3–17. Existence of Optimum Leaf Area (Model graph)

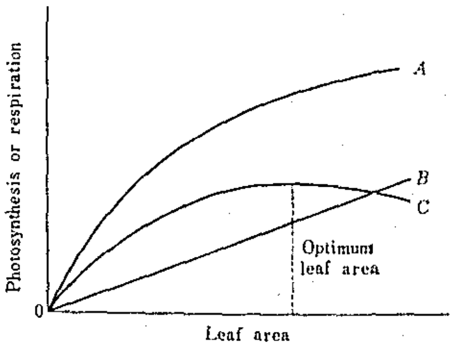
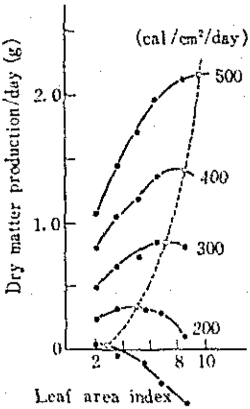


Fig. 3–18. Relationship among Leaf Area, Light Intensity, and Dry Matter Production (TAKEDA, 1959)



The above is the instance in which the light intensity remains unchanged. If the light intensity becomes lower, curve (A) will be further lower, and the optimum leaf area will also show a decrease (Fig. 3–18). Fig. 3–18 indicates that with the rise in the sunlight intensity level, the optimum leaf area is becoming increased. In the case of field tests under the natural condition, there are instances in which the optimum leaf area reaches 4.2 sq. meters at the booting stage, and 3.0 sq. meters at the ripening stage.

Like this, as there are some instances in which due to too large leaf area the negative effects are observed, in order to obtain a highest dry matter production, it is important to keep the leaf area near the optimum value as far as possible throughout the growth period. It is desirable to try to hasten the increase in the leaf area at the earlier growth stage and to prevent the leaf area from being decreased after reaching the state of an optimum leaf area. Such cultural methods as may quicken the increase in the leaf area at the early growth stage by close spacing and as may prevent the decrease in the leaf area at the later growth stage by nitrogen top-dressing can be considered to be effective methods.

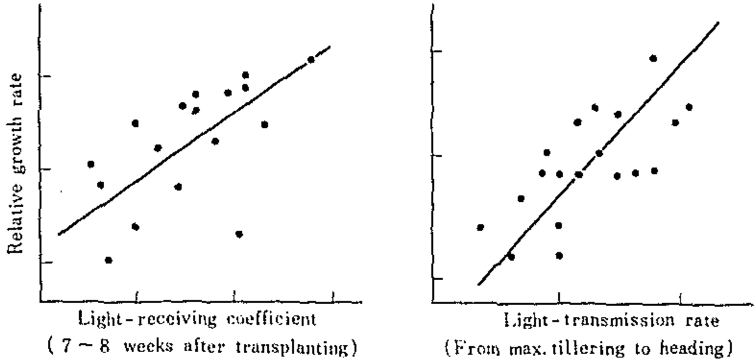
It has also an important bearing on the increased production of dry matter to raise the leaf area ratio (divided leaf area by total weight) by maximizing the proportion of the leaf blade in a whole plant. Thus a positive relation will sometimes come to be found between the relative growth rate and the leaf area ratio.

3. *Light-receiving coefficient*

The decrease in the rate of increasing assimilation depending upon the increasing leaf area is caused by the slow-down in photosynthesis per unit leaf area owing to the decreased light-receiving coefficient resulted from the increased leaf area. Light-receiving coefficient has a dominant influence on the dry matter production ranging over a fairly long period, except the very early growth stage (in which the leaf area is small) and the ripening stage (Fig. 3–19).

A positive relation between the relative growth rate and the light-receiving coefficient or the light-transmission rate is observed among different rice varieties at the time 7 to 8 weeks after the transplanting, as well as during the period from the maximum tillering stage to the heading stage.

Fig. 3-19. Relationship among Light-Receiving Coefficient, Light-Transmission Rate, and Relative Growth Rate



5. Respiration

1. *Meaning of respiration*

A part of glucose ($C_6H_{12}O_6$) produced by photosynthesis is oxidized in the process of respiration and decomposed again into H_2O and CO_2. The equation given for respiration is as follows:

$$C_6H_{12}O_6+6O_2 \rightarrow 6CO_2+6H_2O+690\ \text{K cal}$$

Namely, respiration reaction is exactly reverse to the photosynthetic reaction. At that occasion, a great amount of energy is released. This energy is the radiant energy which was stored in glucose in the form of chemical energy by the action of photosynthesis. In view of this, respiration is defined to be the reaction to yield energy by decomposing glucose and to supply the energy for other physiological activities.

A plant requires to form its components such as protein, cellulose, etc. in order to build up its growing body. These substances are all complicated organic ones originated from glucose. In order to synthesize these substances, and also to absorb nutrients and water by roots, energy is required. Such energies are all provided by the respiratory reactions.

2. Temperature and respiration

Within the range of natural temperature, respiration increases markedly with the rise in temperature. Temperature coefficient (in general physico-chemical reactions, it indicates the increasing rate in reactional speed with a rise in temperature) for the respiration in a rice plant leaf is generally accepted as 2, though somewhat varying with the growth stage. This means that if temperature rises by 10°C, respiration would be doubled. In case of photosynthesis, on the other hand, the temperature coefficient under the natural condition is closely approximate to 1. This is exactly different from that for respiration. This fact, as stated later, has an important bearing upon the dry matter production of the rice plant.

3. Changes in respiration according to the growth stage

At the seedling stage, the rate of respiration per unit dry matter is higher when a seedling is still younger, but it becomes lower according as a seedling becomes older. Immediately after the transplanting, the leaf sheath, leaf blade, and roots of a rice plant grow rapidly and the respiration reaction reaches a peak throughout the whole growth period after transplanting (Fig. 3-20). At the time of a peak respiration, the tillering is in the full swing with the highest value of relative growth rate. This fact indicates that when the growth is in full swing, the respiratory rate is also in full swing. After this period, the respiratory activity slows down and is on the decrease until the ripening stage, though it shows some rise at the heading stage. The respiration of a young panicle registers a markedly higher value than that of any other parts at first, showing a sharp decline with the advancement of its growth, but the value still remains higher than that of the other portion of plant at the heading stage.

The changes in the respiratory activity of a rice plant grown by the direct-sowing system are as given in Fig. 3-21. In this case such peak respiratory rate as seen in the plant

Fig. 3-20. Changes in Respiration according to the Growth of Various Parts of a Paddy Rice Plant (at 30°C) (YAMADA et al.)

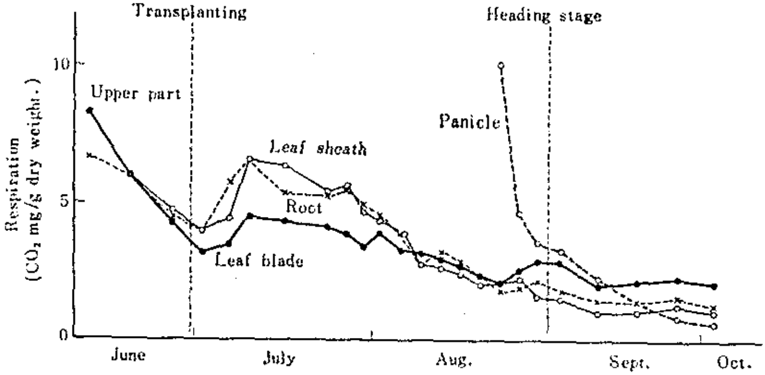
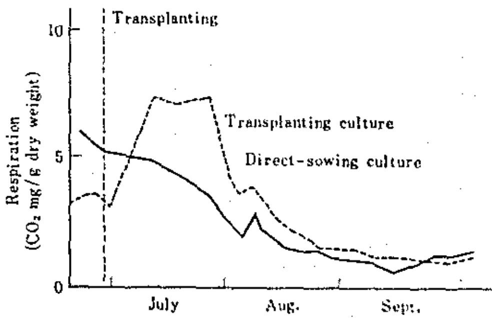


Fig. 3-21. Comparison of Respiration in the Leaf Sheath between Transplanted and Directly Sown Rice Plants (Measured at 30°C) (YAMADA et al.)

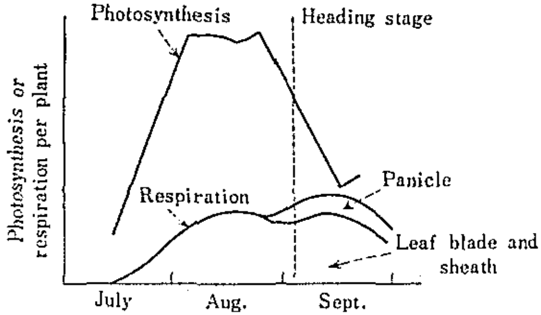


grown by the transplanting system immediately after the transplanting is not observed.

The amount of respiration per hill increases with the advancement in the plant growth, reaching a peak point at the heading stage (Fig. 3-22). Taken a panicle as a whole, a peak respiratory rate is observed in about the second week after the heading. The amount of respiration of a panicle at that time reaches nearly one-third of the total respiration of the tops.

Fig. 3 – 22. Changes in the Quantitative Relation between Photosynthesis and Respiration per Rice Plant Hill, with the Progress in the Growth Stage

(YAMADA)



4. *Dry matter production and respiration, balance between photosynthesis and respiration*

As stated before, the dry matter production is indicated by the balance between the total photosynthesis and the total respiration. The changes in the quantitative relation between photosynthesis and respiration per hill according to the plant growth are indicated in Fig. 3–22. At the early growth stage the intensity of photosynthesis is fairly higher than that of respiration, while when a plant has grown larger and the leaf area becomes greater, the intensity both of photosynthesis and respiration becomes higher and the ratio between them becomes increasingly lower. At the ripening stage, such tendency is becoming increasingly greater. Respiration is not so greatly affected by the light intensity, while photosynthesis is affected markedly. Consequently, the quantitative balance between photosynthesis and respiration will become increasingly unfavorable under bad weather, particularly it becomes remarkable at the later growth stage. At this stage, the existence of such optimum leaf area as stated before comes to be observed.

The above refers merely to the relation observed in the daytime during which photosynthesis acts. In practice, the respiratory reaction during the night participates in the balance between photosynthetic production and respiratory consumption and a greater weight comes to be added to the respiration.

Speaking from large experience, it is very often that the dry matter production shows decreases partly due to the overluxuriance and the unduly high respiration rate resulting from the oversupply of nitrogen, as well as partly due to the unfavorable weather condition.

In keeping the balance between photosynthesis and respiration, temperature is also an important factor. Namely the temperature coefficient for the photosynthesis is approximate to 1, showing little or no increase in photosynthesis with a rise in temperature within a moderate temperature range while the temperature coefficient for the respiration is 2, showing a marked increase in respiration with a rise in temperature. As a result, the higher the temperature, the more unfavorable the photosynthesis-respiration balance, particularly notable when the sunlight intensity is low. Under the weather condition of high temperature and low light intensity, it gives rise to such phenomenon, thus bringing about an ill effect on the dry matter production.

The "ratio of photosynthetic capacity to respiration rate" of population of a rice variety of high fertilizer response around at the heading stage is kept higher than that of a rice variety of low fertilizer response, even when nitrogen has been applied liberally, and it is observed that the efficiency of dry matter production is higher in the case of the former (OSADA and MURATA, 1961).

From the above viewpoint, the respiration indicates a mere consumption of substances, but the respiratory reaction has, needless to say, its own substantial significance. Namely, in the first half of the growth period, the growth of culms and leaves is accelerated to give expanded photosynthetic organs by the active respiration. This function is very important for raising the total production of dry matter during the entire plant growth period.

5. Feature of respiration of a paddy rice plant

Paddy rice plant roots are placed in the state lacking severely in the supply of oxygen, as compared with roots of other crop plants. As a result, the respiration is limited and the physiological functions (nutrient absorption, etc.) are also affected adversely. However, the intensity of respiration in paddy rice plant roots under the low oxygen tension is high, comparing with, for example, that in upland rice plant roots. It is also said that in the case of paddy rice plant roots, the amount of oxygen provided from the tops through the ventilating system is greater than in the case of other upland crop plant roots.

With respect to the respiration in Japonica type paddy rice varieties and Indica type ones, it may be said that, as indicated in Table 3–5, the amount of respiration in the latter (both in leaves and roots) is greater. This fact corresponds well to the fact that Indica type ones are more active

Table 3–5. Respiration in Japonica Type and Indica Type Rice Varieties
(SATO, 1949)

Type	*Variety name*	*Tops*		*Roots*	
		O_2*	*Relative value*	O_2*	*Relative value*
Japonica	Hayashinriki	mg 5.4	100	mg 1.3	100
Indica	Shoseiyu	6.5	120	3.8	123
Japonica	Muboaikoku	4.7	100	2.3	100
Indica	Tankokasen	5.7	121	4.2	183
Japonica	Hogyoku	4.1	100	2.1	100
Indica	Gainkyu	5.8	141	3.1	148
Japonica	Rikuu No. 132	5.0	100	4.5	100
Indica	Early-renkahakuko	5.2	104	4.5	100

Note: * Amount of absorbed oxygen.

in plant growth at the earlier growth period and greater in rooting ability of seedlings than Japonica type ones.

III. INORGANIC NUTRITION

Rice plants contain such elements as nitrogen, phosphorus, potassium, including a large quantity of silica, but contain less quantity of magnesium, calcium and sulfur, and iron or manganese is contained further less in quantity. Besides these, though sodium and chlorine are also contained, these are non-essential elements (Table 3-6).

In the investigations on the essentiality and the physiological functions of the above constituents, the solution culture method is applied without using soils.

Out of the rice plant constituents, nitrogen, phosphorus and sulfur exist as the composing factors in organic components, while potassium, iron and manganese exist chiefly in the form of inorganic components closely related to the physiological function of rice plants.

Table 3-6. Changes in Inorganic Nutrient Contents according to the Rice Plant Growth Stages

(In dry weight percentage)

Date		N	P_2O_5	K_2O	CaO	MgO	MnO	SiO_2
Seedling		1.54	0.664	2.86	0.404	0.265	0.115	10.56
July 15		3.65	0.593	4.15	0.396	0.239	0.112	7.80
July 25		3.45	0.486	4.61	0.317	0.232	0.112	8.11
Aug. 6		3.06	0.527	3.69	0.319	0.342	0.179	11.36
Aug. 15		1.95	0.521	2.98	0.306	0.315	0.167	11.73
Sept. 2		1.17	0.499	2.27	0.289	0.312	0.203	13.97
Oct. 2	Straw	0.46	0.171	1.69	0.397	0.196	0.175	17.50
	Husked rice	1.29	0.810	0.39	0.030	0.211	—	—

1. Physiological Functions of Mineral Elements

1. Nitrogen

Nitrogen is the main constituent of protein which composes protoplasm of a plant, and the constituent forming a plant, particularly, plant stems and leaves.

Ammonia absorbed by plant roots forms a amino acid (known as "glutamic acid") by combining with α-ketoglutaric acid, organic acid found in the krebs cycle (or citric acid cycle) occuring in the living organism in the course of the respiratory pathway, i.e.,

$$NH_3 + \alpha\text{-Ketoglutaric acid} \rightarrow \text{Glutamic acid}$$

Other types of amino acid are formed from this glutamic acid and various organic acids by the process of transamination mediated by an enzyme called "transaminase", as shown below.

$$\text{Glutamic acid} + \text{Pyruvic acid} \rightleftarrows \text{Alanine} + \alpha\text{-Ketoglutaric acid}$$

$$\text{Glutamic acid} + \text{Oxalacetic acid} \rightleftarrows \text{Aspartic acid} + \alpha\text{-Ketoglutaric acid}$$

In amino acids are included generally 22 acids. Among the leading amino acids in the rice plant are glutamic acid, aspartic acid, alanine, serine, etc. Besides these, such acids as valine, threonine, histidine, tyrosine, phenylalanine, etc., are notable. These amino acids condense into peptide. The protein in ordinary crops is the compound made of peptide bond of 300–3,000 amino acid molecules. The action of protein formation from amino acids is called "protein synthesis" or "nitrogen assimilation". For the action of the protein synthesis, energy released by the reaction, ATP (adenosin triphosphate) → ADP (adenosin diphosphate) is used.

In the plant body, the reversible reactions, i.e., protein synthesis and protein decomposition, take place. In relation to the equilibrium: (Protein ⇄ Amino acid), the protein synthesis (from right to left) is predominant in the case of young tissues, while in the case of old tissues, the protein decomposition (from left to right) is predominant.

Ammonia absorbed by plant roots is synthesized in the roots into amino acid, and the ammonia translocates in the form of amino acid into plant leaves and is synthesized into protein. Protein synthesis takes place in roots also, but most actively in the leaf blades.

In recent years, however, it has generally come to be accepted that roots are indispensable for the active protein synthesis in the leaf blades.

The primary function of nitrogen is to form protoplasmatic protein required for increasing the tillers and leaf area.

(i) Excess and deficiency of nitrogen

The secondary important function of nitrogen is to promote the photosynthesis per unit leaf area. Since nitrogen is an essential constituent of chlorophyll, when nitrogen is applied the chlorophyll content will increase and the photosynthesis will be promoted.

The supply of optimum amount of nitrogen increases the leaf area and the photosynthesis per unit leaf area, thus increasing the accumulation of carbohydrate (reserve starch). However, if the excessive nitrogen is absorbed by rice plants, it would result in the over-luxuriance of rice plants and light-receiving coefficients would be lowered. On the other hand, the respiratory action is promoted with the increase in the leaf area. As a result, the balance between photosynthesis and respiration will be disturbed, showing a decrease in dry matter production, particularly, in dry matter production after heading, and the ripening will be affected adversely. Such tendency can be observed markedly when the amount of solar radiation is less.

When a large quantity of nitrogen is absorbed by rice plants at a time in the course of the plant growth period, there occurs a shortage of sugars (organic acids) to be combined with a great quantity of the absorbed ammonia; the amount of sugars (exactly speaking it is not sugars but organic acids, which are derived from sugars, that combine with ammonia-nitrogen) which are produced by photosynthesis and also produced by the decomposition of reserve starch is in shortage in relative proportion to the amount of nitrogen absorbed. In consequence, the absorbed ammonia can not be readily synthesized into protein, and ammonia or amino acids or amides (intermediate substances in protein formation) will be accumulated in the rice plant body.

The analytical results of paddy rice plants containing excessivie nitrogen indicate that it shows no appreciably marked increase in the content of protein-nitrogen, while it shows a marked increase in the content of soluble-nitrogen (including NH_3-N, amide-N, and amino acid-N) (Table 3-7). Rice plants in such state are susceptible to the damage by rice blast or rice stem borers and will become weak in flood or wind resistance.

Table 3 – 7. Effects of Split Application of Ammonia Sulfate and Shading upon the Amount of Various Fractions of Nitrogen Contained in Rice Plants

(SAKAMOTO, 1942)

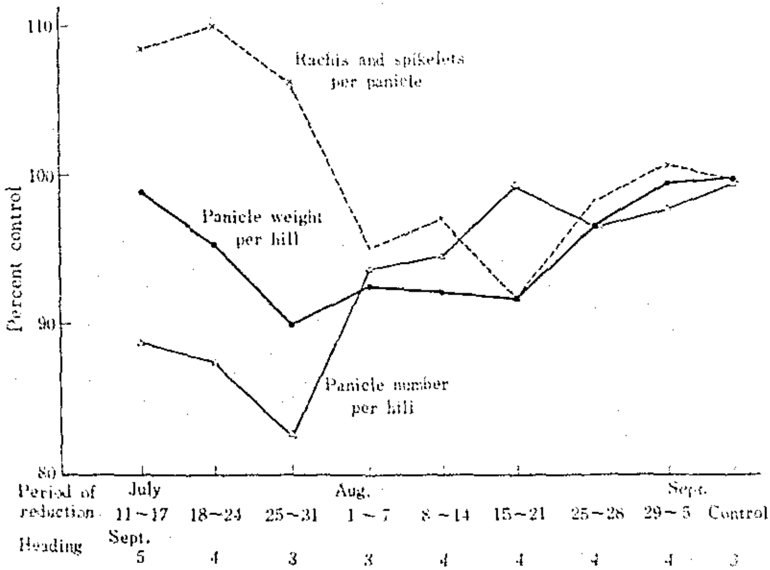
(In milligrams per gram of fresh weight)

Plot	*NH_3-N*	*Amide-N*	*Soluble-N*	*Protein-N*	*Total-N*
Control					
Non-split application	0.026	0.103	1.232	10.349	11.581
Split application	0.038	0.162	1.419	11.243	12.662
Shading					
Non-split application	0.041	0.133	1.227	10.653	11.881
Split application	0.062	0.182	1.558	12.304	13.861

Note: Rice plants were grown in solution cultures.

On the other hand, as shown in Fig. 3-23 which illustrates effect of nitrogen deficiency on plant growth, nitrogen-deficiency at the valid tillering stage causes a decrease in the number of panicles and the lack of nitrogen during the period from the young panicle formation stage to the early booting stage (26–10 days before heading) causes a decrease in the number both of rachis-branches and spikelets (grains) per panicle, thus decreasing the rice yield. During the intermediate period between the above two stages, i.e., invalid tillering stage, rice plants are not affected so seriously by the nitrogen-deficiency, but owing to the excessive nitrogen during this intermediate period, it shows an increase in the number of invalid tillers, showing the waste of nutrients (Fig. 3-23).

Fig. 3-23. Difference in Rice Yields according to the Periods of Reduction in Nitrogen Supply
(BABA, 1944)



Note: Solution culture experiment at Konosu.

(ii) Varietal adaptability for heavy manuring

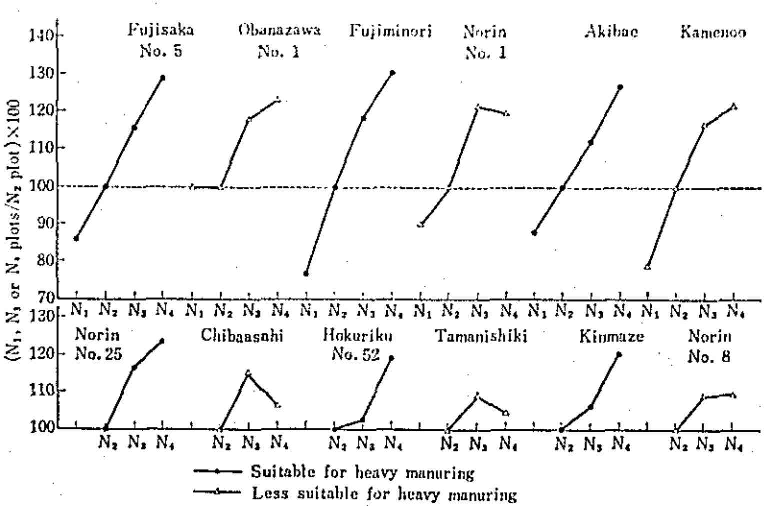
As given in Fig. 3-24, there are: (a) rice varieties showing an increasing trend in the yield according to the increased supply of nitrogen (e.g., *Fujisaka No. 5, Akibae, Fujiminori, Norin No. 25, Hokuriku No. 52, Kinmaze, etc.*); and (b) rice varieties showing an increasing trend in the yield within a certain limit of nitrogen supply, but showing no more increase or a decrease in response to a further increased supply of nitrogen (e.g., Obanazawa No. 1, Kamenoo, Norin

No. 1, Chibaasahi, Tamanishiki, and Norin No. 8). The former are the varieties of high adaptability for heavy manuring and the latter ones of low adaptability for heavy manuring. In foreign countries, the term "fertilizer response" is used generally, but the term "adaptability for heavy manuring", as used in Japan, indicates the "fertilizer response" to the heavy supply of nitrogen. In view of the fact that rice crop in Japan is grown with heavy supply of nitrogen, the term "adaptability for heavy manuring" is considered more suitable than the term "fertilizer response".

In the adaptability of rice varieties for heavy manuring, in a broad sense, are included: (a) physiological and morphological adaptability for heavy manuring; (b) resistance to rice blast; and (c) resistance to lodging.

In this Chapter, the "physiological adaptability for heavy manuring" will be handled.

Fig. 3-24. Varietal Differences in Yields of Paddy Rice Varieties, Different in Adaptability for Heavy Manuring, according to the Amount of Nitrogen Application (IWATA and BABA, 1961)



Rice varieties different in the adaptability for heavy manuring show varied yields of rice according to the increased amounts of nitrogen application, as given in Fig. 3-24. Viewed from the yield components, it can be observed that rice varieties high in adaptability for heavy manuring are characterized by the comparatively low in the decrease in the rate of ripened grains, considering the large increase in the number of spikelets per hill owing to the heavy application of nitrogen (Table 3-8).

Table 3-8. Effects of Nitrogen Application on Rice Yield

Rice variety	*Suitability for heavy manuring*	*Plots*	*Perfect grain weight per hill*	*Total number of spikelets per hill*	*Ripening rate*	*Weight of 1,000 perfect grains*	*Ratio between paddy and straw weight*
Norin No. 25	High	N_1	100	100	100	100	100
		N_2	117	121	97	99	100
		N_3	123	149	84	98	91
Chibaasahi	Low	N_1	100	100	100	100	100
		N_2	115	117	99	100	98
		N_3	106	115	94	99	84
Kinmaze	Very high	N_1	100	100	100	100	100
		N_2	106	115	95	99	93
		N_3	120	127	97	99	95
Norin No. 8	Medium	N_1	100	100	100	100	100
		N_2	109	109	101	99	95
		N_3	109	123	89	99	80

Notes: 1. All figures are indicated by percentage, representing the value of N_1 plot by 100.

2. N_1, N_2, N_3 indicate the amount of nitrogen application; N_1 plot is the lowest, and N_3 plot the highest in the amount of nitrogen application.

