3-18. VARIOUS FACTORS IN FERTILIZER APPLICATION

Fertilizers have a strong effect on yield increase in rice culture. Therefore, fertilizer application technology is regarded as a yield increase measure which can be rather easily extended. The actual acreage of manured fields, however, is still small in the rice production areas in the tropics, although it is expected to expand.

Radical fertilizer application is a flexible technique influenced by such natural environmental conditions as soil, climate and weather, or irrigation and drainage facilities in the rice cultivation areas, and by such technical factors as characteristics of rice varieties, kinds and application methods of fertilizers as well as by social and economic conditions. The aim of fertilizer application technology can be said to be to maximize fertilizer response in rice cultivation, in conformity with the above mentioned conditions. In this respect, fertilizer application should be planned on the basis of the cropping season and duration, selected varieties, soil and irrigation facilities, diseases, pest protection, as well as the indicated countermeasures. Moreover, in order for fertilizer application to be fruitful, smooth distribution of fertilizer, funds for importing fertilizer and encouragement of domestic production are desirable. The above arrangements are necessary to avoid such undesirable situations as: after a systematic fertilizer application method has been built up through various field experiments and research findings have been given to farmers, the farmers are unable to get the said fertilizers adequately because the supply in the local market is insufficient when it is needed.

When a paddy yield increase project is designed using high-yield varieties with high fertilizer response, it is necessary, first, to balance the price of applied fertilizers against the value added by applied fertilizers (VCR), second, to consider the rate at which fertilizers are absorbed by the rice plants (recovery rate), and finally, to evaluate the efficiency of the application method. For example, in the case of staple food crops, fertilizer application is generally evaluated using 3-3.5 as a standard VCR-value (see below). Higher VCR-value has been noted in high yield varieties than in local improved varieties (Ito, 1974).

3-19. NUTRITIVE CHARACTERISTICS OF UPLAND RICE

Systematic fertilizer application requires an understanding of the nutritive changes at every stage of the rice plant growth cycle. There are generally three nutritional stages in the growth of upland rice, as shown in Fig. 3-13, although some differences may be seen in the growing and nutritive states between varieties and under differing environmental conditions.

1) Vegetative growth stage: nutrients for protein production such as nitrogen, phosphorus, and sulfur are the most actively absorbed and the plant body contains large quantities of those components.

*VCR - Price of product increased by fertilizer cost.

2) Reproductive growth stage: the rate of photosynthesis increases and nitrogen content in the body decreases, but cell membrane substances such as cellulose and lignin are produced rapidly. Nitrogen and phosphorus components are continuously absorbed and so is magnesium.

3) Ripening stage: accumulating starch, components such as nitrogen, phosphorus, magnesium, sulfur, etc. are transmitted to ears; ears fill out at this stage.

Potassium and calcium are absorbed throughout all these stages.

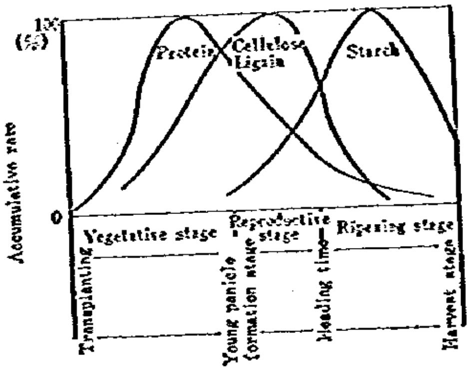

Fig. 3-13 Change of accumulative rate of organic compound at successive stages of growth in rice plant.

Compared with upland crops, lowland rice characteristically shows rather low contents of calcium and magnesium but a high content of silicic acid. Silicic acid is not always an essential component for the growth of the rice plant but it is useful for healthy plant growth and that has a bearing on high yield.

Silicates and potassium components are transmitted only at a low rate to panicles but accumulate in foliage.

Each component element has an influence on yield. Nitrogen, phosphorus and sulfur deficiencies cause decrease in the number of heads and grains per head, and deficiencies of potassium, calcium and magnesium decrease the rate of grain ripening and 1,000 grain weight.

Unit weight of nutrients absorbed by rice plants and which contribute to increased grain production is called "partial production efficiency of paddy" (PPEP).

With PPEP, we can determine the efficiency of nutrients in each growth stage. This is very helpful in setting up a fertilizer application method. It is generally agreed that the PPEP of each element shows that nitrogen application is highly efficient at the tillering and the young panicle elongation stages, phosphorus at the tillering stage and potassium at the non-productive tillering stage. Absorption of each of the three elements, N.P.K., however, shows positive correlation with grain production until the middle stage of heading. The above nutritional characteristics of rice plants show that the background of the fertilizer application method with nitrogen applied as a split dressing of basal with top dressing at the panicle formation stage, phosphorus as a basal dressing and potassium, mainly as a basal dressing, partially at the young panicle formation stage. But it is natural that the supply rate of nutrients from applied fertilizers will change with the fertility of paddy field soils.

3-20. SELECTION OF FERTILIZER

Nutrients needed for rice plant growth are generally supplied from the soil and irrigation water but out of these nutrients large amounts of nitrogen, phosphorus and potassium are required by rice plants and these three are also taken from fields in large amounts as yield. Therefore, we cannot maintain productivity of paddy fields without adequately supplementing the nutrients absorbed and taken away with the cultivated plants, using fertilizer containing these three elements. Moreover, yield increase requires active fertilizer application to improve the fertility of field soil. At present, in tropical areas, however, the greatest importance is attached to nitrogen and phosphorus is also being applied comparatively frequently but potassium is rarely used. Sometimes the effects of calcium, zinc, and silicic acid are also recognized in special paddy field soils. The types of fertilizers applied in tropical paddy fields are generally urea and ammonium sulphate as nitrogen fertilizers, superphosphate as phosphorus and potassium sulphate and potassium chloride as potash ammophos as well. But hereafter how to select fertilizer types suitable to the soil is a problem. As mentioned above, the types of fertilizers applied to paddy fields are mainly single element manures, but the use of compound types of fertilizers is also expected to be extended since every country is now thinking of high-analysis compound fertilizers. There is some interest in slow-release fertilizers, but this type cannot be expected to be beneficial in tropical rice cultivation in which labor-saving is not needed in agriculture. This kind of fertilizer is comparatively expensive and does not meet its VCR-value since the slow-release function has no special effect on yield.

Since a fertilizer application technique simply using chemical fertilizers may not be able to take the place of the productivity of land completely, utilization of organic fertilizers is also important. Application of rice straw or green manure like sun-hemp (*Crotalaria juncia*) etc. to paddy fields is sometimes not inferior to chemical fertilizers as a supply of nutrients to rice plants. And application of compost and barnyard manure are especially effective in sandy soil paddy fields (Inada, 1965; Ralph and Ramlath, 1960); self-supplied manures are very useful, although their production and transportation is somewhat laborious.

3-21. RECOVERY RATE OF FERTILIZERS AND FERTILIZER APPLICATION METHOD

Nutrient absorption by rice plants will fluctuate with differences in the state of nourishment, root development and spread, activity of rice plants and different soil conditions. Therefore, the amount of nutrients existing in the soil is not always directly connected with fertilizer response. Generally, rice plants cannot absorb all the nutrients contained in the applied fertilizers. A part of the fertilizers applied in the fields becomes ineffective through leaching, run-off and gasifying, and another part may also become ineffective through being fixed in the soil in a form which cannot be absorbed by rice plants.

Thus, in order to evaluate the actual effect of applied fertilizers at the locality of growing rice, "recovery rate of applied fertilizer" is used. For example, the recovery rate of nitrogen fertilizer can be obtained by the following formula providing sufficient phosphorus and potassium are applied:

$$\text{Recovery rate of applied N-fertilizer} = \frac{\text{Absorbed amount of N. (at N. fert. app. plo)} - \text{Absorbed amount of N. (at non-N. app. plo)}}{\text{Amount of N-fertilizer application}} \times 100$$

Using a fertilizer labeled with heavy nitrogen (^{15}N), the recovery rate of nitrogen can also be obtained from the amount of nitrogen absorbed by rice plants separately with different resources of the fertilizer and soil (Koyama, et al., 1972A) (see Tables 3-14 and 3-15). The benefit of fertilizer recovery rate is to be utilized in figures for the evaluation of the relative merits of various forms of the same elemental fertilizers or those of different application methods, and also to be utilized as a computation basis to establish a fertilizer application plan for certain paddy fields.

Recovery rate of applied nitrogen fertilizer in ordinary fields is usually 20-50%. The measures which can raise the nitrogen recovery rate are, (1) whole-layer application, (2) split dressing, (3) protection against leakage in leaking fields, and (4) application of slow-release fertilizers, etc. In Indonesia, a kind of ball-fertilizer used for slow-release was helpful in improving the nitrogen recovery rate (Ismunadji, et al., 1973A). The recovery rate varies with different kinds of soil; for example, high recovery rate of nitrogen is seen in the paddy fields* of Montmorillorite clay soil while it was low in the fields of Lateritic soil.

The recovery rate of phosphorus in fertilizer is usually as low as 10-20% because it is easily fixed in soil. The recovery rate can be improved to some extent by weakening the ability of the soil to fix phosphoric acid. For example, maintaining high soil acidity by application of lime or compost. On the other hand, in the case of phosphorus fertilizer application, these techniques can be helpful in enhancing the effect of phosphorus: (1) mixing the phosphorus fertilizer with compost, (2) not broadcasting but applying only at certain parts of the soil layer, (3) using granulated fertilizer, citric-soluble phosphoric or poly-phosphoric acid fertilizers.

The recovery rate of potassium fertilizer is usually as high as 40-70%. However, it is low in the paddy fields in which the soil has low capacity for alkalinity-exchange or is sandy and has a high risk of leaching. Recovery could be increased by split-dressings in such cases.

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* Paddy fields of which the clay minerals are Montmorillorite.

Table 3-14 Plant growth, grain yield and uptake of nitrogen at several levels of nitrogen application (1)

KOYAMA

Level of nitrogen (kg/ha)	Time of nitrogen application: Basic	I.M.**	I.P.P.***	F****	Plant height (cm)	Nitrogen content in plant %	Nitrogen utilized by plant (kg/ha): Total N	^{15}N from fertilizer	^{14}N from soil	Contribution of fertilizer ^{15}N in plant %
0	0	0	0	0	86.8	0.69	32.0	0	32.0	0
37.5	37.5	0	0	0	92.3	0.70	43.3	5.4	37.8	12.5
56.2	56.5	0	0	0	83.6	0.72	41.7	8.9	32.8	21.4
75.0	37.5	0	37.5	0	100.7	0.76	61.7	20.0	41.7	32.4
75.0	37.5(AM)*	0	37.5	0	101.9	0.73	68.8	22.1	46.7	32.1
75.0	18.7	18.7	37.5	0	97.4	0.77	57.3	18.1	39.2	31.6
75.0	0	37.5	37.5	0	100.9	0.76	69.2	23.5	45.7	34.0
93.7	18.7	18.7	37.5	18.7	95.7	0.83	71.1	32.6	38.5	45.9
93.7	18.7	18.7	56.2	0	103.3	0.79	64.1	28.5	35.6	44.5
93.7	56.2	0	37.5	0	103.0	0.78	67.8	25.5	42.3	37.6
93.7	37.5	18.7	37.5	0	106.9	0.82	76.0	23.8	52.2	31.3
112.5	37.5	18.7	37.5	18.7	100.7	0.87	75.2	32.3	42.9	43.0
112.5	37.5	18.7	56.2	0	107.8	0.84	73.3	34.7	38.6	47.3
112.5	75.0	0	37.5	0	104.6	0.76	72.1	29.7	42.4	41.2
112.5	56.2	18.7	37.5	0	100.9	0.79	68.8	25.4	43.4	36.9
131.2	56.2	18.7	37.5	18.7	106.4	0.91	83.3	41.7	41.6	50.1
131.2	56.2	18.7	56.2	0	106.9	0.82	63.8	30.7	33.1	48.1

* Nitrogen fertilizer is mixed with AM (2-amino-4-chloro-6-methyl pyrimidine)
** I.M. 20 days after transplanting
*** I.P.P. 30 days before flowering
**** F Flowering stage
Remarks: Figures in braket indicate using heavy nitrogen (^{15}N-isope)

Table 3-15 Plant growth, grain yield and uptake of nitrogen at several levels nitrogen application (2) (Continude)

KOYAMA

Recovery rete of fertilizer %	Yield Component: Number of panicles	Number of spikelets	Percentage of ripened grains %	Weight of 1000 grains	Yield of paddy (t/ha)	Weight of straw (t/ha)	Total number of spikelets per m²
0	8.9	65.5	71.1	21.4	2.32	2.34	14570
14.4	9.4	81.4	72.4	21.7	3.20	2.93	19534
15.8	9.6	91.3	77.8	23.7	4.18	2.57	22680
26.7	10.3	116.2	67.6	22.3	4.53	3.12	29922
29.5	10.4	118.8	64.0	23.0	4.55	3.88	30888
24.1	9.8	111.9	69.6	22.4	4.23	3.09	27416
31.3	10.0	111.6	70.5	23.3	4.51	3.67	27900
34.8	10.0	122.5	74.2	22.6	5.14	3.29	30625
30.4	10.5	126.6	67.1	24.0	5.33	3.45	33233
27.2	10.3	125.6	70.3	23.3	5.29	3.45	32342
25.4	10.6	123.0	69.1	22.8	5.13	4.15	32595
28.7	10.6	112.9	71.9	22.5	4.85	3.55	29919
30.8	10.9	119.4	69.7	22.8	5.18	3.56	32537
26.4	10.9	125.5	68.8	23.6	5.53	3.93	34199
22.6	10.9	119.3	70.5	23.6	5.39	3.78	32509
34.1	10.5	123.5	69.8	23.0	5.15	4.33	32419
23.4	10.8	125.4	68.1	22.6	5.19	3.37	33858

3-22. FERTILIZER RESPONSE OF RICE VARIETIES

Indica rice varieties are generally tall with vigorous vegetative growth and a strong ability to absorb nitrogen, but their yield increase from nitrogen application is rather small, showing a low grain/straw ratio, and the plants are liable to lodge. However, Bulu type varieties having good quality rice have weak tillering ability and their fertilizer application response is lower than that of indica type. With their vigorous vegetative growth, indica varieties are liable to be over-luxuriant and have severe mutual shading of foliage when fertilizers are applied heavily. This over-luxuriant growth results in unbalanced photosynthesis with respiration of plant body causing reduced productivity of dry matter and eventually the effect of applied fertilizers cannot be realized. Thus, varieties adaptable to heavy application of fertilizers and highly efficient in absorbing the sun's energy have been bred. A breeding project with hybridization between indica type local varieties having tropic adaptability and high-yield japonica type varieties with heavy fertilizer tolerance was carried out and several promising varieties have resulted. Also, IR 8 bred by a hybridization between Indonesian and Taiwanese varieties is a typical heavy-yield variety with a high ability to ripen grains. It keeps the abortive grain rate low even under heavy fertilizer application since it is resistant to lodging with its short and strong culms and is highly efficient in absorbing sunlight (Kurashima, 1971). Thus, IR 8 and IR 5 are now being extended in various places in the tropics. In the meantime, with improved Malaysian varieties, 4.8 tons/ha of grain yield have been recorded, with Ria, under 134 kg/ha of nitrogen application and with Bahagia, under 90 kg/ha (Chee, 1969). Indonesian Pelita has achieved the same rate of yield as IR 5 under 90 kg/ha of nitrogen application but it has better quality than IR 5 (Zainuddin, 1971).

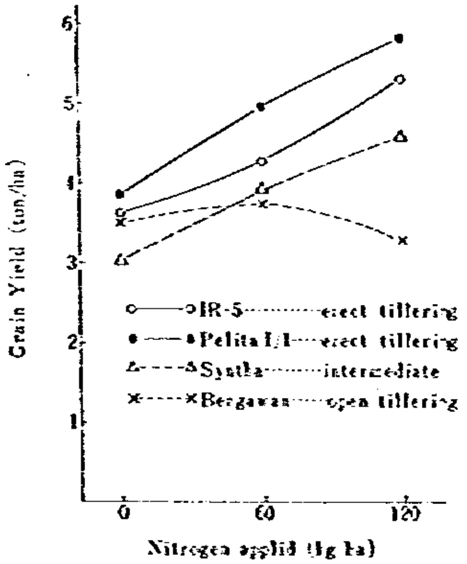

Fig. 3-14 Effect of 3 levels of Nitrogen on the grain yield of rice varieties.

Fig. 3-14 shows responses to nitrogen application of several lowland rice varieties having different plant types, and it can be seen from this that erect tillering types have better response to nitrogen application than open tillering types.

Varietal difference was recognized in Thailand among the growth rates of lowland rices on phosphorus deficient soil (Koyama and Chammek, 1971A; Koyama and Chammek, 1971B). Therefore, when a variety susceptible to phosphorus deficiency is to be grown, an application of phosphorus fertilizer may be necessary after a soil analysis.

Along with the high yield variety breeding aimed at getting better adaptability to heavy manuring, further improvement is expected from varieties having high photosynthesis capacity during the ripening stage, which thereby produce a more constant number of grains per unit area as well as greater volume and weight. A long and healthy life of leaves provides security for maintaining good nutrient conditions during the ripening stage, and thereby results in maximum display of the characteristics of the variety. Thus, soil management involving manuring techniques during the ripening stage and maintaining a healthy root system is also essential as a countermeasure of the above.

3-23. NITROGEN APPLICATION

Nitrogen has the most influence on the growth rate and yield of rice plants. When an adequate amount of nitrogen is applied to rice plants, it promotes their growth and tillering, contributing to flourishing green leaves, and make the nitrogen metabolism and photosynthetic activities smooth. Excess absorption of nitrogen, however, may induce over-luxuriant growth, lodging and severe diseases while nitrogen deficiency induces remarkably poor vegetative growth. Therefore, both excess and lack of nitrogen eventually result in grain yield decrease. To diagnose healthiness in the nitrogen nutrition of rice plants, the best method is to confirm nitrogen response on paddy yield with a field test in order to determine an adequate application rate. This can also be decided by observation and chemical analysis of rice plants or soil analysis. Also, an adequate rate of nitrogen application can be decided taking account of the utilization rate of nitrogen fertilizer and the natural assimilation rate, surveying the nitrogen content of the field soil and irrigation water.

Nitrogen fertilizers are generally applied basally three times with two additional top-dressings at the tillering and young panicle formation stages. If the basal dressing or natural supply of nitrogen becomes short, a top-dressing at the tillering stage may be effective, but increasing the utilization rate by whole layer application of nitrogen, two basal split dressings at the panicle formation stage may give good results. As for fertilization of panicles, top-dressing is done at their differentiation stage examining transition of growing features of rice plants so far. If this top-dressing is done earlier, it may cause elongation of inter-nodes at the lower part of culms, absorbing nitrogen here, and results in lodging. The spikelet (panicle) differentiation stage in rice plants may vary with different varieties and those of short term varieties have been reported as about 20 days before heading; but that the optimum time for top-dressing for panicle formation in Thailand has been regarded as 25-30 days before heading (Koyama, et al., 1972B), may be due to the predominance of long term varieties there (see also Paragraph 4-2-5).

Recent findings showed that top-dressing in the later part of the growing period is effective. But top-dressing at the booting stage and at the heading stage should be done after the growing feature and nutritive state of the rice plants are examined. When the plant growth extends beyond the vegetative growth period and is luxuriant but dropping due to a nitrogen deficiency in the reproductive growth period, top-dressing later in the growing period may be effective, for example, in sandy soil fields having poor ability to maintain nutrients or in Akiochi type fields.

Fertilizers containing nitrogen in the form of nitrate are generally considered to be unsuitable to paddy fields because they tend to run off in water, but with the recent development of top-dressing techniques, the effect of nitrate fertilizers is better understood.

The application rate of nitrogen differs with the actual conditions of the paddy and the season, but is generally regarded as 60 kg/ha of nitrogen for local *indica* varieties and Bulu type varieties while it is 90-120 kg/ha for heavy yield and heavy manuring improved varieties.

In areas suffering from a lack of irrigation water facilities and diseases and pests, the yields of rice in dry season cropping is not always inferior to that in the rainy season. An experiment carried out in Thailand using high yield varieties showed that the yields were higher in dry season than rainy season, and their response to nitrogen was expressed in an increase in the numbers of tillers and ripened grains, and resulted in grain yield increase (Chalernkiat et al., 1969).

3-24. PHOSPHORUS FERTILIZER APPLICATION

Applied phosphorus fertilizers are absorbed by rice plants in the form of orthophosphoric ion (H_2PO_4). Absorbed phosphoric acid is taken into nucleic acid, nucleo protein and phosphorus oil, which are important components of protoplasm, and contributes to cell division, producing growth and morphogenesis of the plant. Also, phosphorus compounds play such extremely important physiological roles in the rice plant as carbonhydrate assimilation, glycolysis, and energy metabolism.

Therefore, phosphorus as well as nitrogen is an important element in the growth of rice plants and is especially necessary for tillering. Shortage of phosphorus in an early growing stage of rice plant severely checks growth rate and no effect will be seen on recovery even if phosphorus is applied at a later stage of growth. At the later stage of rice plant growth, the paddy field soil is in a reduced condition and thereby a part of the phosphorus becomes available, so the plant roots can rather easily absorb phosphorus nutrient. For the above reasons, phosphorus must be applied sufficiently at the early stage of growth and be absorbed by rice plants. Thus, phosphorus fertilizers are generally applied by basal dressing. Phosphorus-deficient soils are common in India, Thailand, Indonesia, Sri Lanka and Pakistan, and phosphorous fertilizer response can be seen in these paddy fields. The effect of phosphorus application was especially remarkable in the paddy fields in grumusol soil areas and in acid sulfate soil areas. Also, the effect was seen in the paddy fields of weathered tuff soil and latosol.

As for soil having a high capacity to fix applied phosphorus, an application by mixing fused phosphorus with concentrated superphosphate or by using it as a starter will improve the fertilizer response. Besides, the effect of phosphatic rock application has long been discussed, and the effect of Ca-phosphate on podosol was seen as stemming from quarzandesite. Phosphatic rock was rather effective also on Laterite. Al-phosphate is notably effective on Marl soil (Hackengerg, 1969).

The proper amount of phosphorus to apply in paddy fields is generally regarded as about 50 kg/ha and broadcasting and localized placement are more effective than whole-layer placement. In the case of using granular compound fertilizer, the phosphorus fixing effect on soil is slight even in the whole-layer placement method.

3-25. POTASSIUM FERTILIZER APPLICATION

Potassium is an essential element absorbed by rice plants throughout their whole growing life. Since it is easily absorbed by soil colloid, that is, good maintenance, the total amount of potassium application can be dosed as basal dressing on soils containing a considerable amount of clay or humus. However, a top-dressing of potassium can be made more effective by dividing a part from the total, in degraded paddy fields, poorly drained or leaking ones. Also, on soil having a low capacity of cation-exchange, a split dressing would be better at the same time with rates the same as those of nitrogen application.

In the paddy fields of Southeast Asia, a good amount of potassium is generally supplied naturally from soil. Therefore, potassium application is taken less care of. The general idea is that potassium would not be short since soils and irrigation waters contain plenty of potassium nutrients and rather less potassium is taken away from paddy fields with harvested products. However, it has been clear with "Mentek," a physiological disease of rice plants, occurring in a grumusol paddy field, that potassium content in the plant body was less than 1%, clearly a potassium deficiency. Potassium application there resulted in a doubled yield (Ismunadji et al., 1973A). Table 3-16 shows the above experimental result obtained in Indonesia. Also in the Philippines, potassium deficiency has been a problem with a calcareous soil stemming from coral, and a notable yield increase can be expected from potassium application of more than 50 kg/ha. This yield increase is more remarkable with the improved varieties. In this case, the assimilable potassium content of this soil was as low as 0.1 me/100g.

Table 3-16 The effect of potassium on yield component and yield of rice in Chihea problem field.

Treatment	No. of panicles/hill	No. of spikelets/panicle	% of filled grains	Weight of 1000 kernels	Grain yield kg/ha
A	23.5	92	51.3	20.1	2958
B	21.7	103	75.9	26.2	5591
C	19.4	112	70.7	25.4	5932
LSD 0.05	n.s.	n.s.	12.0	2.41	726
0.01	—	—	19.8	3.99	1201
C.V. %	10.7	7.38	7.88	4.38	6.63

Urea, triple superphosphate and potassium chloride or potassium sulphate were used as source of N, P_2O_5 and K_2O respectively

A : N.90–P_2O_5.60–K_2O. 0

B : N.90–P_2O_5.60–K_2O.60 (KCl)

C : N.90–P_2O_5.60–K_2O.60 (K_2SO_4) kg/ha

Potassium-deficient rice plants show increasing respiration and reduced root development and activities. Moreover, this trend becomes more remarkable under the high temperature condition of tropical areas, and nutrient absorption may also drop, eventually resulting in yield decrease with poorer grain ripening. In continued cropping of high-yield improved varieties, the necessity for potassium application would become a problem in the near future, for example, in latosol paddy fields having low capacity for cation-exchange.

Generally, it can be said that there is no difference in the fertilizer responses between potassium chloride and potassium sulphate, but it is better to avoid potassium sulphate application in paddy fields with root or Akiochi depression.

3-26. APPLICATION OF CALCIUM

Application of lime is focussed on the improvement of acid soils such as laterite, organic soil and acid sulphate soil.

1.25 ton/ha of lime application is recommended on severely acid laterite paddy fields in the Wet Zone of Sri Lanka. A physiological disease of rice plants, the so-called "Blodging symptom," occurs in these areas and the direct cause of this symptom has been regarded as excess iron damage (Ponnamperuma, et al., 1955), but in this case lime application is effective in reducing iron density in the soil and lessening the "Blodging symptom" (Ponnamperuma, 1960).

In the acid sulphate soil paddy fields widely distributed in tropical countries, physiological disorders of rice plants are seen here and there but the causes are said to be excess iron damage or phosphorus deficiency. But, as fundamental to improvement of these paddy fields, drainage facilities and neutralization of acidity by means of lime application are pointed out. An experiment to improve acid sulphate soil by liming in South Vietnam showed a remarkable yield increase from 4 ton/ha of lime application.

3-27. APPLICATION OF ZINC

Zinc deficiency in lowland rice is often seen on calcareous soil. There is clearly zinc deficiency in soils where the available zinc density is less than 1.5 ppm measured by the EDTA-ammonium carbonate extracting method.

Zinc deficiency has been found in India, Pakistan and elsewhere. In the damaged paddy fields, the rice plants were dwarfed, many hills were missing, heading time and grain ripening were retarded, and there were many abortive grains. The deficient plants showed a remarkably low content of zinc, about 10 ppm (Tanaka and Yoshida, 1970). Typical zinc deficiency of rice plants appears usually two weeks after transplanting; if zinc sulphate is applied to the soil or sprayed on the leaves at this time, the deficiency will speedily disappear. From the viewpoint of efficiency of fertilizer response and economy, good results can be obtained by dipping the seedling roots into 1% solution of zinc oxide water suspension at the time of transplanting.