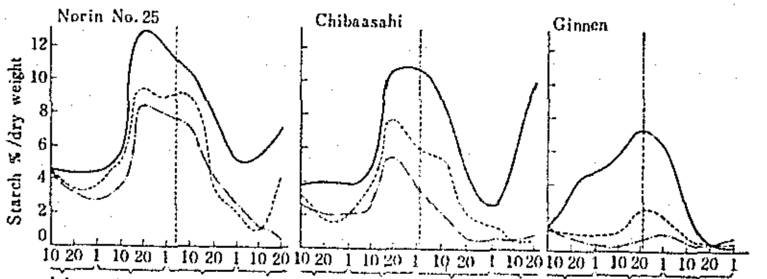
Rice varieties of high adaptability for heavy manuring show a slight decrease in the ratio of grain weight to straw-weight with the heavy nitrogen application and show higher efficiency in the grain production per unit amount of nitrogen absorption, and are great in the nitrogen utility effect in the case of heavy nitrogen application.

Fig. 3–25 indicates that owing to the heavy nitrogen application, rice variety of high adaptability for heavy manuring shows a slight decrease in the starch content in leaf-sheaths and stems and is larger in the starch accumulation before heading as well as after heading than the case of rice variety of lower suitability for heavy manuring.

Varietal differences in the nitrogen absorption are shown in Fig. 3–26. Rice variety of less adaptable for heavy manuring shows larger in the amount of nitrogen absorption and in the plant growth at the early growth stage than those of highly adaptable variety owing to the heavy nitrogen application, but thereafter it will show a marked decrease in the nitrogen absorption. For this reason, in the case of a rice variety of less adaptable for manuring, the split application of nitrogen is more effective than the basic application of heavy nitrogen. Indica type rice varieties are generally less in the adaptability for heavy manuring. Table 3–9 indicates the experiment on the time of nitrogen application using Ptb-16 (Indica type variety) as a material. As shown

Fig. 3–25. Effects of Nitrogen upon the Starch Content in Leaf-Sheaths and Stems of Rice Plants, according to the Amounts of Nitrogen Application

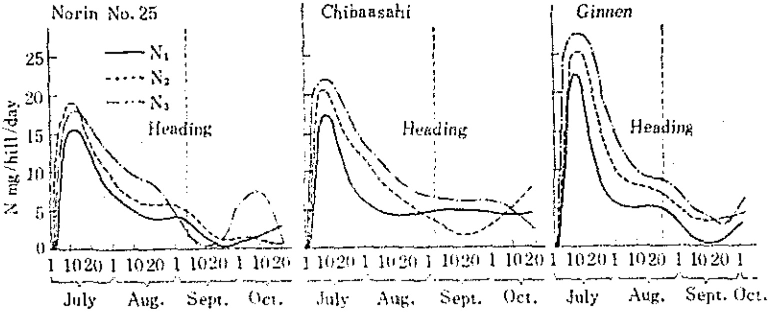
(TAKAHASHI, IWATA and BABA, 1959)



Notes: —— N_1, ... N_2, —·—·— N_3

Norin No. 25, suitable variety for heavy manuring
Chibaasahi of less suitable variety
Ginnen (Indica var.), least suitable variety

Fig. 3-26. Varietal Differences in Nitrogen Absorption Affected by Different Levels of Nitrogen Application
(TAKAHASHI, IWATA and BABA, 1959)



Note: Amount of absorption per day was calculated from the difference in the nitrogen content between two successive determination per hill.

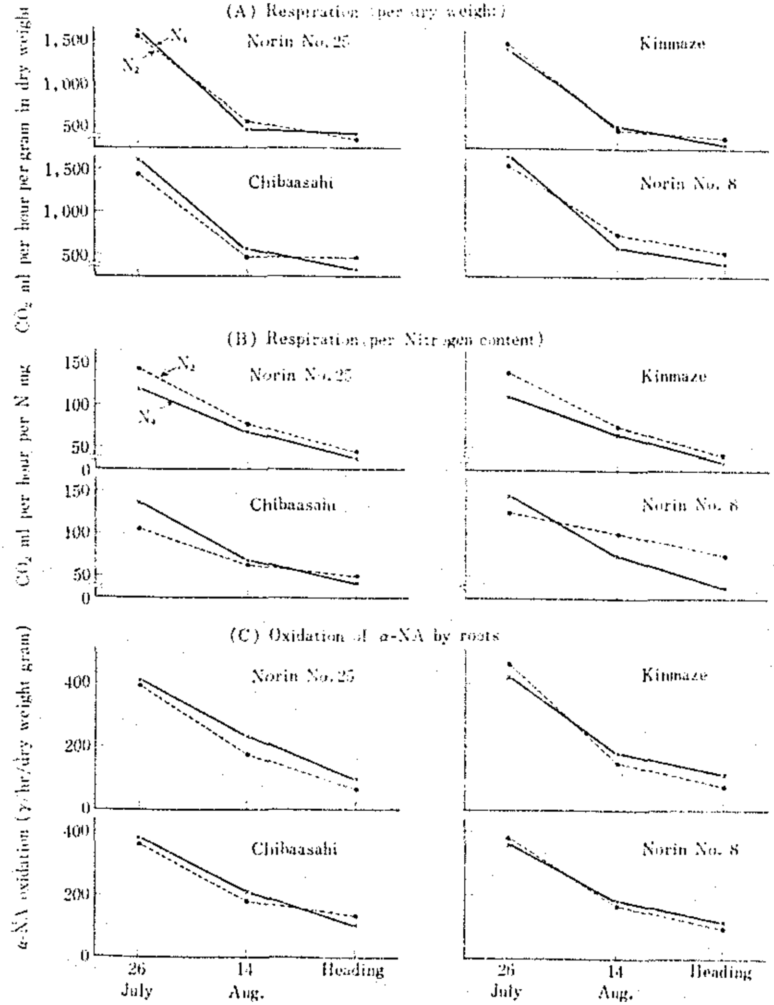
Table 3-9. Differences in Rice Yields according to the Period of Nitrogen Application.
(CHANDRARATNE, 1957)
(*N-60 lbs/acre in* $(NH_4)_2SO_4$)

Period of nitrogen application	*Hulled rice yields (lbs/acre)*
Non-nitrogen	2,854
10 days before transplanting	2,925
21 days after transplanting	3,214
30 days before anthesis	3,545

in Table 3-9, the effect of split application of nitrogen is markedly higher than that of basic application.

It is generally accepted that there is a positive correlationship between the "vitality of rice plant roots" and the "respiration in roots and α-naphthylamine (α-NA) oxidation". Fig. 3-27 shows the changes in the respiration and α-NA oxidation of roots according to the growth among rice varieties different in the adaptability for heavy manuring. The varieties of less adaptable for heavy manuring show higher rate of respiration and α-NA oxidation in the early

Fig. 3-27. Varietal Differences in Physiological Activities of Roots, according to the Amounts of Nitrogen Application



growth period in the heavy nitrogen plot than those in the less nitrogen plot, but this relation is reversed in and after young panicle formation stage. Namely, the vitality of the roots of the varieties of less adaptable for heavy manuring become markedly lowered from about the time of heading and become more liable to root-rot. In the case of rice varieties of less adaptable for heavy manuring, the occurrence of root-rot is believed to be one of the causes for the decrease in the rate of ripened grains due to the heavy application of nitrogen.

2. *Phosphorus*

Phosphorus is contained in the nucleic acid, the principal constituent of the nuclei in the protoplasm of a living cell. As a result, phosphorus is necessary to promote the tillering, which depends upon the active cell multiplication. Phosphorus is one of the elements which are easily translocatable in a plant body. It always translocates from place to place where the growth is in full swing, finally translocating from the plant leaves or stems to the grains. It forms in the plant body the energy-rich compounds like adenosin triphosphate (ATP) or adenosin diphosphate (ADP), performing an important function in transporting and storing the energy. Phosphorus has a close bearing on the synthesis of starch and cellulose or translocation of carbohydrate. Phosphorus contained in the kernel accounts for about 0.45 per cent. This is the phosphorus which has been translocated after heading from plant stems and leaves mainly in the form of hexose-phosphate which is used for the synthesis of starch in grains.

Due to the lack of phosphorus, plant leaves turn dark green color and become more slender, plant height becomes shorter, the number of stems becomes markedly smaller, and heading and ripening will be delayed.

3. *Potassium*

The presence of nitrogen, phosphorus and magnesium in a living body mainly as organic substances, and the presence of iron, manganese and copper as a part of constituent of enzyme have already been known, but the presence of organic substances containing potassium has not been known as yet. A great quantity of potassium is contained in a paddy rice plant, as compared with other inorganic nutrients, but almost all the potassium is solved in the cell sap. Thus it presents in the water soluble form. In the case of a living plant, potassium is not readily flown away by water, but when the plant has withered up, potassium dissolves in water and flows away. Potassium in the plant body translocates most rapidly. Upon this, when potassium is supplemented to the potassium-deficient rice plant, the absorbed potassium translocates to the young leaves which are in rapid growth, or concentrates in other parts where potassium is most needed. Consequently, old leaves begin first to present the symptoms of potassium-deficiency. Therefore, it is evident that potassium concentrates in the part where the metabolism is in full swing. It has recently become clear that potassium is necessary as an activator of enzyme. Potassium performs an important function in the multiplication and growth of plants.

Owing to the lack of potassium, photosynthesis decreases, but respiration increases, thus resulting in the decreased production of carbohydrate. Protein synthesis is also affected by potassium-deficiency. As a result, water soluble-nitrogen fraction such as amino- or amide-N increases in relative proportion to protein-nitrogen. The more nitrogen, the more potassium is needed. The more nitrogen, the more serious shortage is caused in the potassium supply. Consequently, K_2O-N ratio is important for the plant growth and it is important to prevent the ratio from being lowered. Owing to the potassium-deficiency, the plant leaf color becomes darker and the plant height becomes shorter, but unlike the case of phosphorus-deficiency, it shows no decrease in the number of plant stems and the heading is rather hastened. Due to the potassium-deficiency, rice plants become more susceptible to stem rot, *Helminthosporium* leaf spot and bacterial leaf blight, and the stems grow weaker, resulting in breaking and lodging.

Decrease in the rice yield due to potassium-deficiency is

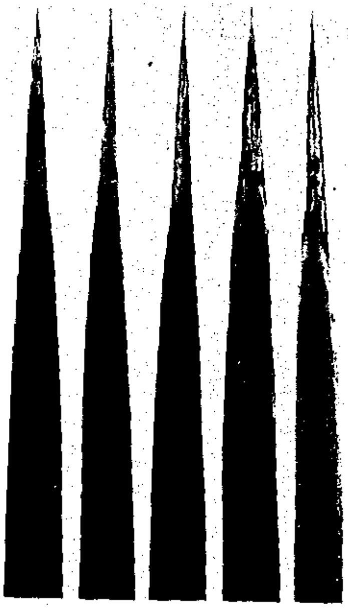
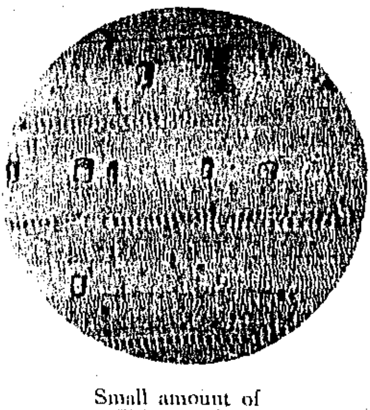
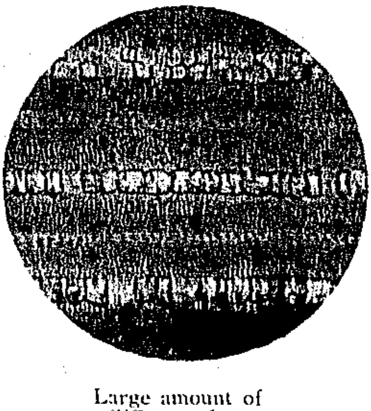


Photo. 3-1. Symptoms of Potassium-Deficiency





Small amount of SiO_2-supply

Large amount of SiO_2-supply

Photo. 3-2. Silicificated Epidermal Cells of Leaf Blade, affected by Silica-Supply

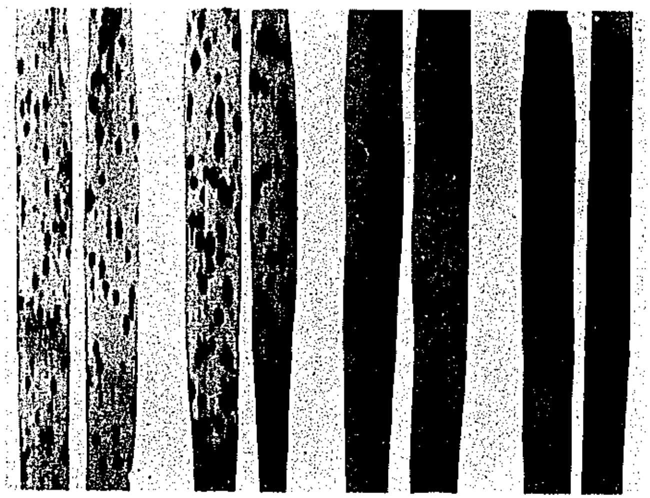


Photo. 3-3. **Occurrence of *Helminthosporium* Leaf Spot affected by Nutrient Supply**

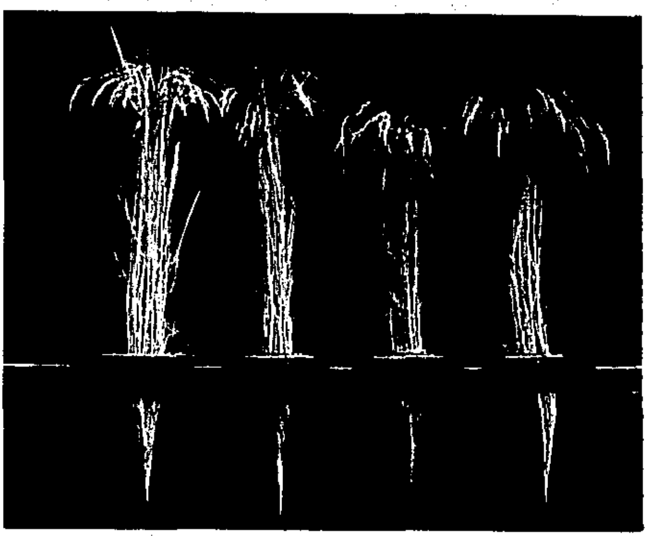


Photo. 3-4. **Rice Plant Growth affected by Nutrient Supply (Aerated Plot)**

observed markedly in the case of potassium-deficiency at the most active tillering stage and young panicle formation stage when nitrogen content reaches to a peak. When potassium-deficiency in the period before the most active tillering stage reaches as low as 0.5 per cent or under, reddish brown spots will appear on the lower leaves (Photo. 3-1). Due to the potassium-deficiency after young panicle formation stage, the number of spikelets per hill will decrease, thus resulting in the decreased rice yield. As the result of potassium-deficiency, the withering of lower leaves will be hastened and the root activity will be slowed down.

4. *Silica*

A paddy rice plant is a typical silica plant which absorbs a great quantity of silica, comprising as high as 10-20 per cent in plant stems and leaves. In the high-yielding rice culture prevailing in Japan, silica content is particularly very high. The absorbed silica ascends in a plant body together with water by transpiration, and the water evaporates from the leaf surface and a great part of silica is deposited in the epidermal cells (Photo. 3-2). This is known as "silicification of epidermal cells". When silica is deposited on the leaf surface, the plant stems and leaves will become stiff, while if silica runs short, the silicification of epidermal cells would be poor and rice plants would become readily susceptible to the fungi of rice blast or *Helminthosporium* leaf spot. Due to the silica deficiency, grains become stained with brown spots caused by disease fungi.

The more nitrogen application, the more effective in silica application. In case where SiO_2/N ratio is high, rice plants grow healthily.

Rice plants absorb silica at the rate of 8-12 kilograms per are. This is the silica contained in top soil and irrigation water. Since silica contained in subsoil is not readily absorbed by plants, it is important to till the top soil as deep as possible in order that greater amount of silica may be absorbed. In Japan, composts made of rice straw have been used. Rice straw composts are the important source of silica. In recent years, silica fertilizers (calcium silicate) have come into wider use.

5. Magnesium

Since magnesium is a constituent of chlorophyll, the lower leaves of rice plants grown in magnesium-deficient paddy field soils will suffer from chlorosis at the early plant growth stage, but thereafter the symptoms will become obscure. Due to the lack of magnesium, soluble-nitrogen and sugar in plant stems and leaves will become increased, and silica absorption will be retarded. Thus the rice plants will become more susceptible to *Helminthosporium* leaf spot and rice blast. The withering of the lower leaves will be hastened. Magnesium acts on the translocation of phosphorus from plant stems and leaves into seeds. It is recognized that phosphorus and magnesium are contained relatively much in seeds. As magnesium absorption is inhibited by the presence of potassium, when a large quantity of potassium is supplied to the magnesium-deficient soils, magnesium-deficiency will become aggravated, thus giving rise to more frequent occurrence of rice blast.

6. Iron and Manganese

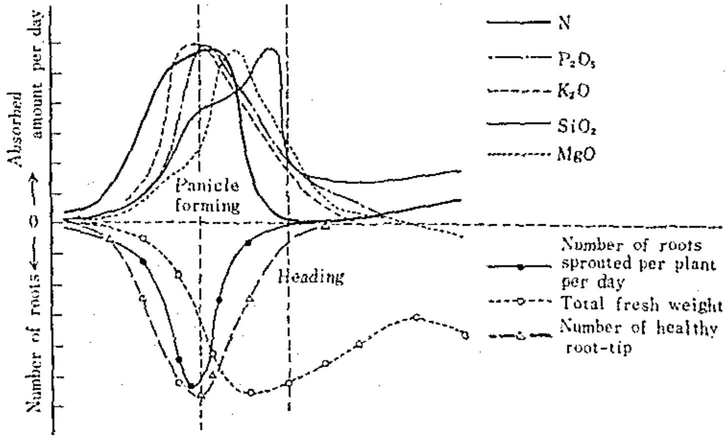
In the case of upland field, the chlorosis of the plant leaves due to the lack of available iron and manganese is not rare, while in the case of rice plants growing on lowland paddy field, iron- and manganese-deficiency will be observed rarely. Due to the lack of manganese, paddy rice plants become more suscepitble to *Helminthosporium* leaf spot, but this disease will completely be controlled by the manganese supply. However, the extent of rice yield increase resulted from the manganese supply is as low as 5–10 per cent.

2. Nutrient Absorption and Functions of Roots

1. Process of nutrient absorption and development of roots according to the plant growth stages

Amount of nutrient absorption (velocity of nutrient absorption) and the development of roots throughout the growth period of rice plants grown in paddy field soils are shown in Fig. 3–28.

Fig. 3-28. Relationship between Nutrient Absorption per Day and Number of Roots, according to the Plant Growth Stages

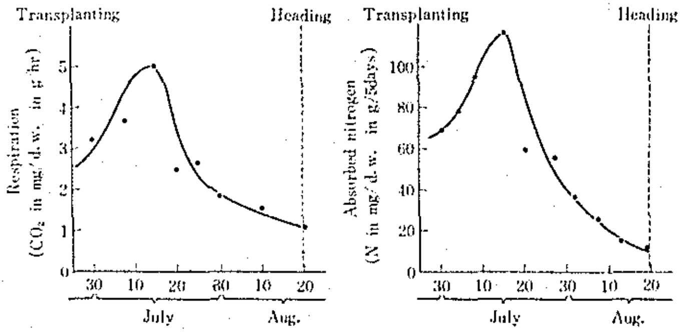


Velocity of absorption of each of elements by roots reaches a maximum before heading and it shows a rapidly declining trend after heading. Of the elements, the absorption of nitrogen, potassium and phosphorus reaches a maximum at the earliest time (20 days before heading). The absorption of magnesium, sulfate and iron reaches a maximum about ten days later than that of the former, and the absorption of silica and manganese reaches a peak at the latest time. Factors contributing to the change in the absorption velocity of various nutrients according to the growth are: characteristics and distribution of roots, metabolism in tops, and the amount of supply of nutrients from the soil. The relation between the process of nutrient absorption and the feature and aging of roots is shown clearly in Fig. 3–28. Namely, the amount of nitrogen absorption is coincident with the number of the newly developed roots. This indicates the fact that nitrogen is absorbed efficiently from the soil by new roots. Potassium and phosphorus absorption shows a close relation to the number of the new roots, but the absorption is compatible chiefly with the total fresh weight of the root apexes of new roots or relatively younger roots approximate to new roots. However, the absorption reaches a maximum several days later. This can be ascribed to the fact that the absorption is done also by the parts other than root apexes. In contrast to this, the absorption of iron, magnesium and sulfate reaches a maximum about 10 days later than the day on which the new roots and the total fresh weight of root apexes reach a maximum. The absorption of silica and manganese reaches a maximum about 20 days later. As a result, it is assumed that the absorption of silica and manganese is made also by fairly older parts other than young root apexes.

2. Nutrient absorption and respiration in roots

Nutrient absorption by roots is done by using the energy obained by the aerobic respiration in roots. Accordingly, the aerobic respiration is indispensable for the nutrient absorption by roots. And oxygen, respiratory substrate, and

Fig. 3 – 29. Relationship between Respiration in Roots and Nitrogen Absorption by Roots
(YAMADA and OTA, 1958)



respiratory enzyme are indispensable for the respiration.

(i) Changes in respiration and nutrient absorption by roots according to the plant growth stages

The relation between nutrient absorption by roots and activities of respiration is shown in Fig. 3–29.

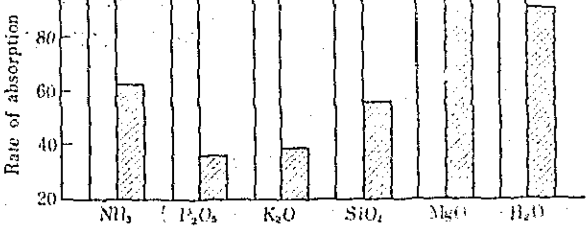
The nitrogen absorption by roots coincides well with the respiration in roots at the respective plant growth stages.

(ii) Transmission of oxygen to the rice plant roots from the tops

Since the supply of energy by the aerobic respiration in roots is indispensable for the nutrient absorption by roots, when the concentration of oxygen in the solution around the roots is lowered, the nutrient absorption by roots will be slowed down. As shown in Fig. 3–30, the absorption of inorganic nutrients is lowered by the shortage in the supply of oxygen in the culture solutions, particularly markedly in the slow-down of the absorption of potassium, phosphorus and silica. This fact indicates that a great amount of energy obtained by means of aerobic respiration is indispensable for the absorption of these nutrients.

The reason "why the paddy rice plant roots spreading in the submerged soils under the dire reductive condition can respirate or absorb the nutrients" is found in the fact that

Fig. 3–30. Effect of Oxygen Shortage on the Absorption of Water and Nutrients by Roots
(BABA and IWATA, 1957)

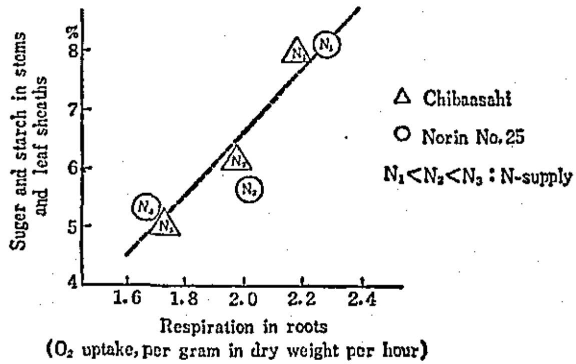


the oxygen supplied from the air through the stomata or the oxygen evolved by the photosynthesis is transmitted to the roots through the intercellular spaces developed in the plant body. There are many evidences to show the transmission of oxygen to the roots from the tops and the amount of the transmitted oxygen.

(iii) Respiratory substrate

Respiratory substrate indispensable for the respiration in roots is transported to the roots chiefly in the form of sugar. If the supply of respiratory substrate from the tops shows a decrease or is small in amount, the respiratory activity of the roots and the nutrient absorption by the roots would become decreased. As a matter of fact, the respiratory activity of the roots is stimulated by adding sugar to the roots low in sugar content at the time of measuring the respiratory activity. Fig. 3–31 shows the relationship between "the starch and sugar contents in stems and leaf sheaths" and "the respiratory activity of roots". When the photosynthetic activity of the tops is vigorous and the balance between the photosynthesis and the respiration is maintained well and the starch or sugar content in the tops is high, the supply of respiratory substrate (sugar) to the roots will

Fig. 3 – 31. Relationship between Respiratory Rate of Roots and Carbohydrate in Stems and Leaf Sheaths
(BABA and INADA, 1960)



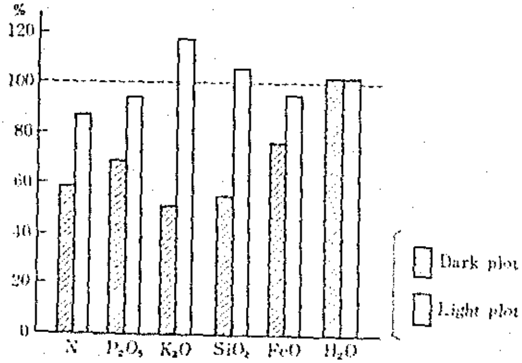
become increased. Consequently, the respiratory activity and the nutrient absorption by the roots are considered to be thus stimulated.

(iv) Nutrient absorption and respiratory system

Fig. 3–32 shows the results of experiment on the nutrient absorption by plants carried out by adding carbon monoxide (CO) to the culture solutions in dark or under light. As seen in Fig. 3–32, on the dark plot the nutrient absorption is inhibited by CO in the order: $K_2O > SiO_2 > NH_3 > H_2O$, while on the light plot, it is restored in the order named above. The similar inhibition to the nutrient absorption is observed also in case where H_2S, HCN and NaN_3 are added to the culture solutions, viz., the absorption of inorganic nutrients, particularly of potassium, phosphorus, silica, and ammoniacal nitrogen, is inhibited in the order named.