Zinc deficiency was also found in calcareous soil having low exchangeable potassium in Cebu Island in the Philippines. In this case, with application of zinc chloride (Zn 100 kg/ha) an extraordinary triple yield increase has been obtained (Yoshida et al., 1971).

3-28. APPLICATION OF IRON

In paddy fields with alkaline and calcareous soils, iron deficiency may be seen at an early growing stage, with rice plants showing chlorosis on the leaves. But this chlorosis may disappear as the plant grows and the leaves recover their green, and this recovery is caused by a reduction of PH in the soil after the flooding time, even on alkaline soil. As a countermeasure against leaf chlorosis of rice plant, ferric sulphate application is most effective; application of sulphuric acid is also being tried on calcareous soils.

3-29. APPLICATION OF SULFUR

Almost no sulfur deficiency has been seen on lowland rice. Therefore, it is not necessary to apply simple sulfur as an element of fertilizer. Especially in areas where there is an active volcano, the soil and river water contain fairly large amounts of sulfur. However, a four-year experiment on nitrogenous fertilizers in Burma showed that the leaves turned yellow in plots where calcium cyanamid, urea, ammonium bicarbonate, and sodium nitrate were applied and only the plot where ammonium sulfate was applied showed no chlorosis on the rice plant leaves and had a yield increase. This example may suggest the possibility of sulfur deficiency. An application of ammonium sulfate could be beneficial in a paddy field which may have a sulfur deficiency.

3-30. APPLICATION OF SILICIC ACID

Silicic acid is not an essential element for rice plant growth but increasing silicic acid content in the rice plant body has the following effects: it strengthens the foliage tissues, contributes to resistance to invasion of pathogenic fungi and baiting of insects, regulates transpiration, lightens the damage from excess iron and manganese, and promotes the development of the root system, reinforcing the oxidizing ability of roots. When the silicic acid content is less than 10%, application of silicic acid is effective. Low silicic acid content can be also seen in tropical rice, but application of silicic acid so far is not a problem in present lowland rice culture there.

Calcium silicate is generally used as silicic acid fertilizer, and 1.5 ton/ha is a standard rate but in Malaysia, yield has been increased with 1.7 ton/ha of magnesium calcium silicate (furnace slag) (Sugimoto, 1965).

3-31. CONCLUDING REMARKS

Tropical lowland rice cultivation methods are changing and tend towards intensive use of high yield varieties. The high response to nitrogen application of these high yield varities has led to heavy nitrogen application culture. If lowland rice is cultivated using this manuring practice with continuous croppings 2-3 times per year, shortage of other elements would develop step by step because the nutrients are taken away from the field with the heavy harvests, and the plant growth would sooner or later be faced with physiological disorders or various diseases in which shortages of such elements are causal factors, and the eventual resulting yield decrease. Therefore, a balanced application of fertilizer nutrients is essential. In this respect, application of a compound fertilizer which balances the three elements, N.P.K., would be simple and beneficial. On the other hand, application of raw straw, compost and stable manure is also effective. In areas where fertilizing is difficult, rather than aiming at partial heavy yield by heavy manuring of high yield varieties in a part of the area, it would be better to improve the fertilizer application method and select a rice variety which uses less fertilizer but has a higher recovery rate than to manure fields over a wider area.

3-32. LITERATURE CITED

CHAPTER FOUR

METHODS OF CULTIVATING RICE PLANTS

Katsuo Sugimoto

There are generally two methods of cultivating rice in tropical Asia: transplanting and direct sowing. The relative areas in which these two types are used in each country are shown in Table 4-1. In so-called South Asian countries, India, Bangladesh and Sri Lanka, direct sowing is extensively practiced while in Southeast Asian countries transplanting is extensively used. In the highland and mountainside areas where irrigation water is not sufficient, upland rice derived from shifting cultivation is grown. In the delta areas of big rivers, lowland rice is grown by either transplanting or direct sowing.

In the transplanting culture, seedlings raised in the seed beds are transplanted into paddy fields after weeds are completely removed by puddling. Transplanting gives higher land-productivity but lower labor-productivity than direct sowing does. Therefore, its practice is dependent on labor availability.

Table 4-1 Rate of direct sowing and transplanting culture including upland rice[10]

Country	Direct sowing culture	Transplanting culture
India	Major	Minor
Pakistan	Minor	Major
Bangladesh	Major	Minor
Sri Lanka	Major	Minor
Burma	Increase because of labor shortage	Many
Thailand	20%	55%
Malaysia	little	Many
Indonesia	little	Many
Khmere	Large-scale cultivated farm households	Small-scale cultivated farm households
Vietnam	Minor in high land	Major
Philippines	20%	80%

The ratio of the area under transplanting culture to that of direct sowing in different countries shows a correlation with rice productivity per unit area in each country, but it is also related to irrigation water availability if upland rice culture is included. Therefore, transplanting is predominant in places where irrigation facilities have been developed.

In this chapter the methods used in the transplanting culture including seedbed management are described.

4-1. METHODS OF RAISING SEEDLINGS

4-1-1. Types of Nursery Beds

The types of nursery beds in different countries are summarized in Table 4-2. Of them all, the irrigated flat bed type is most popular in most countries. The upland nursery bed (dry seedbed) is locally popular in India, Malaysia and Indonesia. In less rainy Pakistan, there is a semi-irrigated seedbed type in which sowing is done under upland conditions and later the seedbed is flooded. The irrigated seedbed with a raised bed is recommended in every country but practiced only in a limited area (Okoshiba, 1968).

Table 4-2 Style of rice nursery in the Asian countries

Country	Upland nursery	Semi-irrigated nursery	Lowland nursery		Others
			Flat bed	Raised bed	
India	O		O	O	*Rabbing* (Burnt field nursery)
Pakistan		O			
Bangladesh			O		
Sri Lanka			O		
Burma			O		
Thailand	O		O	O Partly	
Malaysia			O		*Rakit* (Floating nursery)
Indonesia	5%		O 95%		Raft nursery
Khmere			O		
South Vietnam			O		
Philippines			O		*Dapog*

There are several special types of nursery beds. That is, so-called *rabbing* used in shifting cultivation in India, *rakit* (a floating bed) and *raft* nursery bed in Malaysia and Indonesia where the ordinary lowland nursery bed cannot be prepared because of the depth of water in swampy areas. In the Philippines, there is a nursery bed called *dapog* in which seedlings are grown on banana leaves or vinyl sheets spread over the ground or concrete floors. The seedlings are raised faster by this method than other methods (requiring only about 12 days) and the bed area is only 150 sq m per ha of paddy field due to dense sowing at 450 g/sq m. As the roots of seedlings are prevented from coming in contact with the soil, they are entangled with each other to form a continuous mat-like mass, thus facilitating the pulling and transporting of seedlings and resulting in faster recovery after transplanting (Tanaka, 1971). There are only a few reports on the comparison in growth and yield between seedlings raised in irrigated seedbeds and those raised in dry seedbeds. With photosensitive local varieties, the effect of good characteristics and good rooting of seedlings raised on dry seedbeds is apt to disappear during their long growing period, and does not always increase yield. H.Takahashi (1971) observed that with a non-photosensitive variety, seedlings raised on dry beds gave slightly higher yields than seedlings raised on wet beds (Fig. 4-1). This merit of dry bed seedlings might be manifested with short term varieties which have short vegetative growth periods.

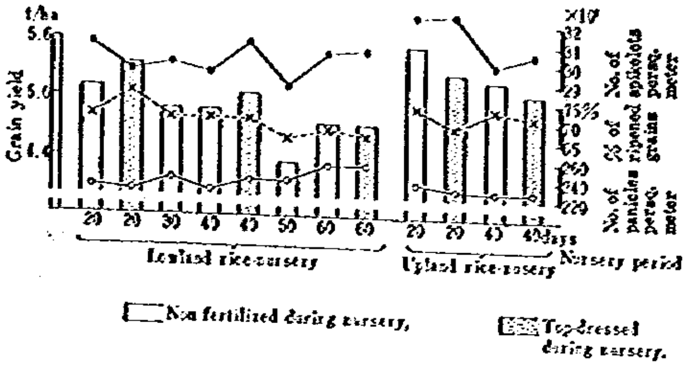

Fig. 4-1 Effect of raising condition of seedling on grain yield and its components (Variety : C4-63, Thailand)

4-1-2. Pre-treatment of Seeds

Many tropical rice varieties have a strong habit of seed dormancy with varietal differences. In general, improved non-photosensitive varieties such as IR 8 show almost no or less seed dormancy while most local photosensitive varieties have strong seed dormancy lasting for 5-9 weeks (UPCA, 1970). Therefore, when the same variety is to be grown two times or more in a year, caution is needed in preparing seeds. Seed dormancy is also affected by conditions during the period of grain ripening such as air temperature, relative humidity, solar radiation etc.

Seed dormancy can be broken by heat treatment at 50°C for 4-5 days (on strongly dormant seeds for 7-10 days) putting the seeds in a flat container. For farmers, a more convenient way may be to soak 1.2 kg of dry seeds in 1 liter of 0.1 normal nitric acid solution (about 8 g of concentrated nitric acid per liter of water) then to dry them in sunlight. In this case, it is necessary to expose the seeds to sunlight for 3-7 days if the seeds are strongly dormant.

4-1-3. Seed Soaking and Forced Sprouting

Seed selection by salt solution and seed disinfection is recommended in every country but not always practiced. Seed soaking and forced sprouting are widely practiced for sowing on wet seedbeds or direct sowing in flooded paddy fields. However, for dry seedbeds or direct sowing in dry paddy fields, dry seeds or soaked but unsprouted seeds are used and depend on rainfall for germination.

Takahashi (1971) reported that 3-4 cm of water on a seedbed remarkably reduced the establishment of seedlings, with the best establishment being at 0 cm of water depth. This result suggests that it would be desirable to maintain shallow water or saturated conditions immediately after sowing. The forced sprouting of seeds are found to be effective at all water levels as shown in Fig. 4-2.

As seen in Fig. 4-3, the response of seed germination to water depth was clearly different between *japonica* and *indica* rices in terms of germination percentage and number of roots developed. While water depth showed almost no effect on the germination percentage of *japonica* rice, all

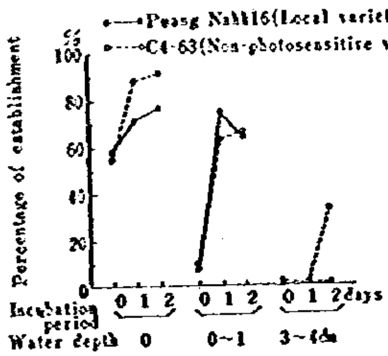

Fig. 4-2 Effect of incubation period of seed and water depth on establishment percentage(Thailand)[17]

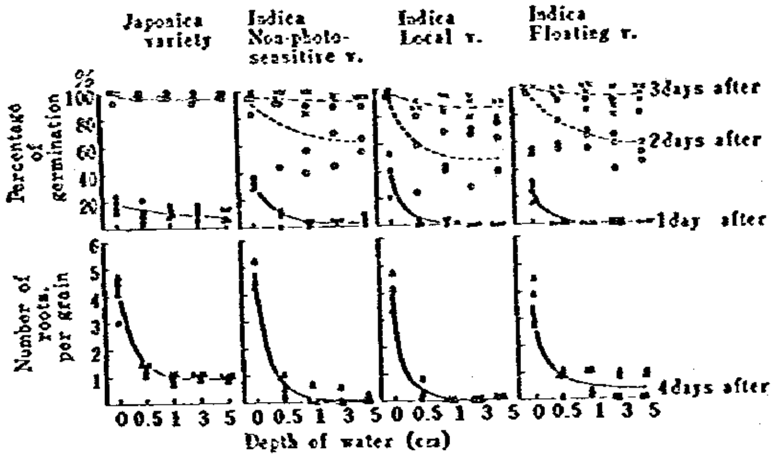

Fig. 4-3 Effect of water depth on germination and rooting of seed (Beaker test, Thailand)[17]

indica varieties showed a delay in germination and reduced root development due to deep water, although the germination was faster at 0 cm of water depth (Takahashi, 1971). Apparently *indica* rice seeds require more oxygen for normal germination and root development than *japonica* rice seeds do. In order to improve the seedling establishment in wet beds, it seems to be effective to use forced sprouted seeds or to expose the surface of seedbeds to air for 2-3 days after sowing until new roots penetrate the soil.

4-1-4. Sowing Density and Nursery Period

A low sowing density of 50-70 g/sq m is recommended in every country but in practice farmers are apt to use dense sowing, 100-200 g/sq m, in fear of poor germination, poor establishment and injury from birds. Fig. 4-4 shows the author's experiment in which growth and yields of plants derived from different seedlings which were raised under various combinations of sowing densities and nursery periods were examined. Dates of sowing were adjusted so that seedlings with different seedbed durations were transplanted on the same day.

While young seedlings showed faster growth and more tillers than old

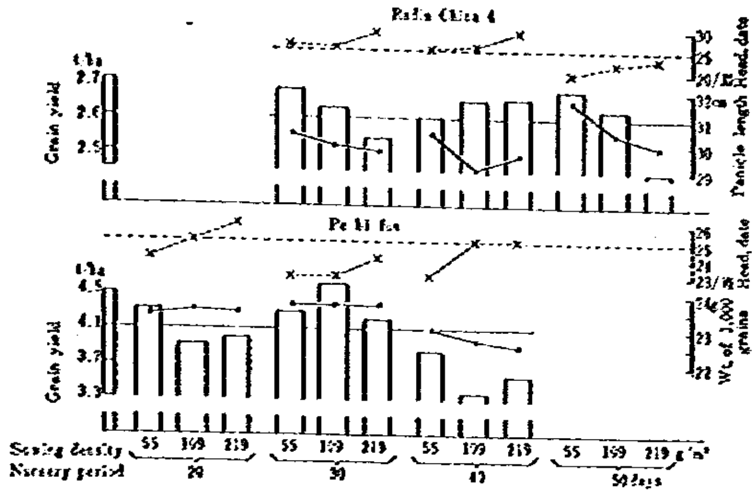

Fig. 4-1 Relation of sowing density and nursery period to grain yield (Bukit Merah, Malaysia)

seedlings in the early growth stage after transplanting, the old seedlings grew more vigorously and developed more panicles than the young seedlings in the later growth stage, and eventually the yields were similar to those of young seedlings. One of the reasons for that may be found in the fact that although the old seedlings were sown 10-20 days earlier than the young seedlings, the vegetative growth periods were almost the same as those of young seedlings, with a difference of only a few days in heading date (Sugimoto, 1965A). The thin seedlings produced by dense sowing also recovered after the middle stage of growth giving no decrease in yield.

However, the oldest seedlings in the densely seeded beds, for example, 40-day seedlings of short term varieties and 50-day seedlings of medium term varieties caused premature heading and were liable to decrease in yield (Sugimoto, 1965A). Moreover, Fig. 4-1 shows that even with weakly-photosensitive short term varieties, premature heading occured when the seed bed duration exceeded 50 days, resulting in an increased number of poor panicles and reduced yield (H. Takahashi, 1971)

In every country, a suitable length of stay in the nursery is recommended in relation to the growth duration of varieties; 20-25 days for short term varieties (with 120-140 days of growth duration), 25-35 days for medium term varieties (140-150 days) and 35-45 days for medium and long term varieties (more than 160 days).

However, it can be said in general that in tropical rice culture in which local varieties are used, even such poor seedlings as those presently used by farmers may not decrease yields in most cases unless premature heading occurs. This is due to the fact that these varieties are usually liable to become overgrown with excessive vegetative growth in the fields and that retarded growth in the early stage caused by poor seedlings is rather effective in reducing the overgrowth. On the contrary, for such high-yield varieties with short growth duration as IR 8, IR 20, IR 22, Bahagia, RD 1 etc., the use of young seedlings 20-25 days old, raised with the sparse sowing density of 55 g/sq m is recommended because not enough time is allowed to recover from poor initial growth.

4-1-5. Fertilizer Application to Seedbeds

Rate of fertilizer application to seedbeds is also recommended along with the recommended seedbed duration in every country but not always practiced by farmers. In the initial growth of seedlings up to the 5-6 leaves stage, seedlings are more dependent on their own endosperm nutrients than on fertilizer nutrients, but older seedlings which already have 7-8 leaves may require nutrient supply by fertilizers in order to grow healthy. Poor seedlings deficient in nutrients show sparser rooting and poor growth after transplanting. As shown in Fig. 4-1, seedlings raised in wet seedbeds with fertilizer application performed better in paddy fields than seedlings grown without fertilizer application.

4-2. PADDY FIELDS

4-2-1. Plowing and Preparation of Land

Rice cultivation generally starts at the beginning of the rainy season in each country. The optimum moisture content of soil for tillage is 15-30% weight of dry soil, but this is different with different soils (Tanaka, 1971). This moisture content is obtained under unflooded field conditions. However, it is rather difficult to carry out all the necessary work on time in general paddy field culture due to insufficient machinery as well as the limited tilling effectiveness of cattle power. In rain-fed fields in tropical areas, therefore, plowing, land preparation and puddling are generally carried out under more or less flooded conditions, awaiting the rains. Under the high temperature conditions of the tropics, however, to maintain flooded conditions for a long time till transplantation is apt to turn the paddy fields to a reduced condition of soil and that results in poor rooting of seedlings and initial growth is thereby checked.

As to the method and timing of plowing, Moriya (1960) suggested that repeated plowing and subsequent harrowing before flooding gives soil a sufficiently crumbled structure and results in good yield, from the point of view of plant growth and performance. Y. Takahashi (1965) also reported that a field which was plowed, prepared and watered just before transplanting gave 40% more yield, since the soil was not in the reduced condition, than a field watered 20 days before the transplanting did.

Matsushima (1962) reported that the drying of soil before transplanting increased the soluble nitrogen content after watering and resulted in an increased number of panicles. One month of drying seems to be the shortest time needed for the highest yield. However, irrigation facilities must be available to operate successfully with this process.

The following preparation process is regarded as a weed control measure in some Asian countries; first, the paddy is plowed at the beginning of the rainy season, then harrowed 2-3 times at about 10-day intervals in order to eliminate sprouted weeds, and level the fields.

Main plowing methods so far in Asian countries are cattle tillage and tillage by hand but recently power tillers and tractors are being introduced. Especially in the areas of double cropping, plowing for second cropping must be done a short time after the harvesting of the first crop, and for this, machinery is indispensable (Nishio, 1972).

With either animal or machinery power, 100-200 PS. hour per ha is estimated as necessary for the whole process of plowing and puddling, making ready for transplanting. Small power tillers of 5-10 PS are more suitable than large power tractors under flooded conditions though their tillage depth is slightly shallower on hard soil. The weak point of small machines is their higher price per unit PS and their higher operating costs. For example, by IRRI's estimate, a buffalo needs 14 times as many hours and 3 times as much expense and a power tiller needs 3 times as many hours and 1.5 times as much expense for the work from plowing to puddling than does large machinery (Tanaka, 1971).

Since almost no adequate roads are available in the paddy field areas of tropical Asia and so many paddy fields are small and on different levels, it is hard to introduce machinery. Moreover, many paddy fields in swampy areas along the sea coast have soil with low yield capacity. Therefore, all the work must depend on cattle power and hand power. The depth of tillage does not have much affect on the yield in low productivity land. However, use of manual power and cattle power limits the depth of tillage while large machinery can improve the depth. Deep tillage helps to widen the rhizosphere of rice plants and promises better yields with greater fertilizer application.

From the above discussion, it seems it would be possible to introduce a rather small type of power tiller into the areas where large machinery cannot be introduced, especially into such rural areas as have long been settled but are now developing.

4-2-2. Pretreatment of Seedlings

In most local variety nurseries, the seedlings are kept for a long time in seedbeds and grow rank. In this case, one-half to one-third of each leaf of the seedlings to be transplanted is cut off. The purposes of this practice are to reduce the transpiration area, to lessen the waste of nutrients by respiration and finally to lessen the rate of floating seedlings until the time of full rooting. Eventually this practice minimizes transplanting injury and improves the efficiency of transplanting work as well.

There are two opposed reports in this respect; in the one (H. Takahashi, 1971), no clear difference was seen between leaf-cut and -uncut seedlings in their early growth stage and in another (Okoshiba, 1968), leaf-cut seedlings showed poorer early growth than uncut seedlings did. In the case of medium and long term varieties which tend to increase their yields when their growth is checked in an early stage, it can be said that leaf-cutting is simply a mean of avoiding transplanting injury.

4-2-3. Density and Type of Planting

The method of transplanting rice in tropical Asia is random planting without any regularity in any direction, except all over Taiwan and in parts of Indonesia, the Philippines and India. Generally it is sparse planting. In particular, in single cropping areas, it is as sparse as 10 hills per sq m which is less than half the number of hills per unit area in Japan. One of the reasons for this sparse planting practice may be the idea that it gives relief from the risk of lodging by dense standing, since *indica* rice has low fertilizer response and its stems are brittle. But it seems to be also the result of the workers' idea that they could improve their lot by hastening transplanting.

Most transplanting is done by hand but sometimes another method is also practiced; that is, holding the grip of the planting nail in the right hand, the planter puts the bases of seedlings drawn from the left hand into the soil.

Regular planting with correct spacing is generally recommended in every country and standards of planting distance are also suggested depending on the length of nursery duration and the characteristics of different varieties. That is, from 6 hills per sq m (40x40 cm) to 25 hills per sq m (20x20 cm). In addition, some countries have a standard for plant spacing dependent on soil fertility. As an extreme example, such superdense planting as 44 hills per sq m (15x15 cm) is particularly recommended in southern India. With dense planting of over 25 hills per sq m, rectangular planting or row planting is suggested for the convenience of field management.

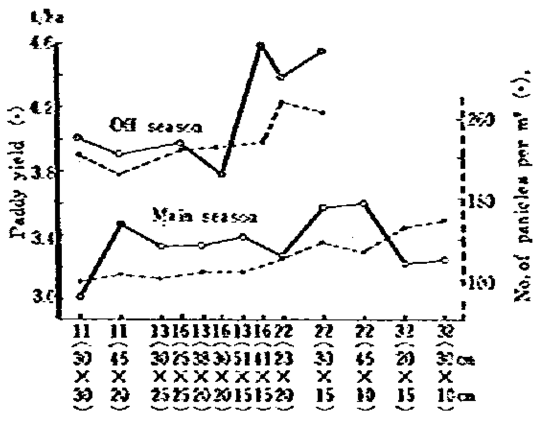

Fig. 4-5 Yield of paddy and number of panicles as affected by planting density per sq. meter and planting pattern (Variety : Pe bi fun and Radin China 4, Malaysia)

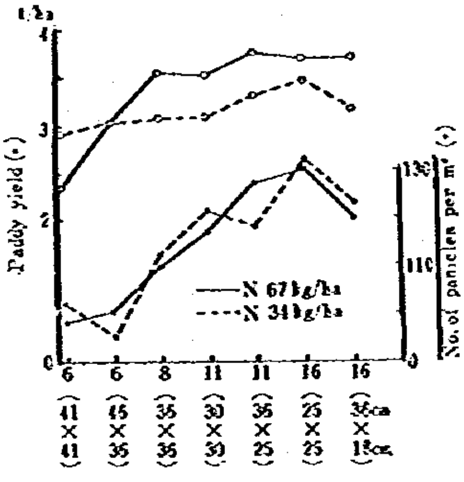

Fig. 4-6 Yield of paddy and number of panicles as affected by planting density (per sq. meter) and amount of nitrogen (Variety : Radin China 4, Malaysia)

Correlation between planting density or type and yield or yield components is discussed later. Figs. 4-5 and 4-6 show the experimental results using local varieties in Malaysia (Nagai, 1962; Sugimoto, 1965A; Y. Takahashi, 1965). Both results show almost a straight-line increase in number of panicles with increase of planting density. As to yield, the highest yields have been shown at the density of 16-22 hills per sq m in Radin China 4 in the main season and at the density of 16 hills per sq m in Pi bi fun in the off-season. But in Pi bi fun no big difference was seen between 11 and 16 hills. This suggests that since the panicle size became smaller with an increase in panicle number and the rate of lodging also increased with the density, the yield came to be definite at a certain density. In this case, it was recognized that the decrease in the size of panicles concomitant with an increasing number of panicles with increasing density can be compensated for to some extent by increasing fertilizer application (Fig. 4-6). As to the type of planting, no definite superiority was seen in either square planting or rectangular or row planting.

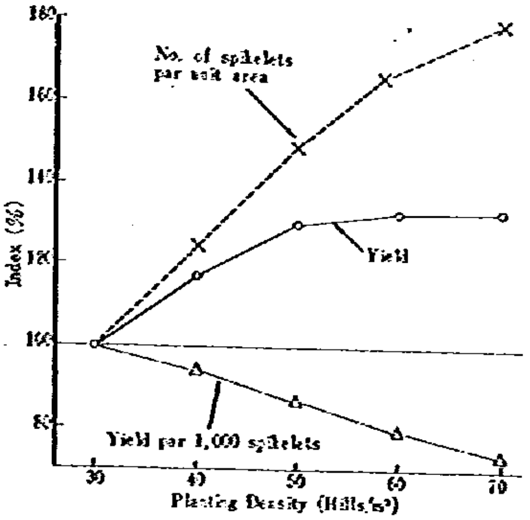

Fig. 4-7 Relation between planting density, and yield and yield components (Variety : IR 8, Mandya, India)

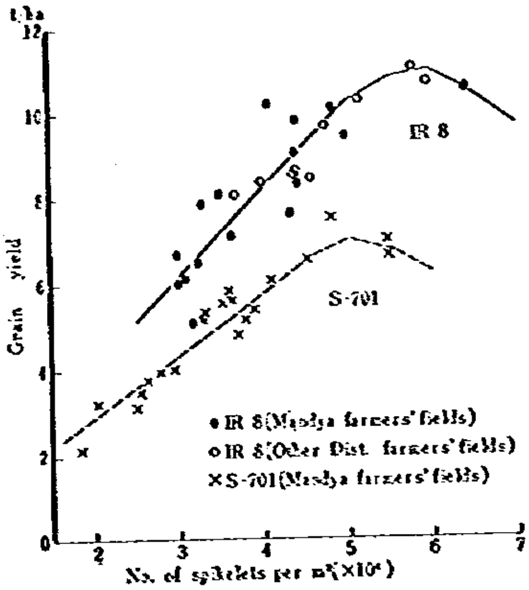

Fig. 4-8 Relation between number of spikelets per m² and grain yield per ha (India)[11]

According to the results obtained in southern India shown in Figs. 4-7 and 4-8, with the high yield IR 8 variety, the number of spikelets per unit area increased in almost a straight line with an increase of planting density while grain weight per spikelet showed a straight-line decrease. The yield per unit area increased as the density increased, reaching a peak at the density of 50 hills per sq m, but the yield showed no marked fluctuation at more than 50 hills. Seven to eleven tons/ha of paddy yields were obtained in the farmers' fields (Fig. 4-8). It was assured in this case that grain yield per number of spikelets would not decrease until the number of spikelets per unit area reached a certain definite number. Both results show that an increase in the number of panicles, eventually the number of spikelets, is the first factor to act on yield increase and this means that an increase in the number of panicles is not always connected with undersized panicles.