Fig. 3–32. Light-Reversible CO Inhibition to the Nutrient Absorption by Rice Plants

(BABA and INADA, 1959)



Connected with the inhibition to the nutrient absorption, it is observed that the respiratory activity of cytochrom oxidase system is important in the nutrient absorption. The degree of the importance varies with the respective nutrients, e.g., most important in the case of potassium, followed by silica and phosphorus in the order. For the absorption of these nutrients the supply of energy through respiration is indispensable, but for the absorption of magnesium or calcium, so large an amount of energy will not be required.

3. Active and passive absorption

Active and passive absorption is cited as the mechanism of nutrient absorption. The absorption of ion (inorganic nutrients) attained by the consumption of energy is called "active absorption", and the absorption attained without consuming any energy is called "passive absorption". In the case of passive absorption, ion contained in the medium outside the roots enters into the free spaces of roots by the action of diffusion. On the other hand, as the roots are charged negatively, cations are easily adsorbed by negative charge of root. It is reported that the process of such diffusion or adsorption is completed within as short as one hour, and thereafter the absorption and accumulation of ion is made exclusively by the active absorption.

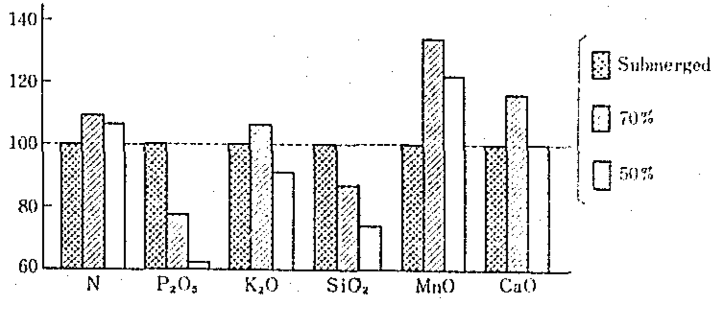
4. External factors and nutrient absorption

(i) Soil moisture

Owing to the decrease in soil moisture, the absorption of phosphorus, potassium and silica slows down (Fig. 3–33).

Fig. 3 – 33. Effects of Soil Moisture upon the Nutrients Contained in Tops and the Dry Weight of Tops

(BABA et al., 1956)



Note: Figures indicate the indexes when those for the submerged plot are represented by 100.

This is considered due to the slow-down of the normal aerobic respiratory activity of roots with the decrease in soil moisture. Adding to this, the change in phosphorus or silica into an unavailable form due to the decrease in the soil moisture can be cited as the cause for the decreasing absorption of phosphorus or silica.

(ii) External factors other than soil moisture

Nutrient absorption by roots varies with such factors as the presence of hydrogen sulfide and organic acids (acetic acid, butyric acid, etc.), excessive presence of ferrous iron, water temperatures, and air temperatures. Regarding this, please refer to the descriptions under the caption "Physiological Injury".

5. *Oxidizing activity of plant roots*

When the roots pulled out from paddy fields are immersed in the diluted H_2S solution, the reddish iron oxide which has been deposited on the roots will change into blackish FeS, but in process of time FeS will become oxidized again and the blackish color will fade away. This is due to the oxidizing power of roots. The oxidizing power of roots can be evidenced by measuring the oxidation of α-naphthylamine (α-NA) by roots. In case where the nutrient absorption by roots is inhibited, the oxidizing activity of roots is usually very low. The α-NA oxidation is related to the respiration. As a result, a parallel relationship is, in most cases, observed between the respiratory activity and the α-NA oxidizing activity.

3. Translocation of Inorganic Nutrients in Rice Plants

Inorganic nutrients absorbed by roots in the water soluble form translocate and ascend through the xylem and are used as the plant constituent or in the process of metabolism. Consequently, in the translocation of inorganic nutrients through the xylem, the transpiration participates. Table 3–10 shows the distribution of the inorganic nutrients in the rice plants according to the differences in soil moisture.

Under low moisture content of soil the translocation and ascension of silica, potassium and calcium within the plant body, are retarded owing to the decreased transpiration. Similar retardation is observed when air humidity is high. But such decrease cannot be observed in the case of nitrogen or phosphorus. The reason why the effect of transpiration is not clear with nitrogen and phosphorus lies in the fact that, since the nitrogen and phosphorus are the principal constituents of protein or nucleic acid and are utilized for the synthesis of starch and other organic compounds, nitrogen and phosphorus retranslocate to the parts where the synthesis is going on vigorously.

Table 3－10. Effects of Soil Moisture upon the Distribution of Inorganic Nutrients in the Various Parts of Rice Plants
(BABA and IWATA, 1956)

Ratio	*Plot*	*N*	P_2O_5	K_2O	SiO_2	*MnO*	*CaO*	*FeO*
Leaf blades/leaf sheaths	Submerged	1.48	1.16	1.31	1.12	2.29	3.72	1.32
	70 %	1.64	1.08	1.20	1.07	1.67	3.25	1.27
	50 %	1.71	1.20	0.92	0.97	1.80	3.33	1.96
Leaves/stems	Submerged	1.46	0.66	0.44	2.61	3.18	3.70	1.13
	70 %	1.13	0.93	0.37	2.13	2.74	3.30	0.95
	50 %	1.09	0.86	0.33	2.55	2.47	3.10	1.23
Panicles/stems and leaves	Submerged	2.34	3.35	0.33	0.31	0.10	0.087	0.30
	70 %	2.37	5.12	0.35	0.31	0.49	0.099	0.35
	50 %	2.43	5.04	0.29	0.33	0.54	0.125	0.41

When the inorganic nutrients which have once been accumulated in the plant body translocate again to other parts of the plant body, the nutrients will pass chiefly through the phloem (sieve tube) instead of through the xylem. For instance, phosphorus sprayed on the leaf surface translocates through the phloem. In case where nutrients translocate through the phloem, the respiratory activity will probably participate therein.

Out of the nutrients, nitrogen, phosphorus, potassium and magnesium translocate readily and retranslocate within the plant body. Accordingly, the symptoms of deficiency in these nutrients are observed in the lower leaves, while iron, calcium, manganese and silica do not translocate so readily. When fixed once in the old tissues, these do not readily re-translocate into new tissues. In consequence, the symptoms of deficiency in each of these nutrients are likely to appear on the upper leaves.

IV. RIPENING OF RICE PLANT

It seems that any exact definition of "ripening of rice plant" has not been given as yet, but from the plant physiological viewpoint, it may be understood that the "ripening of the rice plant" is the phenomenon that the valuable plant components such as carbohydrates, protein, and inorganic substances are translocated to the seed and accumulated therein. From the viewpoint of utilization, as the grains that accumulated the valuable components more than a certain amount in the endosperm are useful, the ripening of rice plant can also be understood as the cause and process contributing to the formation of such useful grains as well as to the formation of other useless grains. From such viewpoints, the descriptions will be made below under the following three captions: (i) *accumulation of useful substances (chiefly carbohydrates) in seed*; (ii) *translocation of useful substances according to the progress in ripening*, and (iii) *percentage of ripened grains* (percentage of the number of fully ripened grains to the total number of spikelets).

1. Changes in the Amount of Various Components in the Seeds of Rice in the Ripening Process

1. Carbohydrates

When the sugars translocated from the stems and leaves to the panicle reach the leucoplasts of endosperm cells, all the sugars are, by reacting with adenosin triphosphate, transformed into D-glucose-1-phosphate which is rich in energy.

In the leucoplasts are contained the enzyme, phosphorylase, and other enzymes which mediate the production of α-1-6 bond (by "leucoplasts" may be meant "group of these enzymes"). These enzymes act on D-glucose-1-phosphate and form a stabilized polymer by removing phosphorus, thus 1 molecule of amylopectin is synthesized. Then by the action of phosphorylase, glucose radical comes to stick to the terminal of amylopectin in succession, thus forming starch grains (granules). The main pathway of transformation from sugar into starch has mainly been interpreted as the action of phosphorylase.

A small quantity of starch grains is found only in the limited part of an epicarp until about the fifth day after anthesis and fertilization. Afterwards the starch grains found in the epicarp are becoming increased in quantity and reach to a maximum on the 6th or 7th day after anthesis and fertilization. After that time the starch grains show a decreasing trend and after the opening of the yellow-ripening stage, little or no starch grains come to be found. Starch grains come to be found in the endosperm from about the 4th day after anthesis and show a marked increase from about the 6th day after anthesis, and from the 8th day onwards a rapid increase in the starch grain accumulation is observed. The starch grain accumulation proceeds from the inner part of an endosperm to the outside. On and after the 20th day after anthesis, the rate of starch grain accumulation per day begins to decrease, and it falls down to a very small increment per day on and after the 30th day after anthesis.

Taken a seed as a whole, sugars are observed from the time immediately after anthesis, and show an increasing trend as time goes on, reaching a maximum amount at about the milk ripe stage. Afterwards they show a marked decrease.

2. Inorganic phosphorus

The equilibrium of the following reaction, by which the starch is synthesized,

$$\text{D-glucose-1-phosphate} \rightleftarrows \text{Starch} + \text{Inorganic phosphate}$$

is regulated by the concentration of glucose-1-phosphate and the concentration of inorganic phosphorus. In order to have a reaction

$$\text{D-glucose-1-phosphate} \rightarrow \text{Starch+Phosphate},$$

the concentration of inorganic phosphorus must be low. For this reason, the inorganic phosphorus evolved from this reaction must be removed from the site of starch synthesis or inactivated. Phosphorus-content in the endosperm immediately after fertilization is high, but it shows a decrease with the progress in the starch formation. Immediately after the anthesis, though the phosphorus-content is high in the various parts of a seed, it shows a decrease as time goes on. At the beginning of the yellow-ripening stage, it decreases to a very small quantity in every part of a seed, except aleuron layer and embryo. In this case, the starch formation in the endosperm proceeds from the central part to the periphery, while inorganic phosphorus seems to begin decreasing from the central part of the endosperm and then to proceed to the periphery. At the beginning of the yellow-ripening stage, little or no inorganic phosphorus is found in the central part of the endosperm, but some quantity remains still in the periphery, and none remains after the yellow-ripening stage. On the contrary, in the aleuron layer or embryo containing a small quantity of starch, inorganic phosphorus eliminated from the starch formation reactions accumulates according as the ripening proceeds, and it is accumulated in the form of "phytin" which is the most efficient storage form of phosphorus.

3. *Nitrogen*

Nitrogen in the endosperm being kept at about a constant concentration from the time immediately after fertilization to ripening will indicates that the changes in the amount of nitrogen in ripening seeds are in parallel to that of the carbohydrates. Most of nitrogen is reserved in the form of protein in the embryo and endosperm.

2. Growth of Seeds

1. Growth of embryo

In most cases, the fertilization of a spikelet is completed in 2–4 hours after flowering. The egg nucleus is divided into 2–4 by fission. Afterwards, the cell division is repeated increasingly and the egg nucleus becomes greater in size. On the second day after anthesis, an egg nucleus develops into an elliptical spherical shape. Six cells can be found on the longer axis and four ones on the shorter axis. On the fourth day after anthesis, primary vascular bundle is found for the first time. On the fifth day after anthesis, the initial of the radicle, the initial of the plumule, and the vascular bundle system come to be observed somewhat clearly. On the seventh day after anthesis, the development of the respective organs of a young plant is nearly completed and the embryo is formed. In some ten days after anthesis, the embryo formation is perfectly completed.

2. Growth of endosperm

It is generally accepted that the fission of an endosperm nucleus begins at the earlier time than the fission of an egg nucleus. In six hours after anthesis, four endosperm nuclei can be found. In 24 hours after anthesis, some 50 endosperm nuclei are seen scattering at regular intervals in the inner wall of an embryo sac. In 46 hours after anthesis, it shows a rapid increase in the number of endosperm nuclei, but cell membrane is not formed as yet, but the endosperm nuclei are covered with protoplasts only. On the third day after anthesis, a cell membrane is formed. By the fourth day after anthesis, the endosperm cells are almost completed and an ovary becomes filled with them. By the fifth day after anthesis, starch grains are found for the first time. Some ten days after, they show a rapid increase in the starch accumulation. Besides, on the fourth day when the ovary has been filled with endosperm cells, the outermost layer (i.e., the cell layer formed for the first time from the endosperm nuclei) is transformed gradually into aleurone layer. Afterwards with the increase in the starch accumulation, the endosperm grows larger and heavier, thus becoming increasingly ripened.

3. *Growth of rice grains*

On the first day after anthesis, an ovary shows an increase in its length and begins to show a leaning towards the palea, thus growing larger along the palea. By the sixth or seventh day, the tip of the ovary reaches the peak of the glumes. Afterwards, it becomes increasingly thicker and plumper. About seven days after anthesis, the length of the ovary reaches a maximum and the width reaches nearly a maximum about nine days after anthesis. Afterwards it shows some increase in width, thus reaching a maximum about 24 days after anthesis. The thickness of the ovary reaches nearly a maximum 12 days after anthesis. Afterwards it shows some increase, reaching a maximum about 28 days after anthesis. The fresh weight reaches a maximum about 20–30 days after anthesis, and the dry weight reaches a maximum on 20–50 days after anthesis. The increase in grain weight varies widely with rice varieties, environmental conditions, and position of grains on a panicle. For instance, in the case of a short-term variety which passes the ripening stage at a high temperature, it shows a rapid increase in the grain weight, while the increase in the grain weight in the case of a long-term variety is slow. The development of the vascular bundle from a panicle axis (rachis) to a rachis-branch and from the rachis-branch to a grain varies markedly according to the position in a panicle. In the case of a strong spikelet with well-developed vascular bundle, the growth of rice grains is rapid, while in the case of a poor spikelet with poor vascular bundle the growth of rice grain is delayed. The rapidity of the growth of rice grains according to the position in a panicle coincides well with the order of sequence in flowering.

3. Translocation of Substances with the Progress in Ripening

1. Carbohydrates

About 10–40 per cent of the total starch accumulated in a seed is derived from the starch stored in the leaf sheath and culm before heading, and the remaining 60–90 per cent is derived from the photosynthate after heading. The above ratio varies with such factors as spacing and arrangement of stand, plant components at the heading stage, and climatic conditions at the ripening stage.

Generally speaking, however, when the carbon assimilation in rice plant is affected favorably by the environmental conditions at the ripening period, the rate of dependence upon the carbohydrates reserved before heading is low, while when the carbohydrates reserved before heading are markedly great in quantity and when the carbon assimilation at the ripening period is low, the rate of dependence upon the starch reserved before heading becomes high. The starch stored in the leaf sheath and culm before heading begins generally to translocate rapidly to a panicle immediately after the completion of flowering and fertilization. Most of the stored starch is translocated into seeds during the period from 10 to 20 days after heading. Sugars assimilated in the leaf blade after heading are immediately translocated to the panicle. At the milk-ripe stage, the photosynthates of the first leaf (top leaf, or flag leaf), second leaf, and third leaf translocate into seeds in 15–24 hours, 24–72 hours, and 48 hours or more, respectively. Namely, the upper the position of a leaf, the higher the rate of utilization of photosynthate. The starches stored before heading in the stems and leaves are transformed into sucrose, blucose, fructose, and other sugars by the action of the enzymes such as phosphorylase, amylase, invertase, or maltase, while the carbohydrates produced by photosynthesis after heading are transformed into sucrose, glucose, and other sugars. These sugars are transported to the panicle through the phloem. (Not only sugars are transported through the phloem but they outflow to outside of the phloem in the course of their translocation, and sometimes they are transported through the xylem.) *In the liquid translocating* from stems and leaves to the panicle is not included any phosphorus ester, such as glucose-1-phosphate. As the reactions, "sugar → glucose-1-phosphate → starch", occur in a seed, a fairly great amount of energy is required in the seeds. *For the starch formation in the panicle, a great amount of* energy evolved in the process of respiration is required. The activity of these various enzymes participating in the translocation of sugars as well as in the starch formation is influenced depending upon the temperature. For these *reasons,* the translocation of carbohydrates from the stems and leaves are greatly affected by the air temperature, e.g., within the range of temperature of 17–29°C. The higher the temperature, the faster the translocation. However, the optimum temperature *for the accumulation of* carbohydrates in the seed varies according to the ability of seeds receptive of carbohydrates, the amount in the supply of carbohydrates, and the number of seeds (paddy). The driving force for the translocation of sugars to the *panicle is deemed to be due to* the difference in the osmotic concentration of the cells between the sugar supply sources (stems and leaves) and the sugar receiving organ (panicle), i.e., due to the sugar concentration head between the two. *Accordingly,* the sugar *translocation from* stems and leaves to the panicle reaches a peak at the time about 2–4 p.m. in the course of a day. The translocation in the daytime is observed to reach 2–4 times greater than that in the night. During the ripening period, the *translocation of sugars into* seeds shows it maximum at the milk-ripe stage, at which the increase of seed dry matter is also at its maximum (at this stage the activity of enzymes such as phosphorylase becomes highest). However, from 30 days after heading onwards the dry *matter increase* in the seed becomes slowed down and when the amount of carbohydrate production comes to exceed the amount of carbohydrates translocated to the panicle, starch comes to be accumlated again in the stems and leaves.

2. Nitrogen

During the period from the time immediately after fertilization to ripening, the nitrogen-content in the seeds remains almost constant. This indicates that the translocation of nitrogen from stems and leaves to the seed takes place in parallel with the sugar translocation. Most of translocating nitrogen is in the form of amino acids and amides. At the ripening period as the nitrogen supply from soils becomes extremely short, a great part of nitrogen in the seed is the nitrogen translocated from the stems and leaves, particularly from the leaf blades and sheaths. In the case of the leaf blades, the nitrogen-content shows a particularly rapid decrease according as the ripening proceeds, while in culms and roots, little or no decrease in nitrogen-content is observed.

3. Phosphorus

The behavior of phosphorus during the ripening period is nearly similar to that of nitrogen, but the translocation of phosphorus from the straws (stems and leaves) to the panicle is particularly marked.

4. Potassium

The amount of potassium translocated from the stems and leaves to the panicle is extremely small, as compared with the cases of nitrogen and phosphorus. Potassium-content in the respective parts of stems and leaves (excluding culms) shows a decrease according as the ripening proceeds. Contrary to the fact that nitrogen and phosphorus content in the straw decreases due to the translocation to the panicle, the decrease in potassium content in the straw is mostly due to the leaching loss from the dead part.

5. Silicate

In contrast to nitrogen or phosphorus, the translocation of silicate from the stems and leaves to the panicle according to the progress in ripening is not so active. Silicate-content in the stems and leaves remains almost unchanged.

As stated above, various components in the stems and leaves translocate to the panicle according as the ripening proceeds. As a result, photosynthesis, respiration, and other physiological functions become declined and the aging is progressing increasingly. In view of this, in order to supplement the decreased nitrogen in the leaf blades, nitrogenous fertilizer is applied again at the heading stage. In doing so, the decrease in the rate of carbon assimilation can be checked to some extent.

4. Percentage of Ripened Grains

"Percentage of ripened grains" is figures indicating the ratio between the total number of spikelets produced of a hill and the number of kernels (perfect brown rice) obtained. Spikelets which do not yield brown rice are: non-fertilized paddy caused by the damage of reproductive organs; non-ripened paddy caused by the suspension of endosperm growth after fertilization; and abortive kernel with under-developed endosperm. A close relationship is found between the extent of endosperm growth and the specific gravity of a paddy. A grain of 1.06 or more in specific gravity (non-glutinous rice) and 1.02 or more (glutinous rice) can be qualified for perfect brown rice.

1. Non-fertilized grains

Non-fertilized grain occurs by the troubles in the reproductive organs due to the cool or drought damage and sunlight shortage during the period from the spikelet initiation stage to the heading stage centering around the stage of pollen-mother-cell reduction division, as well as due to the bad weather at anthesis. Without these damages the rate of non-fertilized grains is considered as low as some five per cent.

2. Abortive kernels

Although there are many factors in the occurrence of abortive kernels, the balance between the number of spikelets produced per hill (per unit area) and the quantity of starch production per hill (per unit area) as well as the rate of translocation of carbohydrates are regarded as the contributing factors. Particularly, the former is more influential in causing the abortive kernels. Namely, the number of abortive kernels shows a decrease according as the supply of carbohydrates per spikelet increases.

3. Optimum number of spikelets

In contrast to the amount of starch per hill (per unit area) which has been produced during the plant growth period, there exists the optimum number of spikelets per hill (per unit area), with which a maximum yield of perfect brown rice is obtained. This is called "the optimum number of spikelets."

However, the optimum number of spikelets does not always indicate a maximum percentage of ripened grains. When the number of spikelets is less than the optimum number of spikelets, the percentage of ripened grains is, in most cases, high, but as a great amount of starch remains in the stems and leaves vainly, the rice yield shows

- Non-ripened grains
  - (1) Non-fertilized grains
  - (2) Imperfectly ripened grains caused by the interruption of endosperm growth after fertilizing
    - (i) Before heading
      - (a) *Chemical composition of a rice plant*
      - (b) Physical structure of a rice plant
      - (c) Number of spikelets
    - (ii) After heading
      - Apparent photosynthetic activity
        - (a) Photosynthetic activity
        - (b) Respiratory activity
      - (c) Translocation rate of substances
      - (d) Duration of activity of grains for receiving the translocated substances

a decrease. On the contrary, when the number of spikelets exceeds the optimum number of spikelets, abortive kernels show a marked increase in number and the rice yield decreases, thus bringing about an absurd result that "he succeeded in growing rice plants, but failed in producing rice." This is an important point in rice culture.

V. PHYSIOLOGICAL INJURY

1. *Akiochi* Disease of Rice Plants

Akiochi (literally means "Autumn-decline" in English) indicates a special feature of the rice plant growth. Namely, "rice plants grow vigorously and healthily in the vegetative growth period (former plant growth stage), but the plant growth is becoming increasingly poorer in the reproductive (or generative) growth period (latter plant growth stage). From around heading period, the lower plant leaves are becoming dead, and stems, leaves or panicles are stained, thus impairing to a serious extent their good looks and showing a sharp decrease from the expected rice yield".

Paddy field soils suffering frequently from *Akiochi* are divided into two types: (i) degraded paddy field soils observed in well-drained sandy field; and (ii) paddy field soils abundant in organic matter found in ill-drained (wet) paddy fields.

In the case of the former, due to the lack of active iron in the soil, hydrogen sulfide is produced and root-rot tends to occur. Plant roots in ordinary paddy fields are reddish-brown in color, while those in the degraded paddy fields turn pale-reddish-brown or whitish color and with the presence of hydrogen sulfide the plant root will turn blackish or pale-blackish color.

In the case of ill-drained paddy field soils abundant in organic matter, owing to the decomposition of organic matter (humus) in midsummer season, the soils will become deficient in oxygen and owing to the formation of harmful substances (e.g., organic acid, ferrous iron, hydrogen sulfide, etc.), root-rot will occur.

In the paddy fields of excessive presence of organic matter, hydrogen sulfide is formed despite the abundance in ferrous iron in the soil. For this reason, roots have reddish-brown color at first, but they turn into blackish color and will become rotten after hydrogen sulfide is produced.

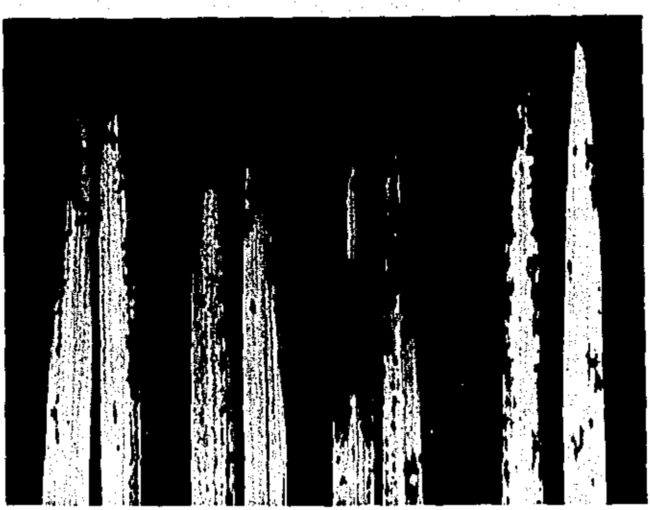
In either case of the above two types of paddy field soils, *Helminthosporium* leaf spot will occur almost without exception. Upon this, the occurrence of this disease has been regarded as an indicator of *Akiochi* occurrence.

1. *Inorganic nutrient in relation to Akiochi*

(i) Deficiency in potassium, silica, manganese, and magnesium in relation to *Akiochi*: Rich plants grown in the degraded paddy fields of *Akiochi* solis are lacking in potassium, silica, manganese, magnesium, etc., as compared with the rice plants grown in ordinary paddy fields. In either case where the roots of rice plant grown by the solution culture method have become rotted by the addition of hydrogen sulfide to the culture solution, or where the plant roots are healthy owing to the aeration to the culture solution, if the culture solutions become deficient in silica, potassium, manganese, or magnesium in and after the middle plant growth period, rice plants would become sensitive to *Helminthosporium* leaf spot (Photo. 3–3), and the lower leaves would begin to wither and rice plants would become miserable just like those in *Akiochi* paddy fields (Photo. 3–4). It is therefore evident that *Akiochi* is caused by the deficiency in inorganic nutrients. In practice, the application of inorganic nutrients to *Akiochi* paddy fields has often been proved fairly effective against *Akiochi*. *Akiochi* caused by the deficiency in inorganic nutrients occurs markedly according as the amount of nitrogenous fertilizer application becomes larger. This fact indicates that the quantitative balance among the constituents in the K_2O/N rice plant is of very importance. Particularly,

Much H_2S Little H_2S No H_2S added

Photo. 3-5. Rice Plant Growth affected by H_2S



Leaves affected by *Akagare* Potash-deficient leaves of the plant grown in potash-lacking solution

Photo. 3-6. Symptoms of Type 1 *Akagare* Disease

if K_2O/N ratio and SiO_2/N ratio become lower, the deficiency in potassium or silica would be aggravated and the occurrence of *Akiochi* and *Helminthosporium* leaf spot would be accelerated further. Therefore in those days when the amount of nitrogenous fertilizer applied was less, less *Akiochi* occurrence had been observed, but with the increase in the amount of nitrogenous fertilizer application, the occurrence of *Akiochi* has become frequent. *Akiochi* occurrence is considered to have a close bearing upon the above reasons.