According to Kurashima (1970) at IRRI, as shown in Fig. 4-9, however, although the number of panicles increased with increased planting density, the yields did not show marked difference at different densities with the same nitrogen application. This case shows that undersized panicles occured in densely planted plots with an increase in the number of panicles. In particular, in the superdense planting plots with heavy nitrogen application (more than 150 kg/ha), and with no increase in the number of panicles, yield decreased somewhat owing to the higher rate of lodging.

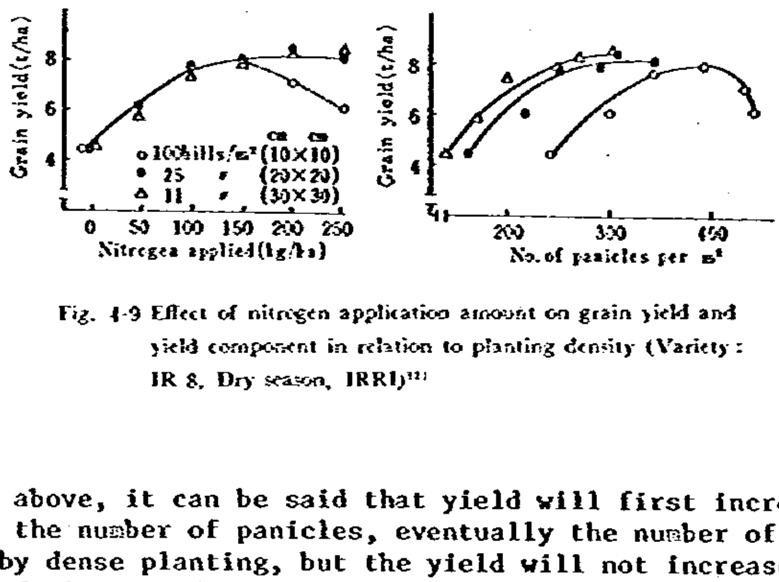

Fig. 4-9 Effect of nitrogen application amount on grain yield and yield component in relation to planting density (Variety: IR 8, Dry season, IRRI)[11]

From the above, it can be said that yield will first increase with an increase in the number of panicles, eventually the number of spikelets, per unit area by dense planting, but the yield will not increase after a certain limit of planting density has been reached. The optimum planting density can be set up from the above density limit but it will vary according to the characteristics of different varieties, rate of fertilizer application and cropping season. Generally the optimum planting density in high-yield varieties is much higher than that of local varieties, i.e., 15-20 hills per sq m. In short-culmed IR 8 which has good plant form for light-interception, high yield can be obtained by dense planting, 20-50 hills per sq m, with heavy fertilizer application. The optimum planting density of 15-20 hills per sq m in the long culmed local varieties is still more than twice the density traditionally practiced by farmers.

With either high-yield varieties or local ones, dense planting results in greater risk of rice stem borer injury and lodging, and also increases the labor of raising seedlings and transplanting. Therefore, the actual density must be designed to balance its positive effect on yield increase against its negative effect of the above-mentioned risk under local conditions. Besides, with random planting, while density could be increased up to 20 hills per sq m as the maximum, dense planting at more than this limit is not effective. So regular planting should be practiced.

4-2-4. Characteristics and Growth Habits of Different Varieties

Most rice varieties distributed in tropical Asia have a long growing period and are photosensitive; they are generally grown in submerged paddy fields utilizing the water of the rainy season. These local varieties differentiate their young panicles, which emerge at certain definite calendar dates when the day gets shorter and this date is independent of their sowing times. Accordingly, their growing period will vary as the sowing time is earlier or later, and this also involves the "Lag vegetative phase" at the middle of their growth (J. Takahashi et al., 1967; Tanaka, 1971; UPCA, 1970; Yamada and Ota, 1961).

On the other hand, in non-photosensitive varieties such as IR 8 etc. growing period is definite regardless of the time of sowing and reproductive growth begins just after the end of vegetative growth. Thus, they can be grown in any season of the year. The second cropping varieties including high yield varieties fall under the latter type.

Table 4—3 Relation between the stage of maximum number of tillers and the earliness of maturity in rice varieties (Malaysia)[29]

Variety	(growing period)	Bukit Merah						Bombong Lima					
		1963			1962			1963			1962		
		F_0	F_1	F_2	F_0	F_1	F_2	F_0	F_1	F_2	F_0	F_1	F_2
	days												
Bengor	(135)	49	48	47	47	47	44	48	44	43	41	37	37
Malinja*	(135)	49	50	49				47	45	44	·		
Sigadis**	(140)	49	49	48	47	45	45	49	43	44	40	37	38
R. China 4	(150)				48	47	45				40	40	38
M. Ebos 80	(153)	49	43	48	51	54	50	49	45	44	44	40	39
S. Intan 16**	(159)	50	47	48	53	54	52	50	46	43	40	39	39
A. Kuching*	(160)	50	48	47	53	53	49	48	43	44	37	35	36
S. Intan 17	(160)	48	47	46	51	49	47	48	43	41	40	35	36
Mean		49.1 ±0.3	48.1 ±0.4	47.6 ±0.4	50.0 ±1.0	49.4 ±0.9	47.4 ±1.1	48.4 ±0.1	44.1 ±0.5	42.9 ±0.5	39.9 ±0.5	37.9 ±0.7	37.6 ±0.5
C.V.		1.4%	2.2%	2.1%	5.3%	4.7%	6.3%	0.6%	2.8%	3.1%	3.4%	4.7%	3.4%
		48.3±0.2 2.5%			49.0±0.6 5.6%			45.1±0.6 6.0%			38.4±0.4 4.5%		

Note : Figures indicate number of days after transplanting.

F_0=Non fertilized, F_1=Standard fertilized, F_2=double fertilized.

*Panicle number type, **Panicle weight type.

In Malaysia the author obtained the results shown in Table 4-3, in which the numbers of tillers at different dates were examined tracing their growths in eight varieties (Sugimoto, 1968). Although some deviations were seen from year to year at Bumbong Lima, the maximum tiller number stage was seen at definite days of plant growth; that is, an average of 49 days at Bukit Merah and an average of 42 days at Bumbond Lima after transplanting. In the maximum tiller number stage, no difference was seen among different growing periods and plant varieties and little difference was seen among different rates of fertilizer application. In the final stage of productive tillering, a similar tendency was recognized though it was not so clear as in the former (Sugimoto, 1968). Moreover, the period from the spikelet differentiation stage to head emergence was almost constant, approximately 20 days, showing no varietal difference (Kurashima, 1970; Ota, 1964; Sugimoto, 1965A). Those results were almost the same as those obtained in Japan.

Differing in their growing period and plant type, different rice varieties have almost a constant span from transplanting to the maximum tiller number stage and little differences in the periods from the spikelet differentiation stage to head emergence. Eventually, in long term varieties, the span from the maximum tiller number stage to the spikelet differentiation stage is longer as seen in Fig. 4-10. This period is called the "Lag vegetative phase" and it sometimes may be 1-1.5 months in the cultivation of long-term photosensitive varieties.

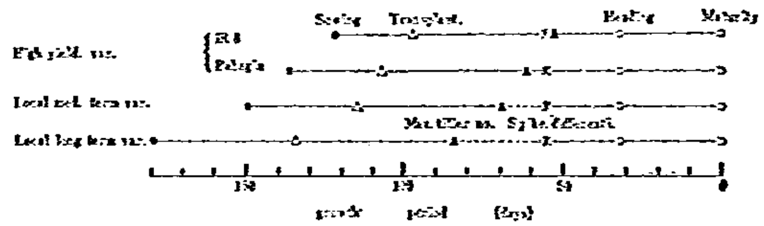

Fig. 4-10 Varietal difference in growth stage

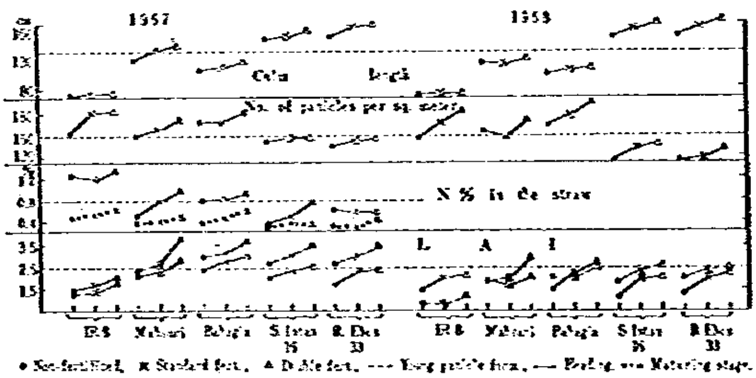

Fig. 4-11 Varietal difference of growth and percentage of absorbed nitrogen (Malaysia)

Fig. 4-11 shows the experimental results of comparing the various growth components of five leading varieties under three grades of fertilizer applications (Sugimoto, 1969). In high-yield varieties especially in IR 8, plant height and culm length showed almost no increase while the number of panicles increased greatly with increasing fertilizer application. On the other hand, in local long term varieties such as Subang Intan 16 and Radin Ebos 33, plant height and culm length increased greatly while the number of panicles increased very little with increasing fertilizer application. Besides, LAI (leaf area index which has a high correlation with yield) of IR 8 was clearly larger at the heading stage than at the spikelet differentiation stage, while that of other varieties reached a maximum at the spikelet differentiation stage and decreased at the heading stage. This tendency was noticable in local long-term varieties (Sugimoto, 1969).

The above seems to be caused by such phenomena as severe physiological withering in the lower leaves due to imbalance between photosynthesis and respiration with an increase of mutual shading during their long lag vegetative phase. Such early decrease of LAI is regarded as one of the characteristics of tropical rice culture in swampy lowlands and is also regarded as a contributing factor to an increase in degenerative spikelets, a decrease in ripened grain percentage and stagnant accumulation of dry matter, eventually connected with stagnant yield improvement.

4-2-5. Fertilizer Application

The effect of fertilizers on yield increase is remarkably affected by the natural supply of nutrients from the growing soil, weather conditions, cropping season, variety and field management methods. Varieties mainly grown in tropical areas have less response to fertilizer application and fertilizers have almost no effect on the rainy season crops; the rainy season is the main rice cropping season there. Moreover, farmers are discouraged from using fertilizers since fertilizers there are comparatively costly in comparison with the price of rice itself, land rents paid in kind are high, and farmers lack money as well.

The nutrients absorbed by rice plants are, first, potassium and silic acid, with nitrogen, calcium and magnesium second (Tanaka et al., 1966). Among these elements, nitrogen is generally deficient under normal rice growing conditions with phosphorus second, but land needing potassium application is rather limited. According to the experimental results of FAO (Tanaka, 1971), while one ton/ha of yield increase can be obtained by 60 kg/ha of nitrogen application, the optimum economic rate of nitrogen application is estimated to be 40 kg/ha. The effect of phosphorus application is notable in some kinds of land, but that of potassium is almost nil (Tanaka, 1971).

In the case of local varieties, how and when to apply about 40 kg/ha of nitrogen is at present a problem there. Results obtained in Malaysia (Nagai, 1962), show that among the three elements, nitrogen, phosphorus and potassium, nitrogen is the main factor in yield increase.

In the reports of the author (Sugimoto, 1965A; Sugimoto, 1965B), on suitable nitrogen application, no definite trend was found between the recommended standard rate of 34 kg/ha and the doubled one using various dressing methods (Fig. 4-12). In the less fertile land of Bumbong Lima, response to nitrogen was high, as it was to additional application of magnesium calcium silicate (furnace slag). As to the optimum time of dressing, basal dressing and top dressing at the tillering stage one month after transplanting increased the number of panicles but this effect was not always directly connected with yield increase owing to the negative effect of lodging which occured later. Top dressing at the spikelet differentiation stage (about 20 days before heading) or at the reduction division stage (about 10 days before heading) had a remarkable effect on yield, increasing the percentage of ripened grains (Sugimoto, 1965A; Sugimoto, 1965B; Y. Takahashi, 1965).

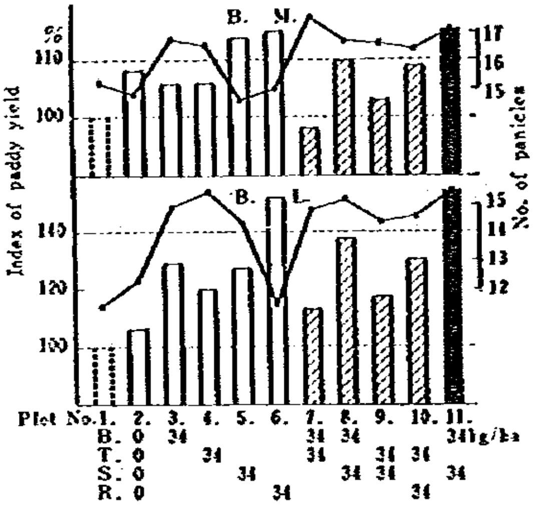

Fig. 4-12 Experiment on the suitable amount of nitrogen and its application time (Variety: Sigadis, Bukit Merah and Bumbong Lima, Malaysia)[27,30]

Note: Basal dressing of 67kg P_2O_5 and 3 4kg K_2O per ha respectively was made in all treatments except No. 1. 1,700kg per ha of furnace slag was also applied in No.11. B.------Basal dressed; T., S., R.------Top-dressed at active tillering, spikelet differentiation and reduction division stage respectively.