(ii) Nitrogen-deficiency in relation to *Akiochi*: When rice plants are grown under the nitrogen-deficient condition throughout the whole plant growth period, no *Akiochi* will occur, but when rice plants are grown with excess of nitrogen at the early growth stage, and then placed under the nitrogen-deficient condition in the latter plant growth period, *Akiochi* will occur (Table 3-11). *Akiochi* due to this reason is observed frequently in the case of degraded paddy fields consisting of sandy soils. Since sandy soils are low in nutri-

Table 3-11. Effects of Nitrogen Application Methods on Rice Plant Growth and Rice Yield.

(BABA, 1958)

Plot		*Weight of panicles per hill (A)*	*Weight of straw per hill (B)*	*(A/B)*	*Degree of root-rot*	*Number of survival leaves (Oct. 2)*	*Number of lesions of Helmin. leaf spot*	*Panicles affected by neck-rot*
		g	g					%
N	A	55.2	80.1	0.69	0.8	3.3	0.26	10.5
	B	49.5	94.9	0.52	1.5	3.0	0.33	13.7
2N	A	57.8	90.5	0.64	0.8	3.8	0.44	16.7
	B	48.5	103.8	0.47	3.0	3.6	0.53	23.0

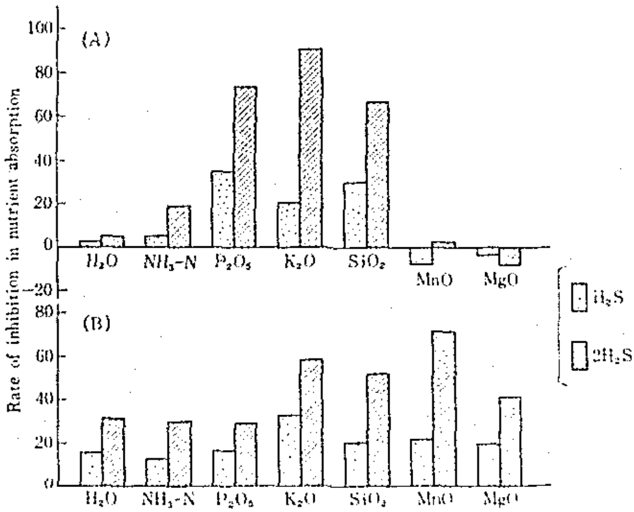
Notes: 1. Water cultural test.
2. A: Normal application of nitrogen.
B: Lacking in nitrogen after the young-panicle formation, though excessive nitrogen has been applied at the tillering stage.

ent-holding capacity, when nitrogenous fertilizer like ammonia sulfate is applied, nitrogen will be absorbed much at a time and the plant growth at the earlier growth stage will be hastened greatly. But the plant will be exposed to the shortage of nitrogen in the latter period. It is therefore necessary to supply good-quality clay or to apply composts or stable manures to such paddy fields. In the case of quick-acting nitrogenous fertilizers, the split application is preferable to the application at a time as basic fertilizers.

2. *Plant root injury and Akiochi*

(i) Root-rot caused by hydrogen sulfide and inhibition of nutrient absorption: In the case of degraded paddy field soils, due to the deficiency in active iron in the top soil, hydrogen sulfide is formed, thus causing root-rot and *Akiochi*. When active iron is contained in the top soil, hydrogen sulfide, which is produced by the reduction of sulfate in the soil under water-logged condition of paddy field, will rapidly be changed to ferrous sulfide and precipitated. As a result, hydrogen sulfide becomes harmless to the plant roots. However, when active iron in the top soil is deficient, the hydrogen sulfide will remain unchanged and causes root-rot. If hydrogen sulfide is added to the culture solution in the solution culture experiment, the rice plant growth would become poor and root-rot would occur (Photo. 3-5). The nutrient absorption would also be inhibited (Fig. 3-34). As indicated in Fig. 3-34 (A), the absorption of K_2O and P_2O_5 is inhibited most markedly and that of CaO and MgO most slightly. The inhibition of absorption of various elements is in the order; $K_2O \cdot P_2O_5 > SiO_2 > NH_3\text{-}N \cdot MnO > H_2O > CaO \cdot MgO$. However, when hydrogen sulfide is added in succession to the culture solution, the inhibition of P_2O_5 absorption would be very slight and that of MnO absorption would become marked in the latter plant growth stage, as seen in Fig. 3-34 (B). As a result, the ratios of K_2O/N, SiO_2/N, and MnO/FeO in nutrient absorption would become lower and the plant growth would be affected adversely and the plants would become highly sensible to *Helminthosporium* leaf spot and *Akiochi*. When root injury by the presence of hydrogen sulfide becomes great, the water absorption by the plant roots and the transpiration will decline. Consequently, the ascension and translocation of nutrients into each part of a plant is checked. K_2O/N ratio and SiO_2/N ratio in leaf blade will decrease, thus accelerating *Akiochi*. As described in the Section "Inorganic Nutrients", the energy required for the nutrient absorption by plant roots is supplied by the respiration of the cytochrome C oxidase system (cytochrome system, for

Fig. 3-34. Rate of Inhibition in Nutrient Absorption by Rice Plants Affected by H_2S Application
(Baba, 1955)



Note: (A) *Aug. 4-6, immediately after H_2S application*
(B) Aug. 27-30, after the continuous addition of H_2S

$$\text{Rate of inhibition in nutrient absorption} = \frac{\begin{pmatrix}\text{Absorption amount per} \\ \text{gram in dry-weight of} \\ \text{the plant in } -H_2S \text{ plot}\end{pmatrix} - \begin{pmatrix}\text{Absorption amount per} \\ \text{gram in dry-weight of} \\ \text{the plant in } H_2S \text{ plot}\end{pmatrix}}{\begin{pmatrix}\text{Absorption amount per gram in dry-} \\ \text{weight of the plant in } -H_2S \text{ plot}\end{pmatrix}} \times 100$$

short). Hydrogen sulfide is a strong respiratory inhibitor and it inhibits the activity of cytochrome oxidase system of rice roots.

(ii) Effects of hydrogen sulfide on the nitrogen and carbohydrate metabolism in rice plants: Soluble nitrogen in rice plants and the ratio of soluble nitrogen to protein nitrogen are increased by the hydrogen sulfide application, and the reducing sugar and nonreducing sugar contents are also increased, while the starch content is decreased. Namely, it indicates that protein synthesis and carbohydrate metabolism have been affected by the action of hydrogen sulfide. Such abnormal change in the carbohydrate and nitrogen metabolism is considered to have taken place due to the lack of the nutrients in the rice plant owing to the inhibited absorption of potassium, silica, and magnesium by plants, but such abnormal change can also be ascribed to the fact that the normal aerobic respiration of rice plants has been affected adversely, directly by the intrusion of hydrogen sulfide into the tops.

(iii) Root-rot caused by the action of organic acid and excessive presence of ferrous iron: In the case of ill-drained paddy field soils abundant in organic matter (humus), there are many cases where, in addition to hydrogen sulfide, toxic organic acids (e.g., acetic acid, butyric acid, etc.) may arise owing to the decomposition of organic matter. The plant roots will be affected, root-rot will be caused, and the nutrient absorption by plant roots will be inhibited by the action of such organic acids. In these respects, their evil effects are similar to those of hydrogen sulfide. Most of the ill-drained paddy field soils abundant in humus, unlike the degraded paddy field soils lacking in iron content, contain water soluble iron (Fe^{++}) rather excessively according to the progress in the decomposition of organic matter (humus). Owing to the presence of a great quantity of Fe^{++}, the root growth is affected seriously, and since the normal respiration of the cytochrome system of the plant roots is checked, the absorption of nutrients (K_2O, P_2O_5, SiO_2, MnO, etc.) is considered to be inhibited by the action of Fe^{++}.

3. Effects of climatic conditions on Akiochi

It is generally accepted that *Akiochi* occurrence is caused not only by soil conditions but also by climatic conditions. For instance, *Akiochi* occurrence is accelerated by such factors as short range of daytime-night fluctuation of air-temperature, particularly, high temperature at night; and high water- and soil-temperatures in the midsummer months.

(i) Effects of water- and soil-temperatures on *Akiochi*: About 30–32°C is the generally accepted optimum temperature of paddy field water. When the water-temperature is as high as 35–37°C, the plant root development, particularly, the new root formation and elongation will become poor.

When the water-temperature is high, the balance between straw weight and panicle weight will become unfavorable and the rice yield will decrease (Table 3-12). This may be partly due to the decline in the absorption of nutrients (particularly of potassium and silica) owing to the high water-temperature, as in the case where H_2S exists in the culture solutions.

Production of hydrogen sulfide or organic acids in the soil will be increased by high water-temperature, and the invasion of these substances into the tops will become increased. With high water-temperature, content of protein-nitrogen or starch in the rice plant is decreased. It is therefore considered that the normal aerobic respiration of the

Table 3-12. Effects of High Water-Temperature on the Rice Plant Growth and *Helminthosporium* Leaf Spot

(BABA, 1955)

Plot	*Panicle weight per hill (A)*	*Straw weight per hill (B)*	(*A*/*B*)	*Number of lesions of Helmint. leaf spot*
Control plot (28°C)	25.4 g	23.6 g	1.01	35.2
High temperature plot (35°C)	23.2	25.4	0.96	39.2

plant roots is inhibited owing to the high water- and soil-temperatures.

(ii) Effects of air-temperature at night on Akiochi: When the night-temperature during the one month after heading is high, such effects can be observed as given in Table 3-13, i.e., hastening of the maturity, decrease in 1,000 grain weight, decrease in panicle weight per hill, decrease in ratio of per-hill panicle weight to per-hill straw weight, decrease in K_2O, SiO_2, and MnO content in stems and leaves, and the increased occurrence of *Helminthosporium* leaf spot. It is considered that owing to the high night-temperature the consumption of carbohydrate will become increased by the ac-

Table 3-13. Effects of Night-Temperature on Paddy Rice Plant Growth, Rice Yield, and Nutrient Contents

(BABA, 1952)

Plot	*Ripening date*	*Per-hill panicle weight (A)*	*Per-hill straw weight (B)*	*(A/B)*	*Weight of 1,000 grains*	*Number of lesions of Helmint. leaf spot*
		g	g		g	
Control (28°C)	Oct. 25	47.0	54.7	0.86	21.09	34.0
High night-temperature (35°C)	Oct. 18	43.5	56.9	0.76	18.87	62.6

(Continued)

Plot	*Contents of nutirients in dry weight of plant*				
	N	*P_2O_5*	*K_2O*	*SiO_2*	*MnO*
	%	%	%	%	%
Control (28°C)	0.444	0.274	1.58	3.33	0.046
High night-temperature (35°C)	0.451	0.267	1.32	3.18	0.041

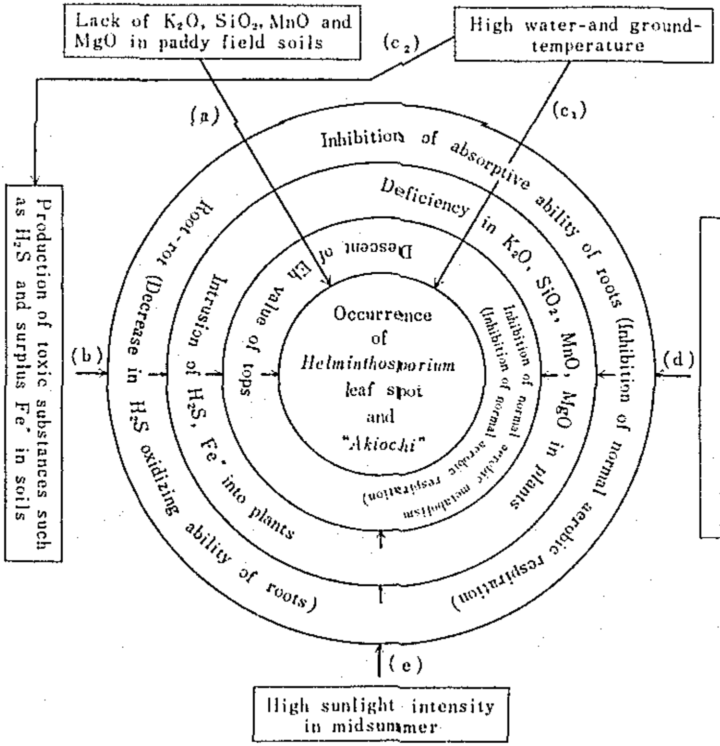
Note: Treatment was given one month after heading.

celeration of plant respiration, and the normal aerobic respiration of plant roots will be inhibited, thus resulting in the *Akiochi* occurrence and the decreased rice yield.

(iii) Effects of sunlight intensity on *Akiochi*: When the sunlight is shaded slightly at the time of high temperature in the midsummer, it will show an increase in the absorption of K_2O and SiO_2 by plant roots. The result suggests that high intensity of solar radiation exerts an unfavorable effect on the normal aerobic respiration of roots with a result of decreased absorption of potassium and silica.

Akiochi occurs markedly in years of high temperature

Fig. 3-35. A Diagram Illustrating the Process of Occurrence of *Helminthosporium* Leaf Spot and *Akiochi*



and high sunlight intensity. This can be ascribed partly to the interruption of the normal function of the plant roots due to the high sunlight intensity, as stated above.

4. Mechanism of Akiochi occurrence

Basing upon the above results and viewed from the general knowledge about *Akiochi*, *Akiochi* phenomenon can be illustrated by the diagram given in Fig. 3-35.

5. Resistance of rice varieties to Helminthosporium leaf spot, root-rot, Akiochi

From the results of varietal tests for rice plants grown in *Akiochi* soils, it has been evidenced that in the case of Japanese varieties, a close relationship is observed among *Helminthosporium* leaf spot resistance, root-rot resistance, and *Akiochi* resistance. In testing root-rot resistance, which has a close relation to the *Akiochi*-resistance, the two major methods are applicable: (i) testing by immersing the plant roots in H_2S solution (reference is made to the section for "Inorganic Nutrients"); and (ii) by measuring the reaction of sulfide and Fe^{--} which have invaded into the basal parts of the stems and leaves.

2. *Akagare* Disease of Rice Plants

1. Mechanism of Akagare disease occurrence

Akagare disease (literally means "red wilting" in English) is also known as "Stifle disease". When rice plants are affected by this disease, reddish brown spots appear on the lower leaves. This is a salient feature of *Akagare* disease. *Akagare* disease will usually occur about 2-3 weeks after transplanting. When rice plants are affected by *Akiochi* (literally means "Autumn-decline" in English), the rice plant growth becomes poorer in the latter growth period, while those affected by *Akagare* disease become poorer in the plant growth from the early growth period. Therefore, *Akagare* disease is also called "*Natsuochi*" (literally means "Summer-decline" in English).

Akagare disease is observed in the ill-drained lowland field soils and classified into two types:

Akagare disease Type 1: *This is observed in the ill-drained sandy paddy field soils or in the ill-drained muck or boggy paddy field soils and can be controlled by potassium* application. The leaf color turns dark green at first and then reddish-brown spots appear near the apexes of the lower leaves spreading gradually over the whole of the affected leaves, and affected leaves begin to wither up from the apexes (Photo. 3-6, by OKAMOTO, 1950).

Akagare disease Type 2: This is observed in the ill-drained muck or boggy paddy field soils. The color of the midribs and borders of them turns yellow at first and thereafter reddish-brown spots begin to appear on these parts and finally spread over the whole of the affected leaves (YAMAGUCHI and SHIRATORI, 1957; BABA and TAJIMA, 1961). The potassium application does not show so great effect, as compared with the case of Type 1 *Akagare* disease. It can not be controlled fully by the potassium application. In this Chapter, the causes for the occurrence and the mechanism of *Akagare* diseases will be described.

(1) *Akagare disease Type 1*

When paddy rice plants are grown in solution cultures without application of potassium, reddish-brown spots will appear on the lower leaves. This symptoms of potassium-deficiency will become marked by the heavy application of nitrogen. The symptoms will become aggravated according to the decrease in K_2O/N ratio.

The occurrence of Type 1 *Akagare* disease is caused by nonpotassium application. The symptoms are similar to those in the case of potassium-deficiency. Type 1 *Akagare* disease is aggravated by those factors such as (a) heavy application of nitrogen; (b) serious soil reduction (oxygen-deficiency) resulting from the starch application; (c) addition of harmful organic acids (butyric acid, acetic acid, etc.) or hydrogen sulphide (H_2S) to the soil; (d) deep submergence; and (e) lower or higher water- and soil-temperatures than the optimum temperatures (30–32°C) (Fig. 3–36). When K_2O/N ratio in the plant decreases to about 0.5 or under, reddish-brown spots will appear on the leaves and reddish-brown colored leaves increase markedly according to the lowering of K_2O/N ratio (Fig. 3–37). From these facts, Type 1 *Akagare* disease is considered to be a sort of potassium-deficiency disease.

In general, for the nutrient absorption by roots, the aerobic respiration (particularly, respiration by cytochrome system) is required. When the aerobic respiration in roots is inhibited due to the lack of oxygen or to the presence of harmful organic acids (butyric acid or acetic acid) or H_2S in the culture solutions, the nutrient absorption, particu-

Fig. 3–36. Effects of Environmental Factors on the Occurrence of Type 1 *Akagare* Disease

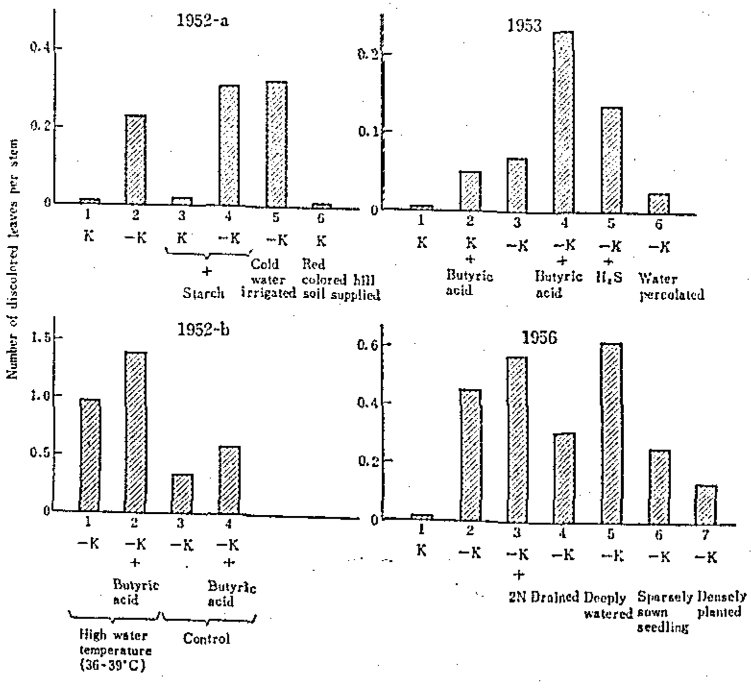
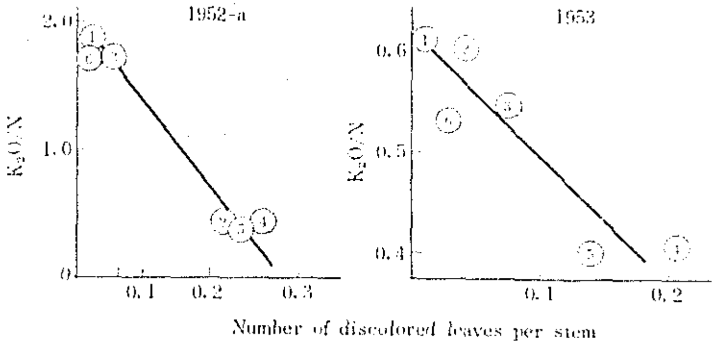


Fig. 3-37. Relationship between *Akagare* (Type 1) Occurrence and K_2O. N Ratio in Rice Plants



Note: Figures in circlets indicate plot Nos. in Fig. 3-36.

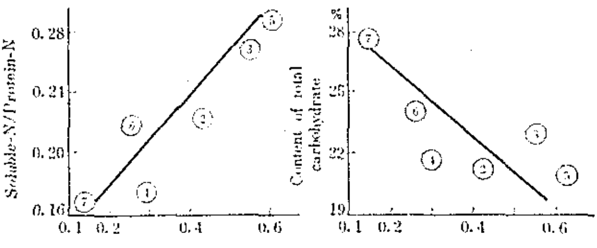
larly potassium absorption will considerably be inhibited (BABA, 1957).

The reason for the severe occurrence of *Akagare* disease due to the soil reduction (oxygen-deficiency) or due to the addition of butyric or acetic acid or H_2S to the soil, or due to too high or low water-temperature, is probably to be found in the fact that owing to the above-named factors the aerobic respiratory activity of the roots will be inhibited, and root-rot will occur, and the nutrient absorption (particularly, potassium absorption) will decrease considerably, thus lowering K_2O/N ratio in the plant.

In contrast to the above, the reasons for the decrease in occurrence of *Akagare* disease or for the control of it through the percolation (subsoil drainage) or the midsummer drainage (surface drainage) are probably be found in the fact that owing to the drainage the aerobic respiratory activity of the roots will be promoted and the potassium absorption will increase, thus raising K_2O/N ratio in the plant.

The disease, which occurred under the different cultural conditions, as stated above, was observed to become severe in parallel to the rise in the ratio of soluble-nitrogen to protein-nitrogen, and on the other hand, the disease is less severe in parallel to the increase in the total carbohydrate content

Fig. 3 – 38. Relationship between "*Akagare* (Type 1) Occurrence" and "Soluble-N/Protein-N and Total Carbohydrate Content"



Note: Figures in circlets indicate plot Nos. (1951) in Fig. 3 – 36.

or starch content (Fig. 3-38).

In the case of discolored leaves affected by *Akagare* disease (Type 1), the respiratory rate is markedly high, while the activity of cytochrome oxidase is slowed down (Table 3–14, A). This indicates that the respiratory activity of cytochrome system which produces a large amount of energy (i.e. highly efficient production of ATP) was decreased, and instead of this system the respiration of lower-efficient system, so to speak, "non-effective respiration", was increased.

Such changes in the respiration process are similar to the changes in the respiration process observed in the leaves of rice plants grown in solution cultures without application of potassium (Table 3–14, B). As a result, it is generally considered that in the case of potassium-deficiency in rice plants the respiration of cytochrome system shows a decrease, but the lower efficient respiration is increased vainly.

To sum up, in the case of rice plants affected by *Akagare* disease (Type 1), it is considered that with the decrease in the respiration of cytochrome system due to the potassium-deficiency in the rice plant, the protein synthesis from amino acids, which may require a large amount of energy is retarded, giving rise to high ratio of soluble-nitrogen to protein-nitrogen, and with the increase in the respiratory rate the consumption of carbohydrate will become greater and the

Table 3–14. Changes in Respiration and Enzyme Activity of Leaves Affected by *Akagare* Disease and Potassium-Deficiency

	*Respiration (O_2 uptake)**	*Cytochrome oxidase activity***	*Peroxidase activity****
A: *Akagare* disease Type 1			
Healthy leaves (+K)	611	565	65
Discolored leaves (−K)	800	437	114
B: Water cultures, without K_2O application			
Healthy leaves (+K)	1,824	442	27
Discolored leaves (−K)	2,389	290	86
C: *Akagare* disease Type 2			
Healthy leaves (+K)	530	360	35
Discolored leaves (−K)	684	161	71

Notes: 1. Prepared by;
A: BABA, TAKAHASHI and INADA, 1958
B: BABA and TAJIMA, 1959
C: BABA and TAJIMA, 1961

2. * Oxygen uptake: mm^3/hr
A and C: per gram in fresh weight
B: per gram in dry weight

** O_2 uptake per gram in fresh weight per hour

*** Guaiacol unit per gram in fresh weight

total carbohydrate content, particularly, starch content will show a decrease.

In case where seedlings grown at low seed rate are transplanted or seedlings are transplanted densely (many seedlings are planted in each hill), the occurrence of *Akagare* disease is less frequent (Fig. 3–36). This is considered to be ascribed to the following fact.

In general, the respiratory substrate required for the respiration in roots is translocated to the roots from the tops in the form of sucrose, but when the percentage for the total carbohydrate contained in the tops is high, it will show an increase in the amount of respiratory substrate transported from the tops to the roots. As a result, the physiological activities (such as respiratory activity, ability of nutrient absorption and oxidizing power) of roots will also become vigorous.

The seedlings grown at low seed rate possess a high total content of carbohydrate in the tops and owing to the large supply of respiratory substrate to the roots, the ability of the roots to absorb the nutrients (particularly potassium) will become higher and the roots will not readily be affected, thus *Akagare* occurrence will become less.

Then by what biochemical changes are the affected plant leaves discolored?

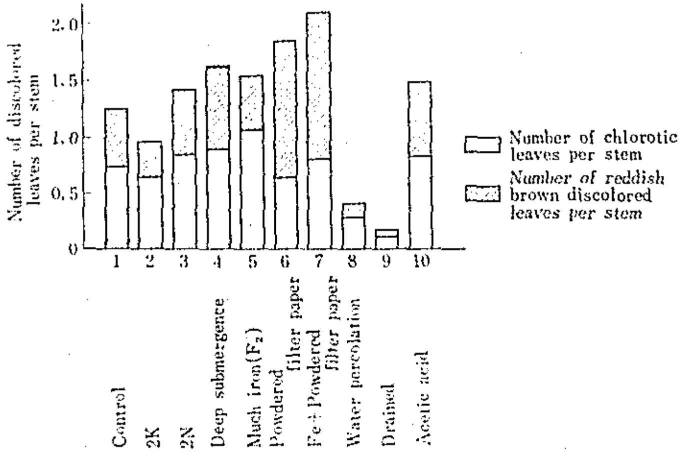
Discoloration of the tissues of plants affected by diseases or injuries has usually been ascribed to the formation of melanine-like substances owing to the oxidative polymerization of polyphenol compounds. NOGUCHI and SUGAWARA (1957) pointed out that the discoloration of plant leaves due to potassium-deficiency can be ascribed to the oxidation of polyphenol. Namely, either in case of potassium-deficiency or in case of *Akagare* (Type 1, peroxidase activity is promoted markedly in parallel with the decrease in the activity of cytochrome oxidase as well as with the increase in the respiratory rate (Table 3–14, A). Peroxidase is generally regarded as an enzyme that promotes oxidation of polyphenol into quinone under the presence of hydrogen peroxide (H_2O_2).

It is, therefore, assumed that, in the case of *Akagare* disease (Type 1), with the conversion of the activity of cytochrome system of high efficiency in energy production into that low in energy producing efficiency, the activity of peroxidase is promoted and consequently polyphenol compounds are oxidized into quinone. Thus, finally a reddish-brown colored substance is formed by the combination of quinone with amino acid (increased due to the inhibition of protein synthesis) and metallic elements (e.g., iron, etc.).

(2) *Akagare* Disease Type 2

The occurrence of *Akagare* disease Type 2 is forced by deep submergence or by the addition of butyric or acetic acid, or it is aggravated under the severe reductive condition of soils (oxygen-deficiency in the soil) resulting from the application of organic matter (such as starch or filter paper powder), as is the case with *Akagare* disease Type 1. *Akagare* disease Type 2 is aggravated also when the concentration of soluble ferrous iron in the soil has become considerably high as the result of heavy application of iron (Fig. 3-39). The occurrence of *Akagare* disease Type 2 is, as is the case with *Akagare* disease Type 1, alleviated by subsoil and surface soil drainage. Its occurrence can be partly controlled by the heavy application of potassium, but the effect is not so great as that of the case with Type 1 *Akagare* disease.

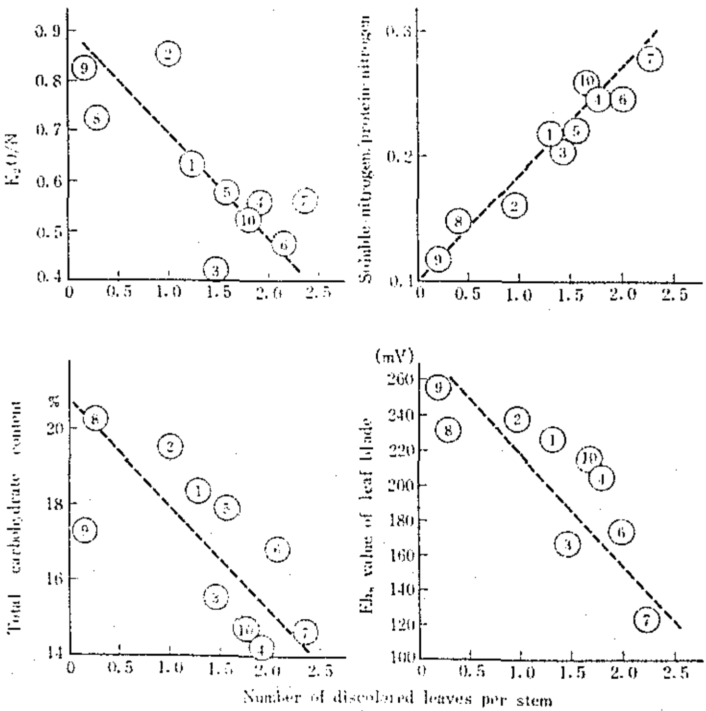
Fig. 3-39. Effects of Environmental Factors upon the Occurrence of *Akagare* Disease Type 2.



Type 2 *Akagare* disease sometimes occurs even when the ratio of K_2O/N in the plant is 0.8, and the relationship between K_2O/N ratio and *Akagare* occurrence is not so clear as in the case of Type 1 *Akagare* (Fig. 3-40).

With respect to the changes in the metabolism of rice plants, the close relationship is observed, as is the case with Type 1 *Akagare* disease, between "*Akagare* occurrence" and "the rise in the ratio of soluble-N to protein-N, the decrease in carbohydrate content and the lowering of oxidation-reduc-

Fig. 3-40. Relationship between Type 2 *Akagare* Occurrence and Metabolism of Rice Plants



Note: Figures in circles indicate Plot Nos. in Fig. 3-39.

tion potential of leaf tissue fluid (Eh)" (Fig. 3-40).

In the case of Type 2 *Akagare* disease also, with the discoloration of plant leaves, the respiratory rate will become high, but the activity of cytochrome oxidase will decrease and the peroxidase activity will increase to the contrary (Table 3-14, C). As a result, it is assumed that the increase in the respiration brings about the decrease in the total carbohydrate content, and with the decrease in the respiratory activity of cytochrome system the protein synthesis is inhibited, thus increasing the ratio of soluble-N to protein-N.

As stated above, there are many points of the similarity in the conditions of occurrence and the changes in the metabolism of the plants between Type 1 and Type 2 *Akagare* diseases. In the case of Type 2 *Akagare* disease, however, since the effect of potassium application is less than that in the case of Type 1 *Akagare* disease and the relationship between the occurrence and K_2O/N ratio is not so close, it is considered that potassium-deficiency is by no means the chief cause for the occurrence of Type 2 *Akagare* disease, though it may be one factor in promoting the occurrence.

When butyric or acetic acid is applied to the soil susceptible to Type 1 *Akagare* disease, yellowing of the midribs will be observed. When harmful organic acids (such as formic acid, lactic acid, etc.) are added to the culture solutions, the symptoms similar to those of Type 2 *Akagare* disease (e.g., yellowing of midribs or discoloration) will be observed (BABA and TAKAHASHI, 1954).

It is also reported that in case where butyric or acetic acid or H_2S is added to the culture solution, the yellowing can be observed (YAMAGUCHI and SHIRATORI, 1957).

In case where a great quantity of ferrous iron is added to the culture solutions, discoloration of plant leaves can also be observed. In this case, it will bring about the changes similar to those in the cases of Types 1 and 2 of *Akagare* diseases, e.g., the increased ratio of soluble-N to protein-N, the decreased total carbohydrate and starch contents, the increased respiratory rate, the decrease in the cytochrome oxidase activity, and the increase in the peroxidase activity (BABA and TAJIMA, 1960).

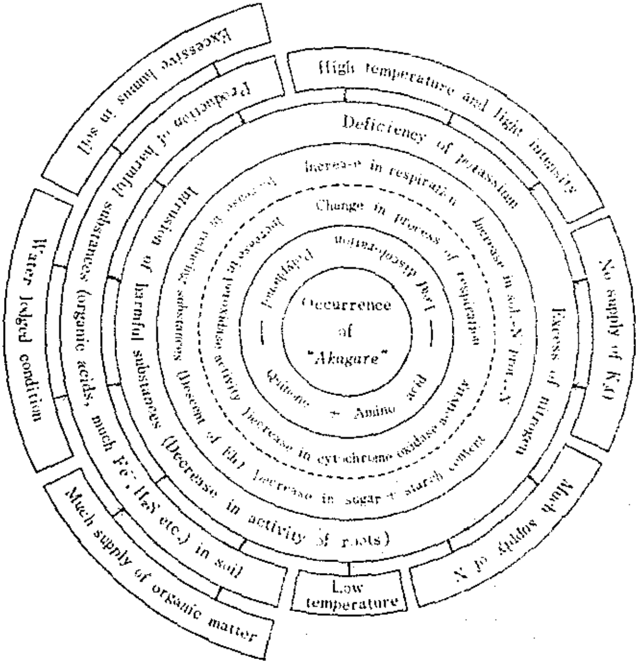
Also in case where H_2S is added to the culture solutions, it will bring about the increase in the ratio of soluble-N to protein-N and the decrease in the total carbohydrate content (BABA, 1957), associated with the increased respiration in plant leaves, the decreased cytochrome oxidase activity, and the increased peroxidase activity.

Based upon the above facts, it can be assumed that potassium absorption will be retarded by the inhibition to the aerobic respiration in roots by the presence of harmful organic acids which may be formed on account of severe reductive state of soils resulting from the decomposition of humus, and by the presence of excessive ferrous iron and H_2S (harmful substances). In addition to this, harmful acids and substances invade into the tops and reach the leaf blades, particularly midribs, thus inhibiting the chlorophyl formation and causing the yellowing. At the same time, the respiration and metabolism within the plant will become abnormal more markedly than the case of Type 1 *Akagare* disease, and the oxidative polymerization of polyphenol compounds is accelerated by following the same course as Type 1 *Akagare* disease, thus causing the discoloration. It is considered that when the total carbohydrate and starch contents in the plants are decreased due to the increasing respiratory rate, the supply of respiratory substrate to the roots will become decreased and the physiological activities of roots (e.g., aerobic respiration, oxidizing power of roots, etc.) will be reduced, thus promoting the invasion of harmful substances into the tops and accordingly bringing the disease severer.

In this case, due to the potassium-deficiency, the physiological activities of roots (e.g., oxidizing power) will be decreased and the invasion of harmful substances into the tops will be promoted, but since potassium-deficiency is by no means the chief cause for the occurrence of Type 2 *Akagare* disease, the occurrence could not be prevented by the heavy application of potassium alone.

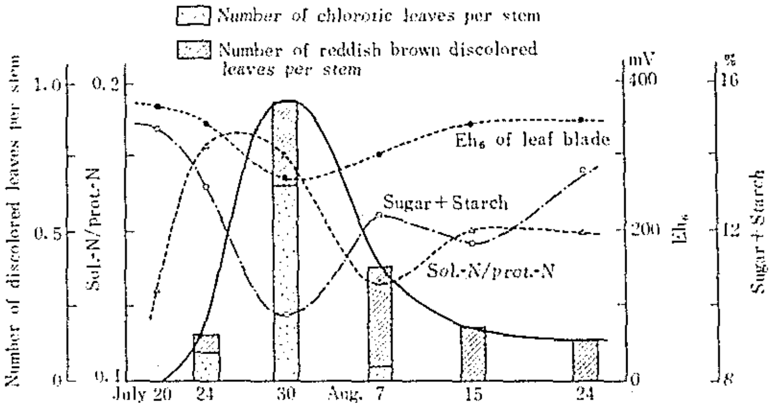
Fig. 3-41 indicates the mechanism of Types 1 and 2 *Akagare* diseases. As shown in Fig. 3-41, conditions such as non-application of potassium, heavy application of nitrogen, and too high or low temperatures cause the lowering of ratio of K_2O/N as well as the oxidizing power (physiological activity) of roots, thus causing the occurrence of *Akagare* disease. On the other hand, excessive presence of humus in soils, ill-drainage, heavy application of organic matter such as Chinese milk vetch, or intensive puddling practices will cause severe reductive state of soil (i.e., decrease in soil Eh value) and the formation of harmful substances, both bringing about the inhibition of potassium absorption by roots as well as the invasion of harmful substances to the tops, and aggravating the occurrence of *Akagare* disease.

Fig. 3-41. Diagram on the Process of Occurrence of *Akagare*



In general, both Type 1 and Type 2 *Akagare* diseases begin to occur two or three weeks after transplanting and reach a peak occurrence at the most active tillering stage in which high ratio of soluble-N to protein-N in the plants, decrease in the total carbohydrate and starch contents, and decrease in the oxidation-reduction potential of tissue fluid (Eh) take place most remarkably (Fig. 3-42). This trend in the occurrence can be explained as below. Owing to the vigorous development of new roots after transplant-

Fig. 3 – 42. Changes in Eh Value, Soluble-N, Protein-N, and Total Sugar+Starch Percentage at Different Growing Stages in Relation to the Occurrence of "*Akagare*"



ing, nitrogen absorption by roots becomes increased, while potassium absorption is inhibited markedly due to the severe reduction of soils through the decomposition of humus and partly due to the increasing production of harmful substances in soils. As a result, potassium absorption can not keep pace with the nitrogen absorption, thus lowering the ratio of K_2O/N, and increasing the invasion of harmful substances. Accordingly, in the tops of plant the respiratory activity of cytochrome system is slowed down, the protein synthesis is inhibited, and the ratio of soluble-N to protein-N is increased. Owing to the abnormally great increase in the respiratory rate, the total carbohydrate and starch contents are decreased. As a result of the decreased Eh value in the plant and the decreased supply of respiratory substrate to roots, harmful substances which invade into the tops will become increased, thus promoting markedly *Akagare* occurrence. After the opening of young panicle formation period, due to the factors such as decreased nitrogen absorption, lowered ratio of soluble-N to protein-N due to the slowed-down progress in the humus decomposition, increased contents of carbohydrate and starch, and increased Eh value in the plant, *Akagare* disease occurrence will become decreased.

In the case of early seasonal rice culture, the occurrence of *Akagare* disease is in general few, because the temperatures at the most active tillering stage (during which rice plants are most readily affected by *Akagare* disease) are still low. Consequently, nitrogen absorption is not much, the plant growth is not so vigorous, and the respiratory consumption of carbohydrates is also less. Under this condition the decrease in K_2O/N ratio, increase in the ratio of soluble-N to protein-N, or decrease in carbohydrate content will not become so marked.

2. *Akagare disease resistance, by rice varieties*

Akagare disease resistance varies widely according to the rice varieties.

Speaking generally, rice varieties resistant to Type 1 *Akagare* disease are resistant to Type 2 of the disease, and also less in the discoloration of leaves when grown in solution cultures without application of potassium.

Total carbohydrate or starch content in the rice varieties resistant to *Akagare* disease is higher than that in those susceptible to *Akagare* disease (Table 3–15).

Highly negative correlation is observed between total carbohydrate or starch content and *Akagare* disease occurrence, according to the rice varieties.

In recent years, it has become clear that the physiological activity of rice plant roots can be expressed by α-naphthylamine oxidizing activity or tetrazolium (TTC) reducing ability. α-naphthylamine oxidizing activity or tetrazolium reducing ability of roots of the rice varieties resistant to *Akagare* disease is greater than that of those susceptible to *Akagare* disease (Table 3–15).

Consequently, it is considered that rice varieties of high total carbohydrate content are resistant to *Akagare* disease of Types 1 and 2, because the supply of respiratory substrate

Table 3–15. Relationship between Resistance to *Akagare* Disease and Total Carbohydrate or Starch Content, by Rice Varieties

Rice variety	*Resistance to Akagare disease*	*Stems and leaf sheaths*		*Roots*	
		Total carbo-hydrate content	*Starch contents*	*α-naphthyl-amine oxidizing activity*	*TTC reducing ability*
		%	%	γ/dryweight /hr	γ/dry weight /hr
Norin No. 36	Susceptible	14.96	6.16	716	1,171
Norin No. 22	〃	13.92	6.60	705	1,058
Norin No. 29	Resistant	15.23	8.13	798	1,362
Norin No. 32	〃	18.51	9.89	925	1,449
Norin No. 37	〃	20.98	11.18	825	1,457

to roots is large in quantity at the most active tillering stage at which the carbohydrate content becomes lowest, and therefore the physiological activities of roots (e.g., aerobic respiration, potassium absorption or oxidizing activity of roots) can be kept vigorous, so that the inhibition to potassium absorption and the invasion of harmful substances are prevented.

VI. SPACING (DENSITY OF PLANTING)

1. Density Effect

Plant growth is affected greatly, qualitatively and quantitatively, by the planting density (this is known as "density effect"). Many research reports reveal that a simple quantitative relationship is always observed between the "average weight of individual plants" (w) constituting a plant population and the "planting density" (ρ). Namely, under the condition that all the cultural conditions except the planting density being equal, plants of the same variety are planted under the same conditions except the planting density, and plants in the respective density plots start to grow at the same time, the following relationship can be observed at a given time (t) of growth;

(1) $$\frac{1}{w}=A\rho+B$$

where

w: average weight of an individual plant.

ρ: planting density (number of plants per unit area).

A and B: constants which are determined as the function of t.

The formula (1) is known as a reciprocal equation of the density effect. It is an important formula which serves as a basis for the analytical theory of the density effect. In the formula (1), the relationship between $1/w$ and ρ expresses a straight line, and the value of A and B indicates the regression coefficient of the straight line and the height of the interception of the line to the $1/w$ axis, respectively. A fairly clear regularity is observed in the changes in the value of the constants. In general, the changes describe a curve as shown in Fig. 3-43. Namely, in case where $t=0$, the average weight of individual plant is equal to the average weight of a seed (or seedling), and always constant, irrespective of the density. As a result, $A=0$ in the formula. Therefore the formula (1) changes as follows:

(2) $$\frac{1}{w}=\frac{1}{w_0}=B$$

where w_0=average weight of a seed or a seedling. Consequently, B becomes equal to $1/w_0$. Subsequently, as time goes by, the value of A becomes rapidly great, and after it has reached the maximum value it will decrease little by little and when the plant growth has reached to the fullest extent, A will approach to a certain value, while B, starting from $1/w_0$, shows an exponential decrease and will approach to zero (Fig. 3-43).

The relation between w and ρ in formula (1) will readily be understood when w and ρ are plotted on a logarithmic scale. Log w—log ρ curve forms the curve as shown in Fig. 3-44. The curve has two asymptotes: one of a horizontal direction

Fig. 3–43. Change in Value of A and B of the Formula (1)

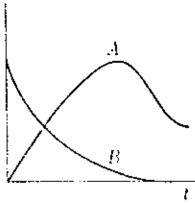
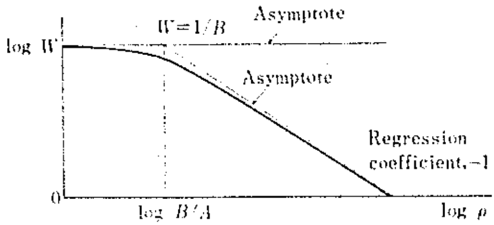


Fig. 3–44. Relationship between Average Weight of an Individual Plant (W) and Planting Density (ρ)



and another with a gradient, −1. The relationship between the asymptotes and A or B is shown in Fig. 3–44. Fig. 3–44 indicates that when the density is low enough, the individual weight is constant irrespective of the density and in non-competitive state, while when the density becomes higher than a certain level, the individual growth will become limited step by step. The shape of the curve is constant irrespective of the value of A and B. When the value of A becomes small, the curve moves horizontally in the left direction, and when the value of B becomes small the curve moves in the left-side upward direction along the inclined asymptote.

2. Density and Yield

In the formula (1), when $t \to \infty$, B becomes zero. As a result, when the plant grows to the fullest extent, the formula reads as follows:

$$(3) \qquad \frac{1}{w} = A\rho \qquad w\rho = \frac{1}{A} = \text{constant}.$$

This indicates that the average weight of individual plant is in inverse proportion to the density and that the whole yield of plants per unit area ($w\rho = y$) becomes constant, irrespective of the density. This is a state, in which the curve in Fig. 3–44 moved fully in the left-side upward direction and it can be regarded as a straight line with a gradient of 45°. If w in formula (1) is replaced by yield (y), formula (1) will be indicated as below:

$$(4) \qquad \frac{1}{y}=A+\frac{B}{\rho}.$$

When the relation in formula (4) is represented by logarithmic scale, it will assume a turned-out form of Fig. 3–44. This phenomenon is a very common one which can be observed generally in the wide range of density except an extremely high density, irrespective of the kinds of plant. This is known as the "law of constant final yield". However, in the case of low density which causes no mutual intervention among individuals, the law of constant yield does not exist. Also, it is doubtful whether or not this law is observed under so extremely high density as that the natural thinning of plants occurs.

3. Relationship between Density and Yield of a Part of Plant

The yield referred to above means the weight of the whole plant including the plant roots. When the yield of a specific organ (x) is considered, its relationship to the weight of the whole plant, i.e., x/w must be taken into consideration. The relative growth law is applicable fairly well to the law concerning the ratio of weight between the whole plant and a part of the plant. The relative growth law was originally discovered as to the animal growth. The formula reads as follows:

$$(5) \qquad \begin{cases} x=Hw^h \\ \log x=h \log w+\log H \quad (h \text{ and } H\text{: constants}). \end{cases}$$

Among the factors which may change x are atmospheric temperature, amount of fertilizer application, and other factors. Supposing that when all the conditions except ρ (planting density) are equal, formula (5) be obtained, since $w=w(\rho)$ and $x=x(\rho)$, when both sides of formula (5) are differentiated with respect to ρ, formula (6) can be obtained:

(6) $$\frac{1}{x}\cdot\frac{dx}{d\rho}=h\frac{1}{w}\ \frac{d}{d\rho}.$$

Namely, formulas (5) and (6) mean that the change in the weight of a part of the plant (which may take place according to an unit change in density) is in proportion to the rate of change in the weight of the whole plant. As a result, h (a proportional constant) has an important significance, and H is nothing but an integral constant.

From formula (5),

(5′) $$\frac{x}{w}=Hw^{h-1}$$

is derived.

The following changes can be observed in the relationship between x/w and w, according as $h>1$ or $h=1$ or $h<1$.

(i) When $h>1$, x/w becomes greater according as w becomes greater;

(ii) When $h=1$, x/w is constant, irrespective of w;

(iii) When $h<1$, x/w becomes smaller according as w becomes greater.

That is, in the case of an organ having $h>1$, the percentage of the organ to the weight of the whole plant will become higher when the whole plant grows larger, and in the case of $h<1$, the percentage will become lower.

This fact will exert a great effect on the relationship between the yield of a specific organ (a part of the plant) and the density. Supposing that the average weight of individual plant be in the state as described in formula (3), and that the relationship between the yield of a specific organ (x) and the average weight of the plant (w) be in the state which satisfies the relative growth law as prescribed in formula (5), yx (yield of x) can be derived from the following formula.

(7) $$yx=x\rho=\frac{H}{A^h}\rho^{1-h}.$$

In formula (7), as (H/A^h) is a constant, yx is in proportion to ρ^{1-h}. Accordingly, if $h>1$, yx (the yield of a part of the plant) becomes higher according as the planting density becomes lower, and if $h<1$, yx becomes increased according as the planting density becomes higher.

When the weight of whole plant, w, has not reached the state of a constant yield, it is apparent that $B \neq 0$. Therefore the formula reads as follows instead of formula (7):

$$\frac{1}{yx} = \frac{(A\rho+B)^h}{H\rho} \tag{8}$$

The relationship between yx and ρ (planting density) expressed by this formula forms a high degree hyperbola. The characteristics are not so simple as stated in formula (7). When $h=1$, yx-ρ curve coincides with that prescribed in formula (4). When $h<1$, the yield will increase together with the density, and in case where $h>1$, there exists an optimum density at which yx may become a maximum.

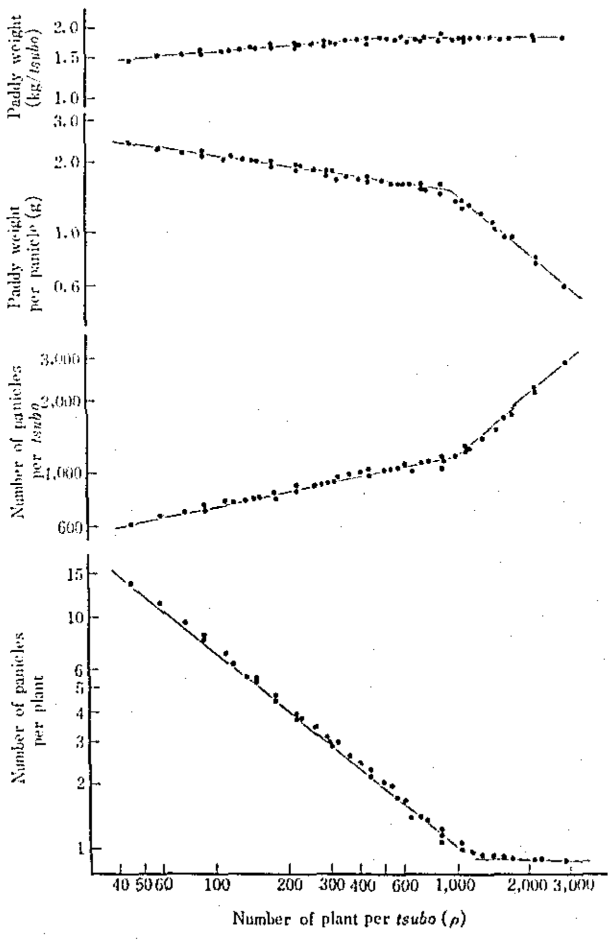
4. Spacing in Transplanting of Rice

The above law is the ecological theory which governs the density effect established by ecologists (KIRA et al.). The discussions will be tried below about the density effect on rice yield.

The density of transplanting of rice seedlings has been studied in various parts of the country from olden times. The study results reveal that, in case where rice plants have grown favorably, if the density exceeds a certain extent, the weight of dry matter of the tops is almost constant, irrespective of the density, and that the panicle weight (consequently the rice yield) can be regarded as constant. Several typical examples will be cited below.

Y. KONDO (1944) tested the density effect by transplanting the seedlings (Ou No. 191) at the rates of 45, 60, 75, 90, 112, and 150 hills per *tsubo* (3.3 m^2), with different number of seedlings varying from 1 to 20 seedlings in each hill. The result obtained shows clearly that the effect of planting density on grain yield depends on the ecological principle of

Fig. 3 – 45. Number of Panicles and Paddy Weight in Relation to Planting Density (♀)



Note: Log-log diagram drawn by YAMADA with the data of KONDO, 1944.

law of constant final yield, as illustrated in Figs. 3-45 and 3-46.