As seen in Table 4-4 showing Ota's results in Sri Lanka, top dressing at eight weeks after transplanting prevents spikelets from degenerating and is more effective in increasing the number of valid spikelets per panicle than top dressing at six weeks after transplanting which can be expected to increase the number of initiated spikelets. This top dressing at eight weeks after transplanting coincides with the reduction division stage and contributes to increasing the number of viable spikelets and decreasing degenerated spikelets. Unlike the result in the temperate zones, in tropical areas, it is noteworthy that the response to nitrogen top dressing was an increase in the number of viable spikelets per panicle. This was greater at the stage of preventing spikelet degeneration than at the stage of increasing initiated spikelets. Moreover, the increase in sterile spikelets after top dressing at four to six weeks after transplanting is not the result of excess increase of initiated spikelets, as

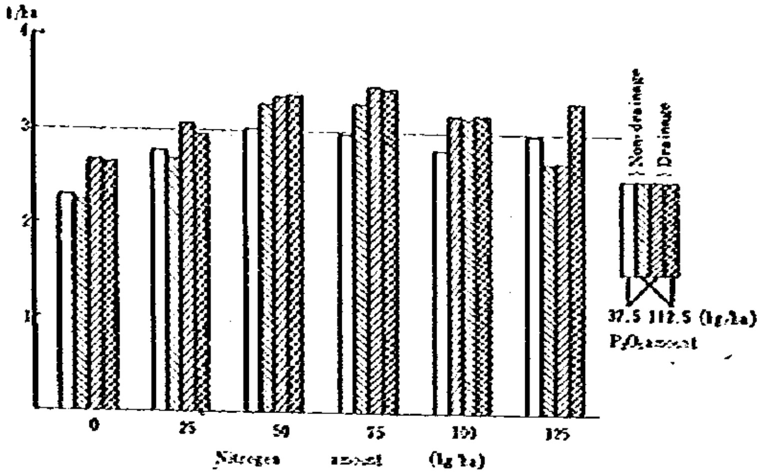

Fig. 4-13 Effect of drainage in relation to fertilizer amount on grain yield (Variety : RD 1, Thailand)[11]

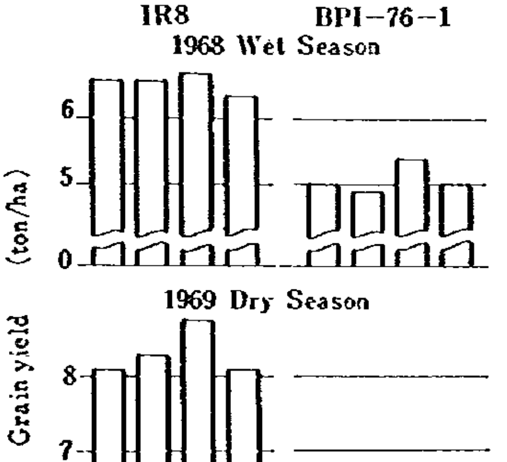

Fig. 4-14 Comparison of basal application of nitrogen with split application at different times (IRRI)[12]

Note——A : Basal application, B : Half the nitrogen applied basally and half 30 days before heading, C : Half applied basally and half 20 days before heading, D : Half applied basally and half 10 days before heading.

in Japan, but is caused by excess vegetative growth on foliage and lodging due to the spindly growth of lower stems.

Table 4—4 Effect of different times of application of nitrogen on number of rachis branches and spikelets per panicle (Ceylon)[10]

Items		0	2 weeks	4 weeks	6 weeks	8 weeks	10weeks
No. of spike. on pri. rachis branches		66	60	70	67	64	63
No. of sec. rachis branches		30	30	25	28	33	25
Percentage of sec. rachis branches degenerated		35	33	42	42	21	39
Total no. of spikelets	initiated	218	206	207	216	202	199
	degenerated	65	61	71	81	37	66
	developed	153	145	136	135	165	133
	degeneration%	30	30	34	38	18	33

Treatments: 45 kg/ha N was split application; 22kg at transplanting and another 22kg at 0, 2, 4, 6, 8 and 10 weeks thereafter.

Table 4—5 Yield of paddy (t/ha) as affected by transplanting time and nitrogen application method (Variety: Luang Praten, Rangsit, Thailand)[35]

Treatment \ Transplanting time	July	August	September	October
Non fertilizer	1.60	1.61	1.65	1.00
Basal N only	2.13	2.79	2.51	1.52
Twice N split application	2.61	3.85	3.15	2.26
Thrice N split application	2.90	3.95	3.07	2.38
Growing period (days)	197	183	158	149

As shown in Table 4-5, J. Takahashi, et al., (1967) in Thailand performed nitrogen application tests using a single photosensitive variety. They found that applying split dressings two or three times resulted in greater yield increase than basal dressing only, and this was especially clear in a prolonged growing period. The yield increase from fertilizer was sometimes more than 100%. As shown in Fig. 4-13, Motomura (1973), working with an improved non-photosensitive variety, though the nitrogen response on yield increase was only 20-30%, estimated the optimum rate of nitrogen application was 50-75 kg/ha.

Kurashima (1970) found the optimum rate of nitrogen application at IRRI for IR 8 was about 100 kg/ha in the rainy season and about 150 kg/ha in the sunshine of the dry season. Comparing both seasons, plots with no or less nitrogen application showed greater yield in the rainy season while plots with high nitrogen application showed greater yield in the dry season, with more than eight tons/ha of paddy yields (Fig. 4-14). In addition, the split dressings of nitrogen were more effective than the basal dressing only and this trend was maximized in the high-nitrogen and

Table 4-6 Effect of split application of nitrogen on grain yield in relation to planting density (Variety : IR 8, IRRI)[11]

Planting density per sq. meter (Spacing)	Applied N	Grain yield (Index)	
		Basal application	Split application[a)b)]
	kg/ha	t/ha %	t/ha %
25	50	6.85 (100)	7.12 (104)
(20cm × 20cm)	100	7.00 (102)	7.35 (107)
	150	7.04 (102)	7.11 (103)
100	50	6.91 (100)	7.58 (110)
(10cm × 10cm)	100	6.67 (97)	7.61 (111)
	150	5.21 (76)[c)]	7.50 (110)

a) Ratio of basal and top-dressing : 50 and 50%.
b) Top-dressing applied at 20 days before heading.
c) Lodged a week before heading.

densely planted plots in the dry season (Table 4-6). Among the results obtained at IRRI, however, there is an example (DeDatta et al., 1970) in which the effect of split dressing was not recognized but this seemed to be due to the high soil fertility of the paddy fields at IRRI. As to the suitable time for dressing (Fig. 4-14), no distinct time was found in rainy season cropping while good response was seen at 20 days and 30 days before heading in dry season cropping (Kurashima, 1970). The effect of top dressing at the reduction division stage was not so clearly seen in this case as in Malaysia and Sri Lanka and this difference seems to be owing to the difference in time of appearance of degenerated spikelets between improved varieties and local ones.

In summary, the optimum rate of nitrogen application varies according to the rice variety, cropping season and soil fertility. That is, in the case of local long-term varieties, split dressings two or three times are more effective than basal dressing only. In this case, rice plants have excess vegetative growth when their growth is accelerated in the early stage of growth and this causes lodging and poor ripening. Therefore, it is better to apply a small amount as basal dressing. As for the top dressing, it is effective at the reduction division stage. In order to increase the number of panicles increased planting density is more effective than fertilizer application. In the case of high-yield varieties, basal dressing combined with top dressing at the spikelet differentiation stage will be particularly effective.

4-2-6. Fertilizer Tolerability of Variety

A greater application of nitrogen fertilizer is the first problem to be overcome for yield of rice in tropical areas to be increased. However, heavy applications of nitrogen are apt to result in excess vegetative growth and stem elongation of the plants, instead of increasing the numbers of spikelets and heads. Eventually, it causes lodging of rice plants, decreasing the grain ripening rate and grain/straw ratio. Therefore, the tolerance of a given variety to fertilizer is an important factor in increasing yields. Since the plants have vigorous vegetative growth which causes an increase of self-shading of foliage, if fertilization is inadequate, in the case of local varieties, this is a weak point, resulting in unsatisfactory form for light-interception and increasing respiration rate (lack of balance between respiration and photosynthesis). Eventually this unbalance results in poor dry-matter production in the latter half of the growing period.

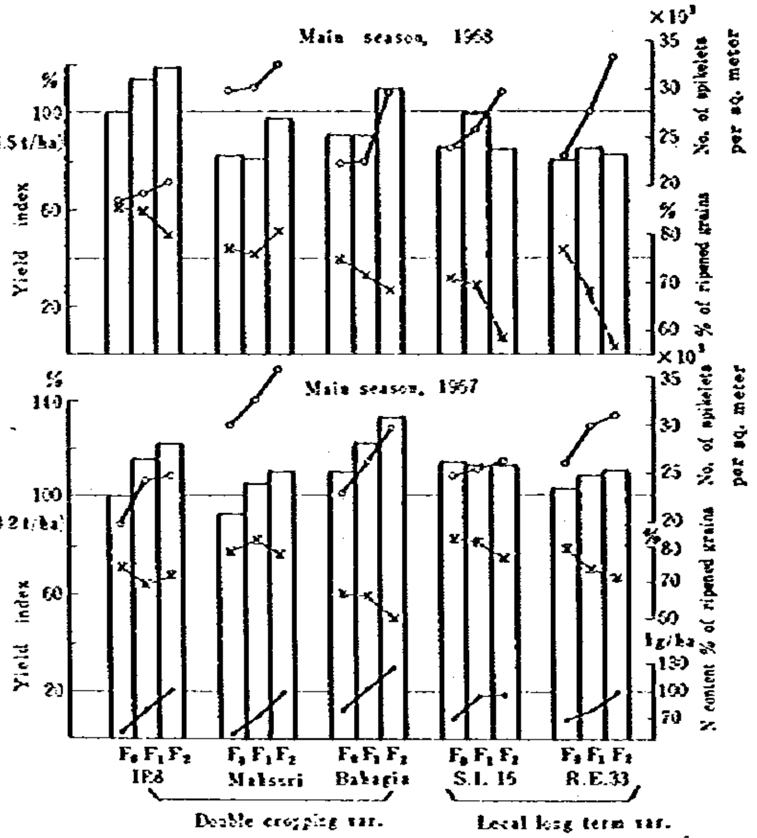

Fig. 4-15 Grain yield and yield components of leading varieties (Malaysia)

Note: Refer to Table 4-3 and Fig. 4-11.

Results of an experiment (Sugimoto, 1969) on fertilizer, the tolerance of five leading varieties in Malaysia are shown in Fig. 4-15. The yields were expressed in the order: IR 8 ≒ Bahagia (a sister line of IR 5) S. Intan 16 ≒ Mahasuri ≒ R. Ebos 33. In the double-cropping varieties, yields increased in response to an increasing rate of fertilizer application, while this fertilizer response was not always clearly shown in the local long-term varieties. Sometimes, remarkable decreases of ripened grain percentages were seen, particularly in local long-term varieties, with increased fertilizer application. It was concluded that double-cropping varieties, especially IR 8 and Bahagia, have a high adaptability to heavy manuring while local long-term varieties show very low adaptability (Sugimoto, 1969). Yields of local long-term varieties, however, are not always low under no-manuring conditions (Sugimoto, 1968). This means that local varieties, in most cases, show better adaptability to the traditional cultivation method of almost no manuring. This varietal difference in fertilizer tolerance may vary with difference of growing conditions, especially soil fertility and growing season.

A negative correlation has been recognized between LAI and NAR* (net assimilation rate) at every growth stage. A double-cropping variety, Bahagia, showed an NAR at every stage of LAI that was superior to those shown in local long-term varieties. Varieties having a high rate of yield increase always show a high NAR during the whole growing period, and this seems to have a good photosynthetic balance with respiration (Sugimoto, 1969). Therefore, a good balance of photosynthesis vs respiration is regarded as one of the factors in fertilizer tolerance (Osada, 1964). As Tanaka et al. (1966) and the author (Sugimoto, 1969) pointed out, the grain/straw ratio could also be an important index of fertilizer tolerance.

4-2-7. Photosensitive Varieties and their Growing Season

As explained in 4-2-4 above, in photosensitive varieties, heading times are almost definite regardless of their sowing times; the earlier their sowing time is, the more their growing time is prolonged. Therefore, there should be an optimum growing period or best cropping time in every variety which gives them maximum grain productivity under given conditions of weather, soil, fertility and fertilizer application.

Table 4-7 Yield of peddy (t/ha) as affected by transplanting time (Thailand, 1965)[10]

Location	Chainat	Bangkhen	Rangsit	Sakon Nakorn	Khonkaen	Sanpathong
Variety / Transplant. time	Kao Dork Mali	Luang Pratew	Luang Pratew	Kea Dork Mali	Kea Dork Mali	Neo Sanpathong
July	3.37(179)	1.89(207)	2.31(197)	2.67(175)	2.64(175)	3.62(177)
August	3.33(149)	2.68(179)	3.05(188)	3.08(145)	2.95(145)	3.93(153)
September	3.01(129)	2.84(156)	3.53(158)	2.89(119)	2.82(119)	3.73(131)

Figures in parenthesis show number of days from sowing to harvest.
Fertilizers: 75kg/ha each of N, P_2O_5 and K_2O was applied at the same does with three different nitrogen split application methods. Yield records indicate the mean of three nitrogen treatment plots and check plot (no fertilizer).