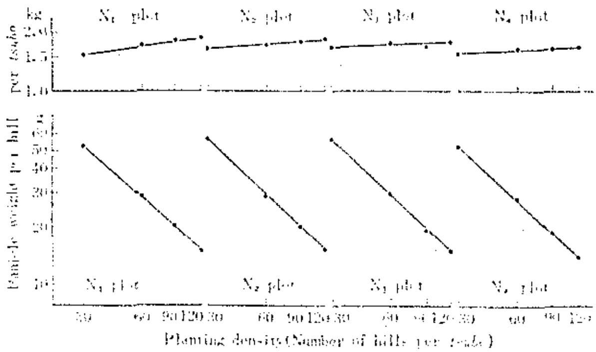
As Figs. 3-45 and 3-46 show, the panicle number per plant decreases according as the density becomes higher, and when the density becomes higher than the rate of 1,000 seedlings per 3.3 sq. meters (300 seedlings per sq. meter), the number of panicle becomes only one (i.e., the panicle of the main culm).

Accordingly, in the case of the density higher than 1,000 seedlings per *tsubo,* the panicle number per unit area increases in proportion to the increase in the density. On the other hand, the average paddy weight per panicle decreases also according to the increase in the density, but the decreasing rate is fairly smaller than that of the panicle number per plant. However, when the density exceeds the rate of 1,000 seedlings per *tsubo* and the panicle of the main culm alone remains, it shows no decrease in the panicle number. Therefore, the paddy weight per panicle shows a rapid decrease in inverse proportion to the increase in the density. The same can also be observed in the experiment by ANDO (1913) and others. It is reported that even in the case of high density at the rate of 4,000 seedlings per *tsubo,* heading is observed. This is an important characteristics of rice plant viewed from the ecological stand point. The fact that the law of the constant yield is observed in rice plants up to the density far higher than that of other plants can be ascribed to the above feature of rice plant.

In 1958, YAMADA made the experiment on the density effect using "Kinmaze" as material. Seedlings were transplanted at the rates of 30, 60, 90, and 120 hills per *tsubo.* The arrangement of hills was quadratic, and each hill consisted of three seedlings. In this experiment, four plots were set up according to the amount of nitrogenous fertilizer application: i.e., moderate plot (N_1), medium plot (N_2), somewhat heavy plot (N_3), and heavy plot (N_4). The results are as shown in Fig. 3-46.

In Fig. 3-46 also, the panicle weight per hill shows a

Fig. 3–46. Effect of Planting Density on Panicle Weight per Hill and per *tsubo* (Log-Log Diagram)
(YAMADA et al., 1961)



decrease regularly with an increasing density, expressing a lineal negative proportion to the density. Respecting the panicle weight per *tsubo* (3.3 sq. meters), on N_1 plot, the panicle weight in 120-hill plot shows about 17 per cent increase over that in 30-hill plot, and on N_2 plot, a 12 per cent increase, but on N_3 and N_4 plots, the panicle weight per unit area comes to show almost a constant value, irrespective of the planting density. Dry-matter weight of tops per *tsubo* shows the same trend as the trend in the panicle weight per *tsubo*. This fact indicates that in the case of N_1 or N_2 plot plants require higher density for reaching the state of the constant yield because due to insufficient supply of fertilizers the plants can not attain the maximum growth which is allowed to them under the given spacing, and consequently the yield increases according to the increase in density. In contrast to this, in the cases of N_3 and N_4 plots, with the increased application of fertilizers the rice plants come to be able to utilize to full extent the space allowed and accordingly reach the state of constant yield. The panicle number per plant shows a decrease according to the increase in density, but the decrease not being in inverse proportion to the density, the panicle number per unit area increases according to the increase in planting density, as already shown in KONDO's experiment.

Next, in the case of density of transplanting of seedlings, the relationship between the number of hills per unit area and the number of seedlings per hill is of importance. The Hokkaido Agricultural Experiment Station (1954) has conducted the experiment in which the number of hills per unit area was fixed (50 hills per *tsubo*) but the number of seedlings per hill was varied from 1 to 24. The result indicated that the panicle number per unit area increased according to the increase in the number of seedlings per hill. While the yield showed an increase by 5 or 6 per cent for every additional seedling up to the density of three seedlings per hill, but in the case of planting more than three seedlings, the yield showed little or no increase. YAMADA (1958) made the experiment in which the total number of plants was fixed but they were planted with different spacing of hill. Namely, by planting 180 seedlings per *tsubo*, five plots were set up: 15-hill plot (12 seedlings per hill), 30-hill plot (6 seedlings per hill), 60-hill plot (3 seedlings per hill), 90-hill plot (2 seedlings per hill), and 180-hill plot (one seedling per hill). The result revealed that on 180-hill plot, dry-matter weight per plant was the greatest, showing a decreasing trend in the weight in proportion to the decrease in the number of hills per *tsubo*. Consequently, the dry-matter production per unit area became increased according to the increased number of hills per *tsubo*. Namely, it means that when it is same in the number of plants per unit area, the yield will increase in case where many number of hills made of a few seedlings are planted closely than in case where a few hills made of many seedlings are planted sparsely. However, this fact can be said when the density is relatively low, while the density exceeds a certain extent the yield, needless to say, becomes constant.

As can be understood from the fact described above, the yield per unit area can not be increased markedly by increasing the planting density alone. Though the panicle number per unit area can be increased by the close planting, but due to the close planting the weight per panicle decreases. As a result, when seedlings are planted at the density higher than the sufficient density, the yield will become constant. Moreover, the closer the planting density, the plants become the more susceptible to adverse effects of unfavorable climatic conditions, and will cause damage by lodging or sheath blight, thus resulting in the decreased yield in many instances. However, in case where plant growth is poor and the full use of the space cannot be made, due to low temperature or the lack of nutrient or water supply, the yield will show an increase according to the increased density. The reason for closer planting in cool parts in the country than in warm parts, a closer planting in the case of early seasonal cultivation than in the case of late seasonal cultivation, and a closer planting in infertile land than in fertile land, can be understood well in view of the principles stated above.

From the above discussions, the following important conclusions will be drawn.

(i) The ecological principle such as "the reciprocal law of density effect" and "the law of constant yield" is applicable well to the case of rice plants;

(ii) The relative growth coefficient of the grain weight to the total plant weight is possibly equal to one. Namely, the ratio of grain weight to the whole plant weight is constant, irrespective of planting density. Accordingly, the law of density effect concerning the total plant weight (formulas 1 and 4) can be applicable directly to the weight of rice grain.

CHAPTER 4

THEORY AND PRACTICE OF FERTILIZER APPLICATION

I. SOME PROPERTIES OF PADDY FIELD SOILS

1. Differentiation of Soil Profile and Chemical Changes in Inorganic and Organic Substances in Submerged Paddy Field Soils

Paddy fields are kept in the state of submergence from several centimeters to about 10 centimeters deep during the period lasting for about four months in the rice cultural season every year, and the four months are highest in atmospheric, water- and soil-temperatures. Accordingly, during the period the chemical and microbial actions take place outstandingly.

The surface layer of soils is interrupted from atmosphere by the submergence. On the other hand, in the case of paddy fields in level lands, the groundwater level is generally elevated by the supply of the water percolated from paddy fields. As a result, the soil layer as a whole is brought under the state completely interrupted from atmosphere. Very small is the amount of oxygen supplied by the percolation of irrigation water. Even if supposed that the percolation occurs at the rate of 30 millimeters per 24 hours for four months, the supply of oxygen would be so small in amount that the amount of oxygen would be used up by the aerobic decomposition of composts and stable manures applied at the rate of 10 kilograms per are.

Paddy fields are abundant in unmatured soil organic matters, as compared with uplands. When paddy fields are brought under the submerged state and when the soil temperature rises, the soil organic matters will become decomposed markedly by the activities of micro-organisms. With the progress in decomposition all the free oxygen presenting in soils has been consumed, and even the oxygen combined with iron or manganese has come to be consumed. Thus reddish color of soils turns to blue-grayish color. The blue-grayish soil layer is known as "reduced layer". The principal color source is divalent iron. The decomposition of organic matter in the reduced layer of soil proceeds anaerobically, and adding to carbon dioxide, reducing gases (such as methane, hydrogen sulfide, and hydrogen) or organic acids different from that in uplands are produced.

On the other hand, the uppermost surface of top soil displays the oxidized state because the amount of oxygen supplied from the water to the surface exceeds the amount of oxygen which is consumed by micro-organisms in soils. This soil layer is known as "oxidized layer". At the peak summer time, the thickness of the oxidized layer reaches from several millimeters to one centimeter. The division of submerged top soil into the reduced layer and oxidized layer is called the "soil layer differentiation". Stable form of various substances in the soils varies depending upon whether these are present in the reduced layer or in the oxidized layer (Table 4-1).

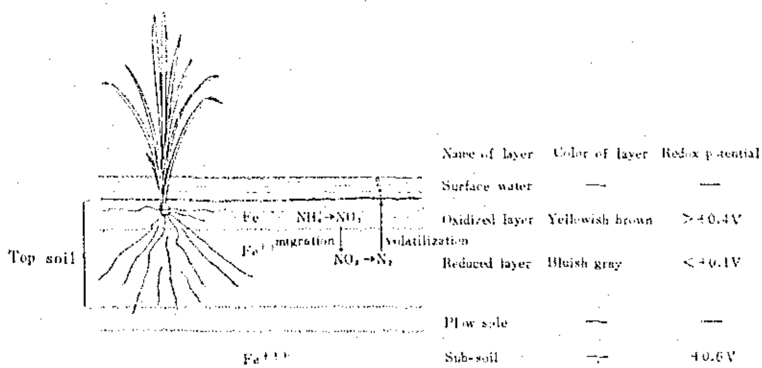
Nitrogenous fertilizers applied to paddy fields become ammonia by decomposition and kept by adsorption to soil-colloids. However, in the oxidized layer the ammonia becomes NO_3 by the activity of nitrifying bacteria. NO_3 flows away readily and descends to the reduced layer together with percolation, but it changes into nitrogen gas or nitrogen-oxide promptly by the reduction at the borders of oxidized and re-

Table 4-1. Changes in the Form of Constituents in Soils according to the Soil Layer Differentiation

Constituent	*Form in oxidized layer*	*Form in reduced layer*	*Changes in the form in reduced layer*
Nitrogen	NO_3^-	NH_4^+	$NO_3 \rightarrow N_2$
Sulphur	SO_4^{--}	S^{--}	$SO_4^{--} \rightarrow S^{--}$
Iron	Fe^{+++}	Fe^{++}	$Fe^{+++} \rightarrow Fe^{++}$
Manganese	Mn^{++++}	Mn^{++}	$Mn^{++++} \rightarrow Mn^{++}$
Carbon	CO_2	CH_4	

duced layers and will volatilize in the atmosphere (Fig. 4-1). The change $NO_3 \rightarrow N_2(NO)$ (i.e., denitrification) takes place almost quantitatively. As a result, if NO_3 is applied to paddy fields, its fertilizer effect would be considerably small. Ammonic applied to the reduced layer secures the relative stability without being affected by nitrification. From this fact, the application of quick-acting nitrogenous fertilizers throughout the soil layer (deep placement of fertilizer of basic application) has been devised.

Fig. 4-1. Differentiation of Soil Profile in Submerged Paddy Field Soils



Sesquioxide such as iron or manganese contained in the top soil layer is reduced in the reduced layer and shows a decrease in positive charge. Accordingly its solubility becomes increased and it flows into the soil water and descends to the lower layer together with percolation of water. It is oxidized again at the relatively aerobic part of the lower layer and deposited there. After the water has been drained, it is oxidized slowly among soil particles, and various oxidized deposits develop, but it is not clearly evidenced in the case of wet paddy field soils.

2. *Readily Decomposable Organic Matter and its Decomposition*

A fairly great quantity of organic matters (e.g., stubbles of rice plants cultivated in the previous year, algae, weeds which have emerged after drainage, composts, stable or green manures) are deposited every year in paddy field soils. The decomposition of these organic matters is unduly incomplete as compared with the case of upland field soils. Organic matters are accumulated on the surface of soil-colloidal complexes in the form of intermediate decomposites or synthesized compounds.

Algae of various descriptions grow on the surface of top soil layer of submerged paddy fields. Some kinds of blue-green algae have action to fix the free nitrogen in the air into the compound of nitrogen. It is reported that the potential nitrogenous fertility of paddy field soils is greater than that of upland field soils. The nitrogen fixation by the action of blue-green algae can be cited as one of the causes therefor.

For the above reasons, a fairly great quantity of organic nitrogen is contained in paddy field soils, but these organic nitrogenous compounds, without any treatment, would not readily be decomposed by micro-organisms. When an appropriate treatment is given to soils, the mineralization of some parts of these organic matters will be hastened and a great quantity of ammonia will be formed.

Organic nitrogenous compounds are involved in "humus" in the broad sense of the term. It is generally accepted that these compounds exist in the state of "organo-mineral colloidal complexes" in terms of TIULIN. Of these, the compounds which are relatively readily mineralized are known as "readily decomposable organic matter".

1. Effect of soil-drying before submergence.

A great quantity of ammonia will become accumulated when paddy field soils are subjected to submergence after the soils have been dried beforehand. This is a hastened mineralization of organic matters chiefly due to the soil dehydrating treatment. It is known that the effect of soil-freezing and the effect of pre-treatment of soils with highly concentrated neutral salt solution can also be ascribed to the same reason. A fairly great soil-drying effect can be recognized by the dehydrating treatment of pF 5 and over. In the case of soils which become dry fully in spring before the submergence, soil-drying effect can be brought about to the full extent. Nitrogen becomes increasingly available from the relatively early stage of rice plant growth (Table 4-2 and 4-3).

2. Effect of temperature rising of the soil under submergence

When the wet soils of paddy field are kept at temperature of 30°C after submergence, the ammonia produced by mineralization will be small in quantity, but when kept at temperature of 40°C, the mineralization will be hastened markedly. Such effect will be brought about on the paddy field with

Table 4-2. Comparison of Effect of Soil-Drying

Great effect	*Little effect*
Paddy fields	Uplands
Single-cropping fields	Double-cropping fields
Ill-drained fields	Well-drained fields
Uncultivated lands	Cultivated lands
Fields to which organic fertilizers are applied in succession	Fields to which inorganic fertilizers are applied in succession

Table 4-3. Effect of Soil-Drying and Soil-Temperature-Rising by Soil Types

(NH_4—N mg/100g oven dried soil)

Soil types	*Soil-drying effect*	*Soil-temperature-rising effect*	*Rate of ammonification by soil-drying effect*
	mg	mg	%
Peat soil	18.9	9.7	5.5
Peaty soil	14.3	—	5.6
Muck soil	14.0	11.6	4.6
Heavy Glei soil	11.9	6.5	6.4
Glei soil	11.0	7.0	6.3
Gray soil	8.0	5.0	5.2
Grayish-brown soil	9.1	5.3	5.4

Note: Derived from the "Reports on the Fertilizer Application Improvement Survey".

the rise in the soil-temperature after submergence, particularly markedly in midsummer. As a result, nitrogen, in most cases, becomes rapidly available after the middle stage of plant growth period.

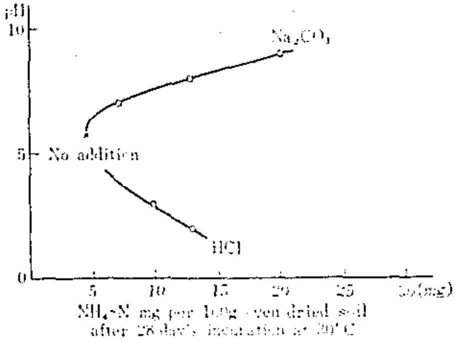
3. *Effect of changing soil reaction*

When the reaction of paddy field soil is changed to pH higher than 8.5 or lower than 3, left for a while at that pH value, and then converted to neutral, a fairly much ammonia will become accumulated (Fig. 4-2). Farmers have known by their experiences that the effect similar to the application of nitrogenous fertilizers can be expected by the application of quick lime at the rate of about 10 kilograms per are. However, when the application of nitrogenous fertilizers or crude organic fertilizers is insufficient, and too much amount of lime is applied in succession, nitrogen contained in soils (particularly nitrogen soluble in N/2 NaOH) is undoubtedly depleted (Table 4-4).

4. *Effect of adding salts*

When paddy field soils are kept in the submerged state after adding humus peptizable salts (e.g., sodium fluoride,

Fig. 4 – 2. Change in Soil Reaction and Mineralization of Organic Nitrogen
(HARADA, 1959)



Note: Test fields are fields to which organic fertilizer are applied in succession, at Konosu.

Table 4 – 4. *Effects of Lime Application on Paddy Field Soils* (Field Tests at Konosu)

(*Milligrams per 100 grams of oven dried soil*)

Amount of quick lime application	*Brown rice yield average for ten years*	*Total nitrogen contained in soils*	*Soil-drying effect*
kg/a	kg/a	%	mg
0	37.4	0.294	14.9
9.4	36.8	0.292	13.0
18.7	38.1	0.287	11.8
37.5	39.3	0.266	11.4

dibasic sodium phosphate, monobasic sodium phosphate, sodium oxalate, etc.), a part of organic nitrogen in the soils is mineralized and ammoniacal nitrogen will become accumulated. Such mineralization has been assumed to be brought about by the peptization of humus contained in soils.

5. *Existing status of readily decomposable soil organic matter*

According to HARADA's theory, the readily decomposable soil organic matter is, in most cases, found in the form of humus-clay complex. However, for the reason that the readily decomposable organic matter is contained in the readily soluble humus, such organic matter is assumed to exist by being adsorbed to the surface of colloidal complex or being combined loosely with colloidal complex. When it exists in such state, it is resistant to the action of micro-organisms, but it can be assumed that when its adsorption or combination with the colloidal complex becomes weak or when its equilibrium is disturbed by the separation or dispersion, such organic matter will become readily decomposed by the action of micro-organisms.

3. Compositions of Irrigation Water

Irrigation water amounting to around 144 cu. meters per are is consumed during the paddy rice cultural season. The amount of nutrients supplied by the irrigation water is, as indicated in Table 4–5, so great that it can not be overlooked. The quality of irrigation water supplied by rivers or streams faithfully reflects the geological nature of the water sources and basins. The amount of nutrients supplied thereby varies widely with the regions. The water of rivers flowing through volcanic ash soil areas is abundant in silicate, that of rivers flowing through lime stone areas abundant in lime, and that of rivers flowing through granite or liparite zone is generally lacking in inorganic salts. In general, nitrogen or phosphorus is not contained appreciably much in river water, but the water of rivers fed by sewage from cities is sometimes abundant in nitrogen or phosphorus.

The quality of irrigation water gives effect on the inorganic components contained in rice plants cultivated by it. Particularly, it is accepted that the concentration of silicate contained in the irrigation water is sensitively reflected in the concentration of silicate in the plant leaves. In case where factories or mines exist in the upper stream areas, it gives rise to frequent problems of damage from pollution due to the heavy metallic salts (e.g., copper, zinc, etc.).

Table 4-5. Concentration of Salts Contained in River Water in Japan (1953)

	Minimum	*Maximum*	*Average*	*Average for the entire world*
	ppm	ppm	ppm	ppm
SiO_2	0	50.50	18.20	11.00
CaO	2.20	51.90	15.20	28.00
Na_2O	1.70	117.60	11.70	8.00
SO_3	0.10	45.20	10.70	10.00
Cl	0	42.00	6.30	5.00
MgO	0.10	15.70	3.30	5.00
K_2O	0.45	6.08	1.66	2.00
Fe_2O_3	0	5.20	0.62	—
T-N	0.02	3.97	0.51	—
P_2O_5	0	0.16	0.03	—
pH	5.7	8.5	7.0	—

Note: On an average for 169 places.

4. Natural Supply of Three Fertilizer Elements

In Japan, as it is traditionally said that "successful culture of rice crop depends upon field soils, while that of wheat or barley crop upon fertilizers," the natural supply of nutrients to lowland (paddy) rice plants is great in amount. As indicated in Table 4-6, when upland rice, wheat or barley crop is cultivated without fertilizers, the yield of them would decrease to 30-40 per cent, while if lowland rice be grown without fertilizer application, the rice crop could, for several years, be harvested to the extent of some 70 per cent of the normal yield.

In the case of lowland rice culture, it is proved that the natural supply of nitrogen is smallest among three nutrients, N, P and K because the rice yield in non-nitrogen plot is lowest. The fact that rice yield in non-phosphorus plot or non-potash plot reaches some 95 per cent of the rice yield in N·P·K-plot indicates that the natural supply of phosphorus or potash to rice plants is comparatively great in amount.

The following descriptions will account for the above reason.

Table 4-6. Natural Supply of Nutrients to Rice, Wheat and Barley (National average in 1953)

Three elements of fertilizer applied	*Paddy rice*	*Upland rice*	*Wheat or barley*
N • P • K	100	100	100
P • K	83	51	50
N • K	95	84	69
N • P	96	75	78
None	78	38	39
Number of sample places	1,161-1,187	117-126	822-841

(1) Fixation of atmospheric nitrogen by blue-green algae: Within the blue-green algae growing on the surface of submerged paddy field soils there are some algae which fix the atmospheric nitrogen and supply nitrogen to paddy field soils (Table 4-7). The amount of nitrogen supplied by such algae is commonly said to be more than that supplied by *Azotobacter* in upland soils.

(2) Ammonia is held in top soil in a comparatively stabilized state: Ammonia derived from soil organic matter or ammonia supplied in the form of fertilizer is finally transformed into nitrate in the upland field soils, and nitrate is liable to be leached away with great rapidity, while the nitrogen compounds remain in the form of ammonia in paddy field soils and no more change takes place in its form in the reduced layer, being adsorbed fairly firmly to the surface of soil colloids.

(3) Potential nitrogenous fertility in paddy field soils is higher than that in upland soils: Reference is made to the previous item.

(4) Phosphorus in the soils becomes readily available because paddy field soils are kept in the reduced state: Phosphorus applied to upland soils, combining with iron, aluminium or lime forms not-readily-soluble ferric phosphate, aluminium phosphate or tricalcium phosphate, thus becoming unavailable. In the case of paddy field soils also, the phosphorus combines with ferric iron, aluminium or lime soon

Table 4-7. Effect of Inoculated Blue-green Algae on Nitrogen Absorption by Paddy Rice Plants

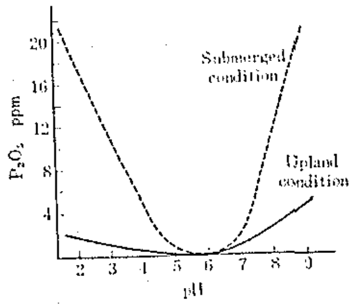
(Pot test using the Arakawa River alluvial soil, By NISHIGAKI, 1951)

(*Unit: N mg/pot*)

Kind of inoculated blue-green algae	*Nitrogen applied (basic dressing)*	*Nitrogen absorption*	*Increase in nitrogen*
Check plot	50	58	---
Tolypothrix	50	76	18
Calothrix	50	69	11

after the phosphorus application, but with the progress in soil reduction the soil reaction will tend increasingly to alkaline reaction from neutral reaction, and such insoluble phosphorus compounds which are unavailable for upland crops are hydrolyzed, some of them being changed to monobasic or dibasic calcium phosphate, that is available for such crops (Fig. 4-3). Organic-phosphorus (maybe phytin or nucleic acid) accounting for 20–25 per cent of the total phosphorus in the paddy field soils is also accepted to become mineralized and available by the paddy rice cropping. As a result, little or no phosphorus-deficiency will be observed, except for volcanic ash paddy field soils.

Fig. 4-3. Solubility of Phosphorus under Submerged or Upland Conditions
(AOKI, 1941)



(5) Inorganic nutrients supplied from irrigation water: As prescribed above, fairly much inorganic elements are supplied from irrigation water.

The high capacity of paddy field soils of supplying nutrients to paddy rice plants can be maintained by the combination of these factors cited above.

II. AMELIORATION OF POOR PADDY FIELD SOILS

1. Ill-drained (Wet) Paddy Fields

1. Definition of ill-drained paddy fields.

YOKOI formulated the definitions as follows:

"Ill-drained paddy field means such field containing the moisture of more than maximum water capacity up to the surface layer throughout the non-irrigation season and the field surface is so wet that if we step into the field the water would easily flow out; and semi-ill-drained paddy field means the field which shows the state of the ill-drained paddy field for a certain period during the non-irrigated season, or the field containing moisture of more than field water capacity, but less than maximum water capacity in its surface layer, and seems somewhat wet and water would ooze out if we step into it."

The so-called ill-drained or semi-ill-drained paddy fields in Japan reach approximately 30 per cent of its total paddy field area.

2. Causes for decreased rice yield on ill-drained paddy fields

From the pedological viewpoint, the following points can be cited as important. Namely, though ill-drained paddy fields are rich in readily decomposable organic matter, soil nitrogen will not become readily available at the early stages of rice plant growth because soils are not dried and the soil temperature is relatively low. For this reason, a relatively great amount of nitrogenous fertilizers is liable to be applied as basic fertilizer. However, with the rise in the soil temperature in the midsummer, the decomposition of soil organic matter becomes quick and much soil nitrogen becomes utilizable rapidly. As a result, due to the oversupply of soil nitrogen to rice plants, rice plants will lodge or suffer from blast. Moreover, the activity of rice plant roots will be retarded or root-rot will occur due to the severe soil reduction as well as due to the gas or organic acid formation caused by the soil reduction, thus giving rise to the difficulty in nutrient absorption, particularly in phosphorus or potash absorption by rice plant roots. In addition, the temperature of inner part of soils is too low. These combined factors contribute to the low rice yield of wet paddy fields. Table 4-8 indicates the results quoted from the nation-wide survey on the fertilizer application improvements conducted by the Ministry of Agriculture and Forestry. The fact that the rice yielding capacity of wet paddy fields is lower than that of dried fields is evidenced well by Table 4-8.