Table 4-8 Yield of rice (t/ha) in relation to transplanting time (Bangkhen, Thailand, 1966)[11]

Variety	July	August	September	October	November
Bangkhen 293	0.23	3.45	4.79	3.39	2.41
Luang Tawng 101	0.07	2.46	4.12	3.10	2.23
Nang Mon S-4	0.16	2.22	2.91	2.01	1.17
Puang Nahk 16	1.14	4.10	4.77	3.49	2.39
Jao Luang 11	0.16	1.79	3.51	2.12	2.68
Khao Dok Mali 105	0.07	1.22	3.03	3.02	1.82
Bai Lod 104	0.39	1.76	3.52	2.24	2.02
Khao Pak Maw 17	0.27	1.51	3.82	2.19	1.53

Fertilizers: 75kg/ha each of N, P_2O_5 and K_2O was applied.

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*NAR is an index expressed by dry matter weight per unit leaf area per hour, showing plant growth rate per unit leaf area, and is utilized as a measure of photosynthetic efficiency.

J. Takahashi et al. (1967) studied this optimum cropping season for leading photosensitive varieties in Thailand (Tables 4-5, 4-7 and 4-8). As seen in Tables 4-5 and 4-7, the growing period varied over a range of some 50 days in the same varieties with differences in transplanting times or sowing times. The lag vegetative phase period was prolonged in the longest growing period plot compared with the shortest one. The earlier the sowing time was, the greater the number of leaves on the main culm became and plant height increased as well. The yield came to a maximum at a certain sowing time (transplanting time) and decreased gradually at earlier or later sowing times. Top-dressing (2-3 split dressing) of nitrogen seemed to be helpful when the growing period was prolonged (Table 4-5). In the results obtained in various parts of Thailand, the maximum yields were seen sometimes in August plantings and other times in September plantings and this fluctuation was caused by differences in varieties and locations. Throughout the varieties, maximum yields were obtained when the growing period was around 150 days, so the optimum growing period is regarded as 150 days. At Bangkhen, all the varieties gave their maximum rice yields from plots planted in September, as seen in Table 4-8. Plots planted in July gave minimum rice yields because the growing period was too long. This seemed to be due to greater risks of fertilizer deficiency, disease and pest injuries. On the contrary, plots planted in November showed the second lowest yields and this was owing to the poor rate of vegetative growth because of the excessively short growing period with too late planting.

In most cases, the rainy season begins around May or June and lasts till November. It is less rainy in December, and then comes the dry season which lasts till April in tropical Asia. The beginning of the rainy season fluctuates rather widely from year to year. Therefore, in monocropping paddy field areas where the cropping depends on natural water, the plowing of land and preparation of seed beds start when the beginning of the rainy season is assured and the soil has become soft from rain water. That is, the seeding time is about the beginning of June. One to one and one-half months are needed in the seed bed. Meanwhile the paddy fields become flooded and in most cases are ready for transplanting in the middle of July. Accordingly, the traditional farmers naturally transplant earlier than the above-mentioned optimum time. If fertilizers are used, advanced planting is not adequate for long-term photosensitive varieties; therefore, in this respect an improvement of planting time by adjusting the growing period to 150 days seems to be necessary. In the meantime, in farmer's fields where there are many inadequate conditions, a prolonged growing period may sometimes be an advantage and may help to compensate for those inadequate factors. So, advanced planting may not always be inadequate in traditional paddy farming in which almost no fertilizers are used.

4-2-8. Weeding

In tropical rice culture, there has been almost no weeding and no manuring work for a long time. In order to gain reasonable yields under such conditions, plant types must be used that have vigorous vegetative growth and the plants must flourish quickly, covering the surface of field with leaves to overcome the competition with growing weeds. Most local varieties have such characteristics.

In paddy fields in alluvial plain areas, the weeds have been controlled by deep water in rainy season. But with the extension of improved varieties of new plant types and the increasing application of fertilizer, weed growth can be naturally anticipated to flourish (Moomaw et al., 1966; Sugimoto, 1965A; Tanaka, 1971). Moreover, if drainage facilities are completed in future by which the water depth of paddy field is adjusted at a reasonable depth, it would certainly result in a proliferation of weeds.

IRRI estimates that the labor of hand weeding is 10-60 man/ha in Asian countries (IRRI, 1966, 224-231). In Malaysia, weeding required the most labor, 50% of the total labor required in rice production. In Japan, 1941, when herbicides were not yet popular, the labor for weeding and intertillerage operation was 20% of the total labor requirement in paddy production, though these two jobs in those days were done in combination, utilizing an efficient rotary weeder.

Weeding at high temperatures in tropical paddy fields is really hard physical work. At present, weeding is done by hand or by using simple traditional weeding tools developed in each country and the use of an efficient rotary weeder is not general.

In Malaysia, weeding is done by hand or using a hand tool called "Keri" having a long handle with a blade which cuts the weeds out, but it is not efficient. The author's experimental results (Sugimoto, 1965A) on the utilization of a rotary weeder in connection with planting density are shown in Table 4-9. The weeding was slightly inadequate when the rotary weeder was used three times on one side, but still its efficiency was far better than that of the Keri. The weeded plots had better yields than the non-weeded plots, while no significant difference was seen among three kinds of weeded plots. The densely planted plots had a greater number of heads per unit area or more grain yield than the sparsely planted plots did.

Table 4-9 Effect of weed control on grain yield in relation to planting density (Variety : Pebifun, Malaysia)[57]

Treatment		Cover degree of weed	No. of panicles per m²	Length of panicle	Grain yield	Index
		%		cm	t/ha	%
Non weeding	Sparse planting	91	168	23.4	3.50	100
″	Dense ″	59	231	22.3	3.77	108
'Keri'(local tool)	Sparse ″	19	178	23.7	3.82	109
″	Dense ″	9	231	22.3	3.74	107
Rotary weeder (cross)	Sparse ″	23	178	23.2	3.57	102
″	Dense ″	28	223	22.7	3.92	112
Rotary weeder (single)	Sparse ″	33	159	23.1	3.69	105
″	Dense ″	43	220	22.7	4.09	117

Note : Sparse spacing 30cm×30cm, dense spacing 25cm×25cm.

Table 4—10 Effect of weed control and herbicides (Variety : Pebifun, Malaysia)[10]

Treatment	Cover degree of weed	No. of panicles	Wt. of 1,000 grains	Grain yield	Index
	%		g	t/ha	%
1. Non weeding	86	17.5	22.0	3.78	100
2. *Keri* (local tool) Thrice	33	19.0	21.6	4.10	108
3. Rotary weeder 〃	38	19.9	21.7	4.23	112
4. 20 days 2,4-D 〃	48	18.5	21.5	4.13	109
5, 30 days 2,4-D Once	66	16.6	22.3	4.18	111
6. 40 days 2,4-D 〃	80	17.2	22.3	3.94	104
7. MCPCA 〃	62	16.3	21.5	3.93	104
8. MCPCA—2,4-D 〃	25	17.9	21.6	4.01	106
9, PCP compound fertilizer	66	19.2	22.2	4.34	115

Note : No. 7 was treated 10 days after transplanting, No. 8 was treated 10 days and 40 days after transplanting, and No. 9 was treated 1 day before transplanting.

Table 4-10 shows the results of a utilization test of various weeders and herbicides. Weeding three times by a Keri and a rotary weeder gave higher weed control while all the weed control plots gave greater yields than those that had no weed control. The effect of aqueous 2,4-D in weed control dropped when applied 40 days after transplanting, and this data suggests it must be applied at an early stage. A combination application of MCPCA and 2,4-D showed the highest effect in weed control among various herbicides. The highest yield increase was shown with PCP compound fertilizer, but it seemed to be rather that growth was checked by PCP at an early stage but had a plus effect on the later growth than that it had an effect on weed control (Sugimoto, 1968).

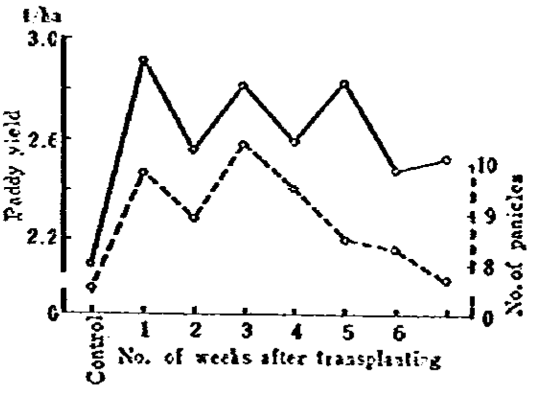

Fig. 4-16 Suitable application time of 2,4-D on grain yield (Variety : Radin Goi, Malaysia)[10]

On the other hand, since rice plants grow quickly, as seen in Fig. 4-16 which shows Moriya's results, 2,4-D can be applied fairly soon after transportation and for a longer period than is done in Japan (Moriya, 1960). Although the effect of herbicides is higher with the earlier application, at the same time the early application may cause checking of plant growth; so the optimum time of application could be at 20-25 days from transplanting. Joseph et al., (1969) stated in Malaysia that 2,4-D and PCP granules can be recommended becuase of their lower costs and easier handling and the expense of weed control with them is estimated as 1/3 - 1/13 of that with hand weeding.

Summarizing the above results, yield decrease from weeds when no weeding is done is estimated to be 15% (5-25%) and this low decrease rate seems to be the result of the deep water flooding which checks the growth of weeds. In the results (Japanese Adviser, 1972) obtained in south India under the shallow water conditions shown in Table 4-11, the yield decrease caused by weeds was estimated to be 17%. It can be concluded that weed control at an early stage is essential and one-time weeding is insufficient for improved varieties.

Table 4-11 Yield of paddy (t/ha) and yield components as affected by hand weeding (Variety: Jaya, Mandya, India)[1)]

Treatment / Block	Non weeding	Once of hand weeding (1)	Once of hand weeding (2)	Once of hand weeding (3)	Three times of hand weeding
I	4.85	4.19	5.07	4.85	5.73
II	5.47	6.42	4.63	4.82	5.45
III	4.95	5.66	4.61	5.51	7.13
Mean	5.09(100)	5.22(103)	4.77(94)	5.09(100)	6.10(120)
No. of panicles per m²	351(100)	367(105)	358(102)	357(102)	365(104)
% of ripened grains	62(100)	62(100)	69(111)	69(111)	69(111)

Remarks: (1) Weeding at 17 days after transplanting
(2) 〃 47 〃
(3) 〃 84 (heading time) 〃

According to IRRI (1966, 224-231), as a result of regional weed control tests in various countries in Asia, Propanil (Stain F-34), PCP-Na, etc. applications resulted in higher yields than various other herbicides. The yield decrease rates in no-weeding plots compared with plots weeded by hand were 20% in Thailand, 27-51% in the Philippines, 16% in Taiwan, and 20% in Korea, and those rates of damage are higher than those shown in various previous experiments.

Moomaw et al., (1966) showed the essential requirements of herbicides for transplanted rice plants as (a) effective under flooded conditions, (b) having low toxicity for fish and (c) posing slight danger of crop injury. The cost of using herbicides would be lower than the cost of hand weeding at 100 hrs/ha.

Leading herbicides for paddy fields (Yamada, 1966) are as follows:

Hormone-type: 2,4-D (W), MCP (W), MCPB (W) and MCPCA (S)

Non-hormone-type: PCP(S), TPCL (S), DPN (S)*, NIP (S)*, Prometryne (S), DCPA (W) and CNP (S)*

*shows low toxicity for fish

Summarizing the above, in tropical Asia use of an efficient rotary weeder is limited due to the fact that the majority of paddy fields are tendency to increase with the length of growing time of the varieties compared with those in Japan. ET/day value in the dry season was 30% larger on the average than in the rainy season and this seems to be affected by the weather.

On the contrary, average irrigation requirement per day (IR/day value) show the wide range of 6.1-30.8 mm among the data measured in various Asian countries and most of the total IR (total IR) fall in the range of 700-1,200 mm. Since ET/day values show no big difference, the big difference in IR/day values at different latitudes seems to be caused by a difference in P/day values. Percolation amount may vary over a wide range with differences in environmental conditions such as the hydraulic condition, soil permeability and levee space of the tested fields (Kung et al., 1965; Nakagawa, 1966-67; Sugimoto, 1971; van't Woudt, 1967).

The difference between IR and ET is generally small in the paddy fields of vast alluvial plains and this is due to the rising of ground water level during the rice growing period which checks all the percolation (Kung et al., 1965; Nishio, 1972; Sugimoto, 1971). From the data obtained in various countries, it can be concluded that ET may be a factor controlling IR where IR is less than 10 mm, while ET is controlled by P where IR is larger than 10 mm. On the other side, since the ET rate is almost constant at 1.2 (1.1-1.3) and no big difference was seen among different varieties, growing seasons and latitudes, ET can be estimate if Em (pan evaporation) is obtained (Nakagawa, 1966-67; Sugimoto, 1971; van't Woudt, 1967).

Since the evaporization from the surface of rice plant foliage (T) and interspaces between plants (E) depends mainly upon solar energy, evaporation and transpiration are a physical phenomenon controlled by solar radiation pouring into the fields (Nakagawa, 1966-67; Sugimoto, 1971; Uchijima, 1962; van't Woudt, 1967). According to IRRI, the latent heat of evaporization expended by ET in dry season cropping was measured as 63% of the total incident solar radiation on the average.
The author showed 74% on the average for various varieties in rainy season cropping. Uchijima (1962) counted this value as an average 70% (59-86%) gathering the ET values measured at various places in Japan by the "heat balance method." Perhaps differing more or less with different varieties, planting densities and cropping seasons, this value is regarded as 60-70% in the tropics. Therefore, it is easy to estimate ET from measured solar radiation value. This means that ET is controlled by solar energy when the paddy field is flooded either with or without rice growing.