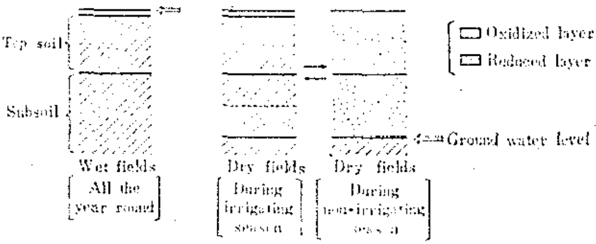
Table 4-8. Brown Rice Yield in the Fields Tested for the Standard Amount of Fertilizer Application throughout the Country (1953–55 Average)

Type of paddy fields	*Soil types*	*Rice yield in Non-N plot*	*Rice yield in the presumptive optimum N plot*
		kg/a	kg/a
Ill-drained	Peat soil	33.4	41.1
paddy fields	Muck soil	36.9	44.0
↑↓	Heavy glei soil	36.9	45.7
Well-drained	Glei soil	38.7	45.0
paddy fields	Gray soil	39.4	47.1

3. *Redox-potential (oxidation-reduction potential) of ill-drained paddy field*

Owing to the supply of oxygen to the soils by percolation, Eh of dry fields is higher than Eh of wet fields, and the vertical gradients of redox-potentials will also become different. Namely, in the case of wet paddy fields, the oxidized layer is found only in the uppermost surface and the reduced layer extends all over the remaining parts, while in the case of dry fields which are submerged in the plant growth period, the oxidized layer is found in the uppermost surface layer, and a part of the lower layer abundant in organic matter forms the reduced layer, but the subsoil portion below that forms the oxidized layer due to the poor presence of organic matter, even if the temperature rises, and the layer thereunder forms the reduced layer because it is filled with groundwater. Fig. 4–4 is a model graph illustrating the above.

Fig. 4 – 4. Cross Sections of Wet and Dry Field Soil Layers



4. *Conversion of wet fields into dry ones and the physico-chemical changes in the soils*

With a view to improving the low productivity and the low efficiency in operations on wet fields, it is generally devised to drain excessive water or to lower the groundwater level by using subsoil or surface drains. In the case of paddy fields in level lands, it is generally accepted to be desirable to drain to the extent that the paddy field surface water may be decreased at the rate of 2–3 centimeters per day of percolation. In some places, paddy fields are kept in the state of submergence all the year round because they are rain-fed without satisfactory irrigation facilities. It is important for such areas to be equipped with irrigation facilities.

When wet fields have been converted into dry fields by the land improvement projects, exchangeable base, iron and humus in the surface soil layer remove to the lower layer by the percolation, and pH of the surface layer soil becomes lowered. Top soil after plowing is liable to become dried and the soil-drying effect will be brought about. Thus the potential nitrogenous soil fertility is on the decrease year after year. Soil humus will thus be improved qualitatively and the humic acid will be converted from rot product into true humic acid.

The soil acidification due to the leaching of exchangeable base particularly of calcium, resulting from the drainage, can be controlled by the application of calcareous fertilizers, and the depletion of soil organic matter can be avoided by the increased application of composts or stable manures (Table 4-9 and 4-10).

Table 4-9. Results of Analysis of Paddy Field Soils by Using Hot HCl

(Nakajo-Machi, Niigata; By KOBO, 1954)

Paddy field	SiO_2	Fe_2O_3	Al_2O_3	SiO_2/R_2O_3	CaO	P_2O_5
	%	%	%	%	%	%
Wet field	9.35	3.97	4.95	2.10	0.68	0.137
Drained field *	9.40	3.19	4.01	2.64	0.46	0.109
Drained field **	11.27	3.11	4.21	3.06	0.36	0.101

Notes: * In the 7th year after draining.
** In the 12th year after draining.

Table 4-10. Changes in Soil-drying Effects on Drained Fields, By Selected Years

(Nishi-Kubiki-Gun, Niigata; By KONISHI, 1954)

(N mg/100 g oven dried soil)

Paddy field	*Total nitrogen*	*Soil-drying effect*	*Rate of ammonification*
			%
Not yet drained	352.0	25.3	7.2
Drained, 2 years ago	345.0	20.2	5.9
Drained, 7 years ago	319.2	16.3	5.1
Drained, 15 years ago	303.0	15.1	5.0

2. Degraded Paddy Fields

1. Definition of degraded paddy field

In the case of upland soils, the leaching losses of nitrate, potash, lime and magnesium are important, but the leaching loss of iron or manganese is minor in importance. In the case of podzolization of forest soils under the humid climatic conditions in cold areas, iron or aluminium removes to the second soil layer by the action of protective colloid of acid humus, under the oxidized state and the strong acid reaction, while in the case of well-drained paddy fields under submersion, iron or manganese decreases its positive charge and becomes readily soluble, and removes under reduced state and the reaction closely approximate to the neutral to the lower soil layer. If such leaching is continued, in the case of sandy soils originated from parent materials poor in iron content and rich in silicic anhydride content of active iron in the soil will shortly be lowered and reddish color of iron oxide will fade away from top soil or plow sole, thus becoming grayish. When such state has been aggravated seriously, the paddy fields are called "degraded paddy fields".

Rocks poor in lime or iron content and rich in silicic acid content can be cited as parent materials liable to become degraded. Among them are acid igneous rocks (e.g., granite, liparite, quartz porphry), tertiary sand stone, Izumi-sand stone of mesozoic system, and the upper and middle series of palaeozoic system.

On the other hand, neutral and basic rocks poor in silicic acid content are cited as parent material not readily degraded. Among them are crystalline schist, basalt and andesite.

2. Chemical and physical properties of degraded paddy field soils

Degraded paddy field soils are generally rich in sand content, but poor in clay content. One example of the analytical results is given in Table 4-11. Hot hydrochloric acid soluble iron, free iron oxide, hot hydrochloric acid soluble manganese, and readily soluble manganese are contained extremely small in quantity in the degraded field soils throughout top soil, plow sole, and subsoil (Table 4–12).

Table 4 – 11. Physical Properties of Degraded Paddy Soils
(Results of surveys on typical soils in the Chugoku and Shikoku Districts)
(SUZUKI and MAEDA, 1956)

Types of soil	*Number of samples*	*Soil layer*	*Soil texture*	*Gravels*
High-yielding paddy field soils	4	Top soil	C L	3.6
		Plow sole	C L	7.6
		Subsoil	C L	12.2
Ordinary paddy field soils	4	Top soil	C L	—
		Plow sole	C L	—
		Subsoil	C L	—
Degraded paddy field soils	24	Top soil	L S	16.1
		Plow sole	L S	13.2
		Subsoil	S C L	20.0

(*Continued*)

Types of soil	*Per 100 of fine earth (under 2 mm)*			
	Course sand 2–0.2 mm	*Fine sand 0.2–0.02 mm*	*Silt 20–2 μ*	*Clay under 2 μ*
High-yielding paddy field soils	13.8	32.6	32.3	21.3
	15.2	34.8	30.6	19.4
	14.1	35.4	30.8	19.7
Ordinary paddy field soils	11.0	36.8	32.7	19.5
	9.5	40.2	34.2	16.1
	10.0	36.2	34.7	19.1
Degraded paddy field soils	32.6	33.0	19.8	14.6
	36.2	32.0	17.7	14.1
	41.2	28.6	14.7	15.5

Table 4 – 12. Chemical Properties of Degraded Paddy Field Soils
(Results of surveys on typical soils in the Chugoku and Shikoku Districts)
(SUZUKI and MAEDA, 1956)

Types of soil	*Number of samples*	*Soil layer*	*pH (H_2O)*	*T-N*	*T-C*	*C/N*	*Soil-drying effect N mg/100g*
				%	%		
High yielding paddy field soil	4	Top soil	5.3	0.22	1.90	8.5	8.28
		Plow sole	5.3	0.19	1.23	7.4	5.84
		Subsoil	6.8	0.09	0.70	8.0	2.29
Ordinary paddy field soil	4	Top soil	5.6	0.20	1.76	9.0	8.47
		Plow sole	5.7	0.15	1.36	9.3	6.68
		Subsoil	6.5	0.08	0.72	9.5	1.83
Degraded paddy field soil	24	Top soil	5.4	0.19	1.83	10.3	7.31
		Plow sole	5.3	0.11	1.07	10.8	3.97
		Subsoil	5.7	0.07	0.73	12.2	2.65

(Continued)

Types of soil	*Base exchange capacity me/100g*	*Hot HCl soluble silicic acid*	*Iron (Fe_2O_3)*		*Manganese (Mn_2O_3)*	
			Hot HCl soluble	*Free*	*Hot HCl soluble mg/100g*	*Readily reduced mg/100g*
		%	%	%		
High yielding paddy field soil	16.2	0.51	3.60	2.15	87	32
	15.9	0.30	2.88	1.40	78	23
	14.0	0.50	4.71	3.39	129	51
Ordinary paddy field soil	12.1	0.34	2.56	1.01	73	6
	12.1	0.29	2.46	1.23	64	6
	10.3	0.29	3.75	2.15	110	59
Degraded paddy field soil	10.3	0.23	1.73	0.50	47	2
	8.4	0.23	1.70	0.49	41	2
	8.3	0.24	2.92	1.37	64	17

3. Mechanism of leaching of iron in the degraded paddy field soils

As to the mechanism of the leaching of iron, SHIOIRI put forth his theoretical views as follows:

"Top soil layer of paddy field soils after irrigation is brought under the reduced state and free iron oxide will change to ferrous ion. Ferrous ion is adsorbed by colloids such as humus or clay and makes the colloids inactive by reducing their negative charge. Hydrogen sulfide is formed in soils by the decomposition of "sulfur containing organic matter" and by the reduction of sulfate, and the hydrogen sulfide becomes ferrous sulfide by combining with ferrous ion, thus precipitating. In this case, when hydrogen sulfide gas comes to be formed due to the abundant formation of hydrogen sulfide, ferrous sulfide becomes sol (a liquid colloidal solution) of negative charge, thus being brought again into solution. Under such state, ferrous sulfide will remove to the lower layer by the downward movement of water".

As Mn^{4+} is reduced more readily than Fe^{3+}, it removes to the lower layer in the form of bicarbonate or sulfide sol, or it is possible to flow away in the form of chelate. As Mn^{2+} is oxidized more hardly than Fe^{2+}, the illuvial horizon of manganese oxide develops generally immediately below the illuvial horizon of iron-oxide.

4. Akiochi disease of rice plants in degraded paddy fields

Akiochi indicates the phenomenon that the rice plant growth in the vegetative growth period is excellent, but the growth becomes poorer in later growth period, particularly from the time a little before booting stage, the lower leaves begin to die back and innumerable spots of *Helminthosporium* disease appear on the leaves, thus resulting in the decreased rice yield. Degraded paddy field soils are very sensible to *Akiochi*.

Under the reduction state, the sulfur compounds in paddy field top soil, or the sulfate applied as fertilizer will change to hydrogen sulfide. In this case, when adequate free iron oxide is contained in the soil, hydrogen sulfide will instantly become ferrous sulfide by combining with iron and precipitate, thus the toxic hydrogen-sulfide is changed to untoxic precipitate. As a result, rice plants will suffer no harm. However, in the case of degraded paddy field soils, due to the lack of iron content, the entire hydrogen sulfide can not be precipitated. As a result, some part will become soluble sulfide and others will remain in the soil solution in the form of free hydrogen sulfide. It is reported that the damage by free hydrogen sulfide will be caused when the concentration of free hydrogen sulfide exceeds "0.02 milligram sulfur per 100 grams oven dried soil". As seen in Table 4-13, hydrogen sulfide exceeding 0.02 milligram is actually contained in degraded paddy field soils. Due to the presence of such hydrogen sulfide, the respiratory enzyme system of rice plant roots will be disturbed and the nutrient absorption by the plant roots is checked, thus resulting in

Table 4-13. Formation of Hydrogen Sulfide in Degraded Paddy Field Soils

(SUZUKI and SHIGA, 1956)

Paddy field soils	*Number of samples*	*Soil layer*	*Free hydrogen sulfide S mg/100 g*	*Sulfide S mg/100 g*
High-yielding paddy field soils	4	Top soil	0.01	19.3
		Plow sole	0.02	22.5
		Subsoil	0.01	26.6
Ordinary paddy field soils	3	Top soil	0.01	24.6
		Plow sole	0.01	26.2
		Subsoil	0.00	0.9
Degraded paddy field soils	26	Top soil	0.43	19.5
		Plow sole	0.08	12.7
		Subsoil	0.01	1.2

Note: Hydrogen sulfide is measured after the incubation at 35°C for 21 days with ammonium sulfate added at the rate of "30 mg-S/100 g oven dried soil" to the various paddy field soils collected from the Chugoku and Shikoku Districts.

the decreased rice yield. A further explanation is given in other chapter.

5. Degraded paddy field soil amendments

(a) Soil admixture (soil dressing): Admixture of new soil is practised widely as one of the effective means for the radical amendments of degraded paddy field soils. The four major objectives of the soil admixtures can be cited: (i) to check the formation of hydrogen sulfide by supplementing iron; (ii) to supplement the special elements (e.g., silicic acid, magnesium, manganese, etc.) or trace elements; (iii) to raise the fertilizer holding capacity by supplementing clay; and (iv) to minimize the percolation by improving the physical properties of soils.

In view of the above objectives, admixture of materials abundant in activated iron or base and clay (particularly montmorin group clay) is preferable. Weathered product of basalt, andesite, chlorite schist and shale, and also river- or lake-bottom muds are effective materials available for the soil admixture purposes.

(b) *Addition of iron-containing materials:* When the admixture of soils is not permissible, iron scraps, bauxite slag, limonite powder and pyrite slag are added to the degraded paddy field soils.

(c) Deep plowing: When the illuvial horizon of iron or manganese exists immediately below the plow sole, it is dug up to mix with top soil.

(d) Fertilizer application: It is evidenced that the application of fertilizers containing no sulphate-radical, or heavier application of potash fertilizers or composts or stable manures is effective.

3. Paddy Field with Overpercolation

1. Properties of overpercolating paddy field soils

When the lower layer of paddy field soils consists of gravels or sands, losses of surface water by percolation are great. Sometimes it shows a percolation loss of over 10 centimeters per day. Such paddy fields are known as "overpercolating paddy fields". The overpercolation is frequently observed on the paddy field originated from volcanic ash and rich in humus, or of sandy soils.

When the losses of water by percolation are great, paddy fields are, in most cases, under continuous flowing irrigation. If the temperature of irrigation water is low, the plant growth would be delayed and the rice yield would become lowered. Losses of nutrients by percolation are also great and NH_4^+ or K^+ will readily flow away though they are cations. As a result, deficiency of fertilizers will often occur in the latter plant growth period. The base exchange capacity is as high as 30-40 me. in many cases with volcanic ash paddy field soils rich in humus but since a great part of electric charge depends upon organic matter or allophane, the electric charge which adsorbs NH_4^+ or K^+ is small, and as a great part of electric charge adsorbs readily Ca^{++} or Mg^{++}, the loss of K^+ or NH_4^+ by percolation is great.

2. *Overpercolating paddy field amendments*

The following measures are now taken for the percolation control, i.e., paddy field bottom consolidation, filling with clay (e.g. bentonite, etc.) in permeable soils, binding of soil particles by the addition of polyvinyl-group soil amendments, or plowing-under of organic matter (e.g., straw of rye, etc.).

It is also practised to spread vinyl cloth all over the field at the depth of 30-40 centimeters below the soil surface. This method is practised mostly when the land of sandy gravels is newly reclaimed to open paddy field. In the case of volcanic ash paddy field soils, liberal application of phosphatic fertilizers is preferable.

III. CHARACTERISTICS OF MAJOR FERTILIZERS

1. Nitrogenous Fertilizers

The principal nitrogenous fertilizers applied to paddy rice fields are as given in Table 4–14. Besides these, ammonium nitrate is cited, but this is not applied to paddy rice fields.

1. Ammonium sulfate

Ammonium sulfate is readily soluble in water. This is a chemically weak acidic fertilizer and a physiologically acidic one. N contained in ammonium sulfate is NH_4-N which can be directly absorbed by paddy rice plants. In this sense, this is a quick-acting fertilizer.

Ammonium sulfate is applicable either as basic fertilizer or as top dressing. When ammonium sulfate is applied to paddy rice fields, changes will take place in plant leaf color within 3 or 4 days.

Ammonium sulfate contains sulfate radical as the secondary constituent. At the reduced soil layer, ammonium sulfate is reduced and forms hydrogen sulfide which is harmful to paddy rice plants. In the case of ordinary paddy fields, hydrogen sulfide will become water-insoluble iron sulfide by combining with iron contained abundantly in soils, but in the case of degraded paddy fields lacking in iron in soils, due to the toxicity of hydrogen sulfide the plant roots will be damaged, thus decreasing the rice yield.

2. Ammonium chloride

Ammonium chloride, the by-product of the alkali manufacture, is like ammonium sulfate a physiologically acidic fertilizer. Ammonium chloride is somewhat more soluble in water than ammonium sulfate, but somewhat higher in hygroscopicity than the latter (Table 4–15). For the purpose of preventing moisture-absorption and in order to make easy of scattering, ammonium chloride is marketed in granular form. In the case of ordinary paddy fields, no difference is observed in the fertilizer effect between ammonium chloride and ammonium sulfate, but since the former contains no sulfate radical, it presents no hydrogen sulfide. In this respect, it is superior to ammonium sulfate as the fertilizer to the degraded paddy fields (Table 4-16).

Since ammonium chloride contains chlorine as the secondary constituent, soils are liable to be acidified by its application more readily than by the application of ammonium sulfate. And in the case of phosphorus-deficient soils, its fertilizer effect is inferior to that of ammonium sulfate. This is ascribed to the fact that, in the case of the former, as the result of combination of chlorine with base in soils, readily-soluble chloride will be produced, thus causing the deficiency in lime or other base, while Boas effect accounts for the latter case.

Table 4-14. Principal Nitrogenous Fertilizers

	Ammonium sulfate	*Ammonium chloride*	*Urea*	*Calcium cyanamide*
Chemical structure	$(NH_4)_2SO_4$	NH_4Cl	$CO(NH_2)_2$	$CaCN_2$*
	%	%	%	%
N-content	20.6	25.0	46.0	20.0
Reaction	Acidic reaction	Acidic reaction	Alkaline reaction	Alkaline reaction
Fertilizer effect	Quick-acting	Quick-acting	Quick-acting	Somewhat slow-acting
Secondary constituents	Sulfate (73%)	Chlorine (66%)	None	Calcium oxide (20%)
Production(1960)	1,586,000 tons	306,000 tons	784,000 tons	369,000 tons

Note: * Principal consituent.

Table 4-15. Hygroscopicity of Major Nitrogenous Fertilizers (Relative humidity of air in equilibrium with the vapor of saturated solution of respective fertilizers)

Fertilizer	*10°C*	*20°C*	*30°C*	*40°C*
Ammonium sulfate	79.8	81.0	79.2	78.2
Ammonium chloride	79.5	79.3	77.2	73.2
Urea	81.8	80.0	72.5	68.0
Ammonium nitrate	75.3	66.9	59.4	52.5

Table 4-16. Tests for Fertilizer Effect of Ammonium Chloride

(A) Ordinary paddy field test

Plot	*Brown rice yield (kg/a)*						*Index*
	1951	*1952*	*1953*	*1954*	*1955*	*Average*	
Ammonium sulfate	61.09	52.32	49.29	50.20	55.64	53.52	100
Ammonium chloride	60.78	57.00	47.02	53.52	58.21	55.34	103

(B) Degraded paddy field test

Plot	*Brown rice yield (kg/a)*			
	1942		*1943*	
	A	*B*	*A*	*B*
Ammonium sulfate	33.87	32.05	34.78	28.58
Ammonium chloride	38.10	35.23	33.57	32.21

Notes: A: Irrigation water-intake side field.
B: Drainage side field.

3. Urea

Urea is a fertilizer, chemically and physiologically neutral. Urea is higher in hygroscopicity than ammonium chloride (Table 4-17). Urea is marketed usually in granular form.

As urea is not only absorbed by rice plants, but also quickly decomposed into ammonium (NH_3) and carbon dioxide (CO_2) in the soil, it is a quick-acting fertilizer. Urea is also changed into ammonium carbonate by the action of urease of micro-organisms, as given in the following equation:

$$CO(NH_2)_2 + 2H_2O = (NH_4)_2CO_3$$

The degree of decomposition varies with the amount of urea application, soil classes, temperatures, reaction (pH), and soil fertility, but at temperature of 30°C, a great part of urea will usually become ammoniacal nitrogen within two or three days (Table 4-17). The fertilizer effect of urea is almost similar to that of ammonium sulfate when applied to ordinary paddy fields, but urea is suitable for application to degraded paddy fields, and very effective also when applied to acid soils, volcanic ash soils, and peat soils. No harmful effect is brought about even though applied continuously (Table 4-18).

4. *Lime nitrogen (calcium cyanamide)*

Lime nitrogen is made of carbide and nitrogen gas. Lime nitrogen on the market contains various impurities such as calcium oxide, calcium carbonate, and carbon. Since lime nitrogen absorbs moisture easily and the quality is liable to be changed readily, attention must be paid to the handling.

Table 4-17. Urea Decomposition
(Hiroshima Pref. Agr. Exp. Sta.)

(A) By soil classes

Soil class	*Ammoniacal nitrogen formation (%)*		
	1st day	*2nd day*	*3rd day*
	%	%	%
Sand	39	61	73
Sandy loam	76	95	71
Loam	85	90	98
Clay loam	96	98	100

Note: Soils were kept under water logged condition at temperature of 30°C; nitrogen is added at the rate of 20 mg per 100 g soil.

(B) By tmperatures (Under water logged condition)

Temperature	*Ammoniacal nitrogen formation (%)*		
	1st day	*2nd day*	*3rd day*
	%	%	%
10°C	4	20	67
20°C	76	95	71 *

Note: * Decrease due to the nitrification and denitrification.

Table 4-18. Basic Dressing of Urea on Paddy Fields (1956-58)

Treatment	*Agr. Exp. Sta.*				
	Hokkaido	*Tohoku*	*Kanto-Tosan*	*Aichi*	*Kyushu*
Urea, deeply placed, irrigated immediately	100	100	100	100	100
Urea, deeply placed, irrigated after 5 days	106	105	99	97	93
Ammonium sulfate, deeply placed, irrigated after 5 days	106	106	99	98	90

Note: Figures given above average yield indices with the base number for "urea, deeply placed, irrigated immediately" plot represented by 100.

Since lime nitrogen is an alkaline fertilizer containing much lime, when applied to paddy soils, soils are not acidified unlike the application of ammonium sulfate or ammonium chloride. Soil acidity is rather rectified.

Lime nitrogen applied to soils is converted into ammonium carbonate according to the following processes.

(i) $CaCN_2 + 2H_2O = CN \cdot NH_2 + Ca(OH)_2$

(ii) $CN \cdot NH_2 + H_2O = CO(NH_2)_2$

(iii) $CO(NH_2)_2 + 2H_2O = (NH_4)_2CO_3$

The velocity at which $CaCN_2$ is changed to $(NH_4)_2CO_3$ depends upon the equation (ii), but when the reaction velocity in the equation (ii) is slowed down due to the soil conditions, $C_2N_2N_2H_4$ is sometimes formed owing to the polymerization of two molecules of $CN \cdot NH_2$ produced by the equation (i). Since this dicyanodiamide checks the action of nitrification, it contributes to the increase in the fertilizer effect by mitigating both of the loss by denitrification as well as the loss by leaching of nitrogen. Being a non-sulfate-radical fertilizer, lime nitrogen has larger fertilizer effect than ammonium sulfate when applied to degraded paddy fields. When applied to ordinary paddy fields, its fertilizer effect is similar to that of ammonium sulfate, but when applied to wet paddy fields, its fertilizer effect is inferior to the latter because the decomposition of lime nitrogen is slowed down in the case of wet paddy fields. The fertilizer effect of lime nitrogen is great when applied to the colloid-rich soils because lime nitrogen is decomposed by the contact with soil colloids. As compared with ammonium sulfate, ammonium chloride and urea, lime nitrogen is somewhat slow-acting fertilizer. The toxicity of cyanamide in lime nitrogen can be utilized for soil sterilization, disease and insect pest control, and weed control.

2. Phosphatic Fertilizers

The principal phosphatic fertilizers applied at present to paddy fields are given in Table 4-19.

Table 4-19. Principal Phosphatic Fertilizers

Item	P_2O_5 %	*Reaction*	*Fertilizer effect*	*Form of phosphorus*	*Principal secondary constituents*
Calcium superphosphate	16.0-20.5	Acid	Quick-acting	Calcium phosphate	Calcium sulfate
Fused phosphate	16.0-20.0	Alkali	Somewhat slow-acting	Calcium, silicic and magnesium phosphate	Magnesium, lime, and silicic acid
Calcined phosphate	30.0-40.0	Neutral	Ditto	Tricalcium phosphate	Silicic acid and lime

1. *Calcium superphosphate*

The principal constituent of calcium superphosphate is water soluble calcium phosphate monobasic. In addition to this, it includes a small quantity of free phosphoric acid and calcium phosphate dibasic. These elements are all absorbed well by plants. Calcium superphosphate is a high acidic fertilizer having a peculiar odor. When the humidity is high, it becomes hygroscopic. It is not allowed to be mixed with alkaline fertilizers such as calcium cyanamide, because, if mixed, a part of water soluble phosphate would become insoluble. And when mixed with chloride compounds, it will show an increase in hygroscopicity.

Soils are by no means acidified by phosphatic fertilizers in general because phosphoric acid, an acidic constituent of phosphatic fertilizer is generally absorbed better by soils or plants than calcium or magnesium (alkaline constituent).

Calcium superphosphate contains calcium sulfate as the secondary constituent. As to the formation of hydrogen sulfide from this calcium sulfate, a further study is required to be made. It is generally regarded as safe not to apply calcium superphosphate to degraded paddy fields.

2. *Fused phosphate*

Phosphoric acid contained in fused phosphate is not water soluble, but soluble in 2 per cent citric acid. Fused phosphate contains a great quantity of such secondary constituents as magnesium, lime, and silicic acid. A great part of them are soluble in 2 per cent citric acid. Chemical structure of the principal constituents is not clarified well, but the chemical formula is supposed to be "$3MgO \cdot CaO \cdot P_2O_5 \cdot 3CaSiO_2$" (Table 4-20).

Since fused phosphate is an alkaline fertilizer, it is better to avoid the mixture or storage together with NH_3-contain-

Table 4-20. Composition of Fused Phosphate

Phosphate composition	*Ratio*
	%
Phosphorus, total	18.6
Citric acid soluble phosphorus	18.4
Silicic acid	24.9
Magnesia	21.6
Lime	28.6
Iron oxide	5.1
Alumina	1.7

ing fertilizers such as ammonium sulfate. When applied to ordinary paddy fields, it is fertilizer effect is almost similar to that of calcium superphosphate. However, since it contains no sulfate radical as the secondary constituent but contains a great quantity of silicic acid, lime, and magnesium, it is effective to apply fused phosphate to degraded paddy fields, highly acidic soils, or allitic soil. As almost all the volcanic ash soils are aluminous, being high in phosphorus absorption capacity, citric acid soluble phosphate is utilized more easily for crops than water soluble phosphate. Fused phosphate is somewhat slow-acting fertilizer as compared with calcium superphosphate, but in the case of warm areas its fertilizer effect will never be affected adversely due to its slow-acting effect. In the case of cold areas, it is better to use it together with calcium superphosphate. Being an alkaline fertilizer, fused phosphate has an action to hasten the decomposition of soil organic matter. As a result, it is better to apply it in combination with composts and stable manures or green manures. It is reported that the fertilizer effects of both are accelerated further when applied with green manures.

3. Calcined phosphate

Calcined phosphate is a new phosphatic fertilizer. Its manufacturing on an industrial scale was started in 1955. Phosphorus contained in calcined phosphate is citric acid soluble tricalcium phosphate. It includes lime and silicic acid as its secondary constituents. Calcined phosphate is suitable for degraded paddy fields, volcanic ash soil paddy fields or acidic paddy fields, but when applied to ordinary paddy fields its fertilizer effect is considered to be similar to that of fused phosphate.

3. Potash Fertilizers

A great part of potash fertilizers used in Japan at present is potassium chloride and the remaining part is potassium sulfate.

1. Potassium chloride

Potassium chloride (containing 60 per cent or more K_2O) is water soluble and high in hygroscopicity, and needs caution to be handled under the conditions at high temperature and humidity.

When applied to ordinary paddy fields, its fertilizer effect is similar to that of potassium sulfate, but when applied to degraded paddy soils in which root-rot is caused by the presence of hydrogen sulfide, no sulfate radical being contained, the fertilizer effect of potassium chloride is superior to that of potassium sulfate, as is the case with ammonium chloride against ammonium sulfate.

2. Potassium sulfate

Potassium sulfate (containing 48 per cent or more of K_2O) is water soluble and chemically neutral and physiologically acidic. This is most stable among chemical fertilizers and even though stored for a long time, no change in its composition is brought about. Moreover, it can be mixed with any other fertilizer. As described above, when applied to paddy fields other than degraded paddy fields, its fertilizer effect is similar to that of potassium chloride.

4. Silicic Fertilizers

Superior fertilizer effect of silicic acid which is produced as by-product of metal refinery has come to be appreciated highly since the end of World War II. As late as 1955, silicic fertilizer appeared for the first time on the market. Being composed of impurities derived from mother rocks and additions, it has complicated compositions. The principal constituent is calcium silicate (Table 4–21). According to the official standards, calcium silicate is defined to be one containing 20 per cent or more of ½N-HCl soluble silicic acid, and the calcium silicate containing 3.5 per cent or more of citrate soluble magnesium is called "calcium magnesium silicate".

Table 4 – 21. Soluble Components of Slag
(NAKAMURA)

	Total			*½N- HCl soluble*			*2% citrate soluble*		
	SiO_2	*CaO*	*MgO*	SiO_2	*CaO*	*MgO*	SiO_2	*CaO*	*MgO*
Blast furnace slag	33. 7	40. 1	6. 61	20. 7	40. 0	6. 5	18. 5	29. 5	—
Electric furnace slag	42. 1	48. 0	—	—	—	—	19. 4	27. 3	—
Ferro-manganese slag	34. 4	41. 4	—	28. 4	41. 4	—	20. 3	31. 1	—
Phosphorus slag (basic)	45. 1	46. 2	—	37. 4	44. 8	—	34. 7	36. 9	—
Phosphorus slag (acidic)	50. 9	42. 3	6. 30	2. 5	36. 9	—	2. 2	23. 2	—

Silicic acid is not an essential nutrient for the plants, but it is regarded as an essential element for rice plants. Fertilizer effect tests conducted at various agricultural experiment stations throughout the country showed that an average 9 per cent increase in rice yield was caused by the application of calcium silicate. Its optimum application amount is some 10 kilograms per are. Silicic fertilizer is suitable well for sandy soils or degraded paddy soils. Table 4-22 indicates the relationship between soil classes and the fertilizer effect of calcium silicate.

Table 4 – 22. Comparative Tests for Fertilizer Effects of Silicic Fertilizer, By Soil Classes
(OBATA)

Paddy field soils	*Brown rice yield index*
Diluvium	114. 5
Diluvium black-bog	107. 1
Alluvium (degraded)	116. 1
Alluvium (ordinary)	106. 2
Alluvium (ill-drained)	109. 8
Alluvium (wet)	104. 4
Average	111. 1

Notes: 1. Rice yield on the check plot (non-calcium-silicate plot) is taken as 100.
2. Tests conducted in 1954 at 53 places.

5. Lime Fertilizers

Among lime fertilizers are calcium oxide (quick lime), calcium hydroxide (slaked lime), and calcium carbonate. Calcium silicate is sometimes used for the same purpose as lime fertilizers.

Lime fertilizers are applied to paddy fields in order to eliminate the harmful effects of green manures and to quicken the decomposition of organic matters, but these are applied to upland chiefly for the purpose of neutralizing the soil acidity. Besides these, such effects can be cited: effect of improving physico-chemical properties of soils, multiplication of soil micro-organisms, and of increasing fixation of atmospheric nitrogen.

And, moreover, owing to the application of lime fertilizers, a part of insoluble phosphorus and potash contained in soils is converted to an available form.

6. *Composts and Stable Manures*

Stable manures are the mixture of animal dung, urine and litters, while such manures which are made by piling and ripening of materials like wild grass, straw and fallen leaves are called "composts".

Compositions of raw materials used for making compost and stable manure vary from one another, and fertilizer elements will also vary according to the making or storing methods. An example will be shown in Table 4–23.

(1) Nitrogen: Nitrogen contained in composts and stable manures is mostly organic nitrogen. As a result, its fertilizer effect is slow-acting and durable. Decomposition of organic nitrogen in a paddy field depends upon the temperatures.

(2) Phosphorus: Phosphorus contained in composts or stable manures is absorbed well by crop plants. Its fertilizer effect is regarded as similar or superior to that of calcium

superphosphate.

(3) Potash: Potash contained in composts or stable manures is mostly soluble in weak acid or water. Its fertilizer effect is almost similar to that of potassium sulfate or potassium chloride.

(4) Other elements: Composts or stable manures include various elements such as silicic acid, magnesium, calcium and others in addition to three fertilizer elements, and effects of them should not be overlooked. Besides the nutritious effects, owing to the application of such manures, soil properties are improved. Namely, with the following combined effects, these manures contribute toward the soil fertility increase.

Table 4-23. Fertilizer Elements of Composts, Stable Manures and Green Manures

Manure		*Moisture (%)*			*N (%)*		
		Max.	*Min.*	*Ave.*	*Max.*	*Min.*	*Ave.*
Composts	(Fresh matter)	78.0	66.1	72.5	—	—	0.45
	(Dry matter)	—	—	—	2.18	1.07	1.64
Stable manure	(Fresh matter)	78.9	66.1	71.1	—	—	0.54
	(Dry matter)	—	—	—	2.79	1.21	1.87
Chinese milk vetch	(Fresh matter)	91.0	87.2	89.2	—	—	0.35
	(Dry matter)	—	—	—	3.88	2.46	3.23
Soiling soybeans	(Fresh matter)	82.4	77.1	80.2	—	—	0.58
	(Dry matter)	—	—	—	3.47	2.47	2.91

(*Continued*)

Manure		*P_2O_5 (%)*			*K_2O (%)*		
		Max.	*Min.*	*Ave.*	*Max.*	*Min.*	*Ave.*
Composts	(Fresh matter)	—	—	0.23	—	—	0.48
	(Dry matter)	1.11	0.60	0.83	3.14	0.79	1.74
Stable manure	(Fresh matter)	—	—	0.32	—	—	0.58
	(Dry matter)	1.99	0.50	1.09	2.80	1.03	1.99
Chinese milk vetch	(Fresh matter)	—	—	0.08	—	—	0.24
	(Dry matter)	1.46	0.47	0.74	3.23	1.66	2.23
Soiling soybeans	(Fresh matter)	—	—	0.14	—	—	0.58
	(Dry matter)	1.04	0.42	0.72	3.48	2.10	2.93

Improvement of physico-chemical properties of soils: Owing to the increase of humus, soils are kept in the swelling and soft state, the volume-weight and specific gravity will become less, the cohesion or adhesion will be decreased, and development of soil aggregate will be accelerated, resulting in the increase of water holding capacity of soils. Rectification of soil reaction, increase in base exchange capacity or buffer capacity, increase in exchangeable bases and silicic acid content, increase in fertilizer effect of phosphorus, acceleration of activities of soil micro-organisms, as well as mitigation of denitrification of paddy field soils are also caused. However, unripened composts or stable manures consume oxygen in the process of their decomposition. This causes soil reduction and is apt to induce yield decrease in some cases.

7. Green Manures

Kinds of plant used as green manures are many, but most of them are leguminous crop plants. Above all, Chinese milk vetch and soiling soybeans are pre-eminent above the rest (Table 4-24).

Table 4 - 24. Green Manure Crops

		Chinese milk vetch	*Soiling soybeans*	*Other crops*
1955	Planting area (1,000 ha.)	182	22	17
	Production (1,000 tons)	2,986	203	197
1959	Planting area (1,000 ha.)	142	19	12
	Production (1,000 tons)	2,296	157	189

Since leguminous crop plants grow by utilizing atmospheric nitrogen, much nitrogenous fertilizers are needless to apply them. Owing to the strong absorption of nutrients other than nitrogen, nutrients contained in the subsoil are collected up to the surface soils. Physico-chemical properties of top soils and subsoils are also improved. Depletion of soil humus being checked, the soil fertility is increased. In addition, leguminous crops can be cultivated with ease. In view of this, leguminous crop plants can be said to be valuable green manure crops.

Green manures are readily decomposed in soils. In this case, however, soil oxidation-reduction potential will be lowered and organic acid will be formed. As a result, the development of paddy rice plant roots are sometimes affected adversely depending upon the conditions of paddy fields. When green manures are applied by combining with lime fertilizer, the organic acid is neutralized by the action of lime, and the coagulation and precipitation of soil colloids are hastened and the water permeability is accelerated. As a result, the injurious effects will be mitigated. Moreover, it is recognized that when applied in the dried state, the formation of organic acid in soils becomes less than in case where green manures are applied in the fresh state.

Green manures applied to the soils are readily decomposed (e.g., when applied to paddy fields green manures will be decomposed in one or two weeks during the summer months) and the nitrogen changes to ammoniacal nitrogen, thus exerting the fertilizer effect similar to that of ammonium sulfate. When green manures are applied, the decomposition of the organic matter which has already been contained in soils is hastened and the fertilizer effects of nitrogen and phosphorus are increased. The results of lysimeter experiment conducted by KONISHI indicate that nitrogen contained in green manures (Chinese milk vetch) is more resistant to leaching than that of nitrogen contained in ammonium sulfate. Particularly, it is generally accepted that nitrogen in green manure gives a long-lasting effect in the paddy field with a great percolation such as shallow top soils or degraded paddy field.

Green manures must be plowed under at least two weeks prior to the transplanting and the paddy fields must immediately be brought under irrigation. If delayed in irrigation, a part of nitrogen will become nitrate-form and flown away by irrigation. When plowed under immediately before transplanting, the rooting of seedlings will be injured. The optimum amount of application for rice culture is around 200 kilograms per are in warm areas and some 100~150 kilograms per are in cold areas. It is also desirable to apply slaked lime at the rate of five kilograms per 100 kilograms of fresh green manures.

8. Compound Fertilizers (Mixed Fertilizers)

Compound fertilizers, as used in the Fertilizer Control Law, are defined to mean the fertilizers containing two or more elements of the three fertilizer elements (N, P_2O_5 and K_2O). Compound fertilizers are grouped into five classes as follows:

(i) Class 1 compound fertilizer: A total percentage of N, P_2O_5 and K_2O must be 15 per cent or more;

(ii) Class 2 compound fertilizer: A total percentage of N, P_2O_5 and K_2O must be 7.5 per cent or more;

(iii) Class 3 compound fertilizer: Liquid fertilizer containing two or more of the three fertilizer elements, or fertilizers adsorbed by bentonite, peat or diatom earth and containing 5.0 per cent or more N, 3.0 per cent or more P_2O_5, and 2.0 per cent or more K_2O, respectively;

(iv) By-product (fertilizer) of sodium glutamate: Fertilizer containing 5.5 per cent or more N, and 1.0 per cent or more K_2O (1.0 per cent or more P_2O_5);

(v) By-product, ammonium potassium chloride: Fertilizer containing 13.0 per cent or more N, and 5.0 per cent or more K_2O.

Of the above five groups of compound fertilizers, Class 1 compound fertilizer is overwhelmingly great both in production and kinds. Class 1 compound fertilizer is again subdivided into various kinds according to the manufacturing methods and the forms of nitrogen or phosphorus. For convenience of easier handling and easier application by using machines, and for the purpose of raising in fertilizer effects, compound fertilizers are marketed in granular form.

IV. METHODS OF FERTILIZER APPLICATION TO PADDY FIELDS

The results of the experiment for the three fertilizer elements conducted on the principal paddy fields in Japan are as given in Table 4–25. Table 4–25 indicates clearly that the yields of paddy rice, wheat or barley in non-N plots are lowest next to those in non-fertilizer plots, but the paddy rice yields in non-P plots or non-K plots show no great difference from those in NPK plots, namely, this fact indicates that the rice yields are affected most by the fertilizer effect of nitrogen.

Table 4–25. Three Fertilizer Elements Tests

(Average for the entire country)

Crop	*Three element plot (NPK)*	*Non-N plot (KP)*	*Non-P plot (NK)*	*Non-K plot (NP)*	*Check plot*	*Number of test*
Paddy rice						
Pot test	100	55	89	88	53	2,850–2,898
Field test	100	83	95	96	78	1,161–1,187
Wheat or barley						
Pot test	100	34	62	81	26	1,937–1,991
Field test	100	50	69	78	39	822– 841

1. Methods of Basic Application of Fertilizer

1. Nitrogen

When a paddy field is submerged, top soils are differentiated into two layers: oxidation layer and reduction layer, and the change will take place in the form of nitrogen, thus causing the loss of nitrogen. In order to minimize the loss of nitrogen, the method of applying fertilizer throughout the top-soil layer is devised (Table 4-26). In carrying out such fertilizer application, if not submerged as early as possible (within 3 or 4 days), ammonia would be converted into nitrate, and after submergence nitrate would flow away or denitrification would occur (Table 4-27). A "ball" fertilizer application method is by far more intensive than the whole top-soil layer placement. SUZUKI et al. made ball fertilizer weighing 70-80 grams each by mixing urea with earth, and on the tenth day after transplanting one ball fertilizer per 4-hills was placed at 6-7 centimeters deep at the center of 4 hills. The test results are given in Table 4-28.

Table 4-26. Whole Top-soil Layer Placement of Ammonium Sulfate to Paddy Rice Fields

(Shiga Agr. Exp. Sta.)

Plot	*Brown rice yield*	*Amount of N-absorbed*	*Percentage of ammonium sulfate-N absorbed*
	kg/a	kg/a	
Before plowing application	51.41	0.95	47
After first-plowing application	49.44	0.97	48
After harrowing application (submerged immediately after mixing with mud)	45.06	0.82	33
Before puddling application	40.52	0.73	23
After final-puddling application	39.01	0.70	20
Non-N plot	31.30	0.51	—

Table 4-27. Whole Top Soil Layer Placement of Fertilizer and Rice Yields, by the Upland and Submerged State

Plot	*Rice yields*	
	When left in upland state	*When left in submerged state*
	kg/a	kg/a
Non-N plot	25.70	25.70
20 days before puddling	32.51	46.87
15 days before puddling	37.20	47.78
10 days before puddling	48.08	52.47
5 days before puddling	49.75	57.61
On the day of puddling	52.16	—

Table 4-28. Fertilizer Effect Tests for Ball Fertilizer (SUZUKI, 1953)

Plot	Rice yield	Application methods
Check plot (Non-N)	kg/a 28. 27	
Urea plot	50. 35	Urea (1. 5 kg/a) was applied before final puddling; and urea (0. 5 kg/a) at tillering stage.
Urea ball fertilizer plot	51. 56	Ammonium sulfate (0. 54kg/a) was applied before final puddling; urea ball (1. 97 kg urea per are) 10 days after transplanting; and ammonium sulfate (0.54 kg/a) at time of "*Hogoe*".

In the case of submerged paddy fields, it is better to mix calcium cyanamide with mud 10–20 days after its application. Granular fertilizer would readily permeate the soils when the soils are stirred immediately after irrigation. In the case under extremely low temperature, it is better to scatter some portion of fertilizer on the soil surface for the purpose of hastening the plant growth.

2. *Phosphorus*

As the results of three fertilizer element tests indicate, paddy fields in Japan are abundant in natural supply of phosphorus. Consequently, no marked difference is observed in the rice yields whether phosphatic fertilizers are applied or not. However, this fact does not imply that the application of phosphatic fertilizers is needless, but it implies that, under high temperature of submerged paddy field soils, the insoluble phosphorus contained in soils becomes available to a greater extent. The amount of natural supply of phosphorus varies with the climatic and geological conditions (Fig. 4–5 and Table 4–29). Namely, the fertilizer effect of phosphorus becomes less according as the climate of areas becomes warmer. The Kanto District only is the unusual case, owing to the wide distribution of volcanic ash soils. Paddy fields in the

Tohoku District are mostly of volcanic ash soils, while paddy fields in West Japan are mostly of granite soils rich in natural supply of phosphorus. For a series of the above reasons, the fertilizer effect is greater in the Tohoku District, while that in West Japan is less.

Fig. 4-5. Fertilizer Effect of Phosphatic Fertilizer, by Regions

Note: Yield index on non-P plot, taking the yield on NPK-plot as 100.

Table 4-29. Paddy Rice Yield Index in Non-P Plots, by Geological Group of Soils

(*NPK plot*=100)

Geological group	*Rice yield index*
Granite	90.8
Paleozoic strata	89.8
Quaternary new strata	89.2
Tertiary	89.0
Quaternary paleozoic	86.3
Volcanic ash	79.9

HAYASHI et al. examined the grain production efficiency of phosphorus absorbed by rice plants by the use of solution culture method (Table 4-30). Table 4-30 indicates that the efficiency for grain production is high with phosphatic fertilizer applied until early-July. Moreover in paddy fields the soil reduction proceeds after submergence and the phosphorus accumulated in soils will become effective. From these reasons, it is better to apply phosphatic fertilizer mainly as basic fertilizer. When applied as fertilizer, phosphorus will be fixed in soils due to the various causes and converted into insoluble form. Even in the case of water soluble phosphorus like calcium superphosphate, the absorption rate in the year in which it was applied is at some 10–20 per cent. Phosphorus which was fixed once will afterwards become again available for crop plants in the case of paddy field. Phosphorus fixation varies with soil reaction, silica-aluminum ratio, and soil classes.

Table 4 – 30. Efficiency in Grain Production of Phosphorus Applied at Different Stages of Plant Growth

Plant growth period (Date)	*Grain-producing efficiency*		
	Moderate application	*Medium application*	*Liberal application*
June 29—July 8	144	270	193
July 8— 17	245	167	300
July 17— 29	213	285	197
July 29—Aug. 7	139	64	51
Aug. 7— 19	136	74	30
Aug. 19— 28	−1,433	27	−21
Aug. 28—Oct. 2	—	−1	—

Concentration of available form phosphorus contained in soils is, in the case of alluvial paddy fields, generally 30 milligrams or more per 100 grams of dried soil, but some 5 milligrams in the case of volcanic ash soils. In order to obtain husked rice of about 40 kilograms per are, it is generally accepted that the concentration of 15 milligrams or more is desirable. As a result, in the case of volcanic ash paddy fields, it is necessary to apply more liberally than to alluvial paddy fields.

3. *Potash*

Amount of potash which has been absorbed by rice plants up to the time of harvesting is rather more than nitrogen absorbed. The results of the three fertilizer element tests, as described before, indicate that the fertilizer effect of potash on paddy yield is very low. The reason for this is found in the supply of potash from irrigation water and due to the decomposition of potash-content clay minerals contained in soils. A great quantity of potash is also provided from composts.

In general, it is accepted that the optimum amount of potash fertilizer application is some 80 per cent of the amount of nitrogenous fertilizer application. However, the balance with other elements, particularly with nitrogen, should not be overlooked. Namely, the amount of potash fertilizer application is required to be increased with the increase in the amount of nitrogenous fertilizer application.

2. Top Dressing Method

1. Nitrogen

In cold region like Hokkaido, it is general that nitrogen is applied chiefly as basic fertilizer and no top dressing is practised. But in other regions the rice yield will be increased

Table 4 – 31. Experiment on Method of Ammonium Sulfate Application

Ammonium sulfate application (kg/a)				*Brown rice yield (kg/a)*
Basic fertilizer	*Mid-July*	*Late-July*	*"Hogoe" at panicle primordia initiation stage*	
0	0	0	0	39. 31
3. 02	0	0	0	47. 33
2. 27	0. 76	0	0	45. 36
2. 27	0	0. 76	0	47. 78
2. 27	0	0	0. 76	53. 07
0. 76	0. 76	0. 76	0. 76	51. 26
1. 51	0. 76	0. 76	0	46. 12
1. 51	0. 76	0	0. 76	50. 50
1. 51	0	0. 76	0. 76	51. 26

Note: Basic fertilizer is placed throughout the top soil layer. Split application is made on July 15 and July 25, and *Hogoe* on August 5.

by giving the top dressing.

An example of ammonium sulfate application to paddy yields in the warm parts of the country is illustrated in Table 4–31.

Table 4–31 indicates that the *Hogoe* (it literally means the fertilizer for panicle), i.e., application of ammonium sulfate at young panicle initiation stage (20–25 days before heading) is very effective in increasing yield, and when basic fertilizer is placed throughout the top soil layer, it is profitable to apply a great part of nitrogen as basic fertilizer and to apply the remaining part as *Hogoe* at the young panicle initiation stage. It is accepted that *Hogoe* application makes the living function of rice plant during the period from young panicle formation to heading more active (e.g., the concentration of chlorophyll and carotinoid and the enzyme activity of catalase and amylase are increased and the panicle growth is affected favorably). However, no effect of the *Hogoe* application is observed either in the case of such paddy field as may not run short of nutrient even in the later plant growth period owing to its highly fertile soils, nor in the year of unfavorable weather conditions. The amount of fertilizer application at time of panicle initiation stage is not required so much, e.g., 0.4–0.8 kilograms per are of ammonium sulfate will do.

When applied to degraded paddy fields, the effect of *Hogoe* application is generally great. In the case of paddy field soils poor in monovalent base absorption capacity or great in percolation losses of water, it is better to adopt the split application at the intermediate period between basic application and *Hogoe* application.

In the case of rice plants in cold regions, unlike those in warm regions, young panicle initiation stage comes prior to a maximum number of tillers stage. Top dressing of nitrogen at the stage of panicle initiation, therefore, causes an increased production of uneffective tillers, resulting in a low percentage ratio of effective tillers to total number of tillers, and also induces an impeded ripening when much nitrogen remains available after the maximum tillers stage.

2. Phosphorus

The fertilizer effect of phosphatic fertilizers is great when applied during the period from the incipient stage to middle stage of rice plant growth, but the effect is low when applied in the later growth period. Phosphorus which had been applied in past time and accumulated in soils becomes soluble from around July when microbial activity becomes animated with the rise in temperature. As a result, when phosphatic fertilizers have already been applied sufficiently, no spilt application is required, except for special cases.

3. Potash

Potash is the element absorbed by plants till the later growth period as compared with nitrogen or phosphorus, but in general no split application is required when potash has been applied as basic fertilizer. However, when potash fertilizer applied liberally in order to obtain heavy rice yield, the split application of potash fertilizers is preferable, taking into consideration the antagonism of potash against NH_4 and Mg. In the case of paddy fields of sandy soils or volcanic ash soils poor in potash holding capacity, the split application of potash fertilizer is more preferable than the basic dressing of the entire amount, which causes a great loss by leaching. OGIHARA reported that the top dressing ten days before young-panicle formation stage is most effective. SUZUKI evidenced that physiological disease (known as *Aogare*) of rice plants observed in warm regions is due to the nitrogen-oversupply and potash-deficiency. It has become evident that when potash is applied sufficiently at invalid tillering stage, rice plants become markedly resistant to *Aogare* and the injury due to the oversupply of nitrogen can also be overcome. In view of this, in the case of paddy fields in warm regions, it is better to adopt the method of split application of potash fertilizer 35–40 days before heading (i.e., at earlier time than nitrogen application of *Hogoe*). The basic application and top dressing at the ratio of 50:50 is optimum.