The IR discussed so far is only concerned with the paddy field itself. To establish a comprehensive irrigation plan, however, and to estimate total water consumption, all the steps throughout the whole rice cultivation period such as preparation and operation of nursery beds, preparation of paddy field (plowing, preparation and pudding), transplantation and rice growing period thereafter must be considered.

Table 4-13 shows the author's estimate in Malaysia, and this is an example of a paddy field in an equatorial rainforest climate area which has almost no percolation ($P \fallingdotseq 0$) (Sugimoto, 1971). The water consumed in main season cropping can be recovered almost fully by rainfall water randomly planted. Utilization of herbicides is also limited because of the necessity of providing free irrigation and drainage facilities. Water treatment herbicides available for flooded conditions, without surface drainage have been developed recently. Of them, aqueous 2,4-D is especially promising because of its low price and may be more economical than hand weeding. Most non-hormone-type herbicides have more toxicity for fish than the hormone-types; therefore, they are limited in their use in most tropical countries where fresh water fish are important sources of p otein.

4-2-9. Evaporation, Transpiration and Water Requirements

Since lowland rice is grown under flooded field conditions, the rice plants grow under different environmental conditions than upland crops. Water is an essential factor for lowland rice culture, as are day length and temperature. This water depends upon rainfall and river flooding as well as irrigation water. Thus, the water condition is the key to rice cultivation in Mons on Asia.

Irrigation requirement (IR) can be determined by (Nakagawa, 1966-67):

$$IR = E + T + P$$

Where E is amount of evaporation from field surface,
T is amount of transpiration from rice body and
P is vertical percolation loss at the bottom of the field and lateral percolation loss through levees.

An example from the author's investigations in Malaysia, an equatorial rain-forest area, is shown in Fig. 4-17 (Sugimoto, 1971). E was as much as 5 mm/day at an early stage but it decreases step by step as the plant growth drops to 2 mm/day. On the contrary, T was very small at the beginning and increased in almost a straight line with plant growth showing 3 mm/day at the maximum tiller number stage, and reached the maximum value of 5 mm/day at the stage just after heading which for awhile showed a slow bimodal curve. The evapo-transpiration value (ET) was 5-7 mm/day, but this value changed showing a similar type of curve to T's with the maximum value at the early ripening stage. In order to eliminate the effect of weather fluctuations, the pan evaporation value (Em), evaporation ratio (E/Em), transpiration ratio (T/Em) and evapo-transpiration ratio (ET/Em) were calculated. These three data are convenient to compare with those of E, T and ET measured under different conditions for different rice varieties, cropping seasons and growing places. In this case, both mean evaporation and mean transpiration rates throughout the growing period showed about 0.6, showing only small fluctuations and the mean evapo-transpiration rate was 1.2. These values showed small differences among different varieties and growing seasons. Transpiration rates showed two peaks, one at the maximum tiller number stage and one at the heading stage, and a similar transition was seen also in the evapo-transpiration rates. These data are regarded as a phenomenon common throughout the tropics.

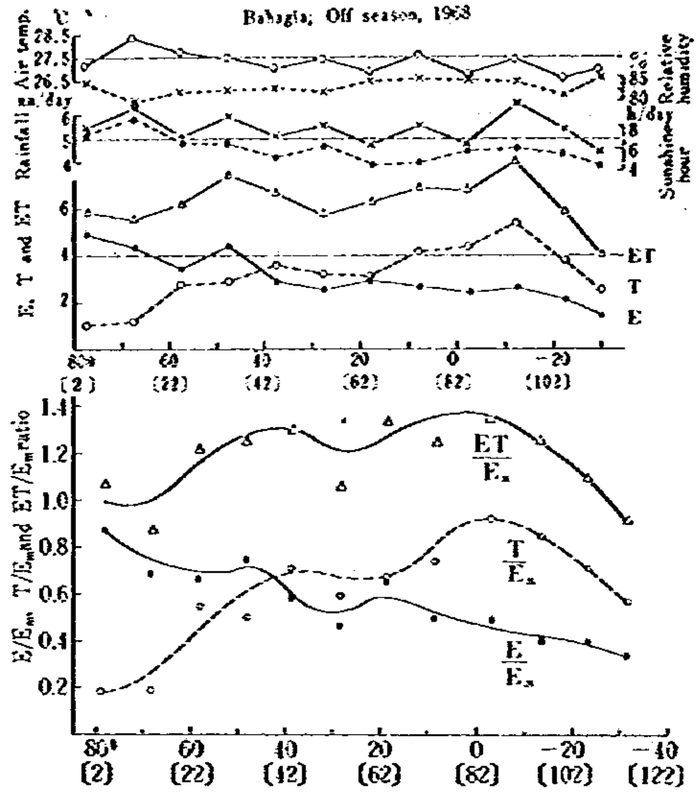

Fig. 4-17 Changes in evaporation, transpiration and evapo-transpiration, and evaporation ratio, transpiration ratio and evapo-transpiration ratio (Malaysia)[11] Note: * Days prior to heading and figures in parenthesis show number of days after transplanting.

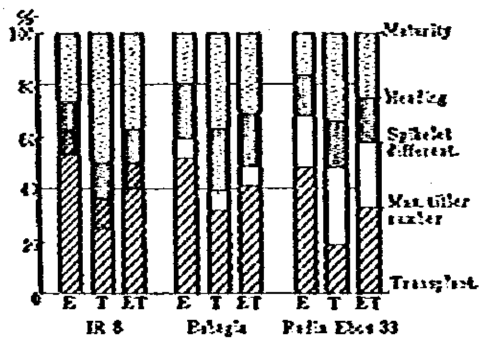

Fig. 4-18 Rate of evaporation, transpiration and evapo-transpiration at different growth stages (Main season, Malaysia)[11]

Since daily values of E, T and ET show no marked differences among varieties and growing seasons, the total value of the three is in proportion to the growing days. As seen in Fig. 4-18, in high-yield varieties, the proportion of T and ET-values in the vegetative growth period is 60-70% of the total while that of the local long-term variety, Radin Ebos 33, shows only 40-50% and that of the lag vegetative phase period shows as much as 30% (Sugimoto, 1971). Eventually, as far as water requirement goes, the fault of local long-term varieties is not only caused by increases in E, T and ET (net water requirement of the variety) with their long growing period but also by the large amount of those in the lag vegetative phase period (needless consumption).

Table 4—12 Results of irrigation requirement determined in some Asian countries[11]

Country	Author	Location	Season	Meas. period	Total (Average daily amount) E	T	ET	P	IR	ET/Em ratio
				day	mm	mm	mm	mm	mm	
Thailand	Kung *et al.*[11]	Central Plain 15°N	Main season 1964	151 (25/VI—22/XI)	291 (1.9)	591 (3.9)	835 (5.9)	97 (0.6)	983 (6.5)	
			Off season 1965	91 (20/II—21/V)	346 (3.8)	343 (3.8)	695 (7.6)	43 (0.5)	743 (8.2)	
	Royal Irri. Dept.	Northeast 15°N	Main season	91	233 (2.5)	255 (2.7)	458 (5.2)	278 (3.0)	765 (8.2)	
Cambodia	Hatta	Battambang 13°N	Dry season 1965/66	106 (22/XI—7/IV)			710 (6.7)	244 (2.3)	954 (9.0)	(Rainfall 152mm)
Laos	Kotter	Vientian 18°N	Wet season 1957	102 (10/VI—20/IX)	270 (2.7)	245 (2.4)	515 (5.1)	742 (7.3)	1,257 (12.4)	
East Pakistan	Kung[11]	Kushtia 24°N	Wet season 1959	78	382 (4.9)	733 (9.4)	1,115 (14.3)	78 (1.0)	1,193 (15.3)	(Effect. rainfall 541mm)
			Dry season 1958/59	101	436 (4.3)	515 (5.1)	951 (9.4)	54 (0.5)	1,005 (10.0)	(0)
Ceylon	Murakami[11]	Dry zone 8°N	Dry season 1965	112 (31/V—19/IX)	420 (3.8)	552 (4.9)	972 (8.7)	2,475 (22.1)	3,447 (30.8)	ET/Em 1.23
India	Vamadevan *et al.*	New Delhi 29°N	Wet season 1968	87 (10/VI—4/X)			493 (5.7)	1,189 (13.7)	1,683 (19.3)	
Malaysia	Sugimoto[11]	Kedah 6°N	Main season 1967/68	97 (20/IX-26/XII)	266 (2.7)	262 (2.7)	527 (5.4)	61 (0.6)	588 (6.1)	1.21
			Main season 1967/68	139 (29/VIII-15/I)	347 (2.5)	387 (2.8)	734 (5.3)	201 (1.4)	935 (6.7)	1.09
			Off season 1968	116 (14/V-7/IX)	364 (3.1)	372 (3.2)	737 (6.4)	−19 (−0.2)	718 (6.2)	1.17
			Main season 1968/69	110 (14/VIII-1/XII)	336 (3.1)	312 (2.8)	649 (5.9)	57 (0.5)	705 (6.4)	1.20
			Main season 1968/69	179 (11/VII-5/I)	574 (3.2)	448 (2.5)	1,022 (5.7)	204 (1.1)	1,226 (6.8)	1.18
	Nishio[11]	Kedah 6°N	Main season 1970/71	102 (13/X-23/I)			542 (5.3)	371 (3.6)	913 (9.0)	1.04
			Off season 1971	122 (19/IV-18/VIII)			834 (6.8)	618 (5.1)	1,452 (11.9)	1.12
		P. Wellesley 6°N	Main season 1970/71	103 (29/X-9/II)			576 (5.6)	321 (3.1)	897 (8.7)	1.10
			Off season 1971	117 (25/IV-20/VIII)			725 (6.2)	358 (3.1)	1,083 (9.3)	1.10
Philippines	IRRI	Southern Ruzon 14°N	Dry season 1965	91					559 (6.1)	
			Wet season 1966	86			396 (4.6)	172 (2.0)	568 (6.6)	

Country	Author	Location	Season	Meas. period	Total (Average dailp amount)					ET/Em ratio
					E	T	ET	P	IR	
			Dry season 1968	91 (27/I--27/IV)			607 (6.7)			
			Wet season 1968	97			430 (4.4)			
Taiwan	Citied by Maki	Central 24°N	Interme. season 1923—26	103 (VI—X)	352 (2.9)	323 (3.3)	675 (6.2)			1.17
		Southern 23°N	Interme. season 1923—26	96 (VI--X)	259 (2.6)	304 (3.1)	557 (5.7)			1.03
		Southern 23°N	Interme. season 1923—26	93 (VI—X)	485 (5.0)	296 (3.1)	781 (8.1)			1.43
			Average	97	355 (3.5)	317 (3.2)	672 (6.7)			1.24
	Shibuya	Southern 23°N	Second season 1919—22	106 (VII—XI)	416 (4.0)	93 (0.9)	509 (4.8)	160 (1.6)	669 (6.4)	1.10 (0.93—1.37)
Korea	Tsubouti	Central 37°N	Normal season 1931	90 (22/VI-20/IX)	231 (2.6)	241 (2.7)	472 (5.2)			1.28
Japan	Ishikawa and Nishio	Shikoku 34°N	Early season 1956—59	105 (6/V-19/VIII)	201 (2.0)	315 (3.1)	517 (5.1)	487 (4.8)	1,004 (9.9)	0.97
			Normal season 1956—59	112 (21/VI-10/X)	199 (1.8)	372 (3.5)	571 (5.3)	808 (7.5)	1,379 (12.8)	1.19
			Late season 1956—59	81 (29/VI-18/X)	156 (2.0)	219 (2.7)	375 (4.7)	445 (5.5)	820 (10.2)	1.31
			Average 1956—59	99	185 (1.9)	302 (3.1)	487 (5.0)	580 (6.0)	1,067 (11.0)	1.09
	Nakagawa[1)]	37places in the country 32—44°N	Normal season 1947—64	100 (VI—IX)			440—550 (4.4—5.5)			1.30 (0.9—1.7)
	Iwakiri	Kyushu 23°N	Early season 1960—63	91 (1/V-30/VII)	120 (1.3)	233 (2.6)	353 (3.9)	223 (2.5)	575 (6.4)	1.65
			Normal season 1960—63	103 (1/VI-16/X)	160 (1.5)	251 (2.3)	411 (3.8)	420 (3.9)	830 (7.7)	0.96

Note: There are several other papers reporting irrigation requirement of rice determined in tropics, subtropics and temperate zone. However, only the papers in which average daily consumption of water can be calculated are selected and listed in the table.

Table 4-12 gives a summary of the main experimental results obtained in various Asian countries including the author's. The majority were measured by the "water balance method" (Kung et al., 1965; Murakami, 1966; Naito, 1969; Nakagawa, 1966-67; Nishio, 1972; Sugimoto, 1971). Results in Japan show that T is always larger than E, while plants in tropical countries do not show a tendency of T>E. This difference is considered due to the fact that tropical rice culture is less productive because of its sparse planting and lack of manuring, unlike rice culture in Japan. In the majority of cases, ET/day values are about 5-6.5 mm and these are larger than the 4-5.5 mm obtained in Japan. ET/day values, however, fall within a range of 4-6.5 mm throughout the temperate, subtropical and tropical zones, and it can be said there is no big difference in ET/day values at different latitudes. Total ET value in the tropics has a

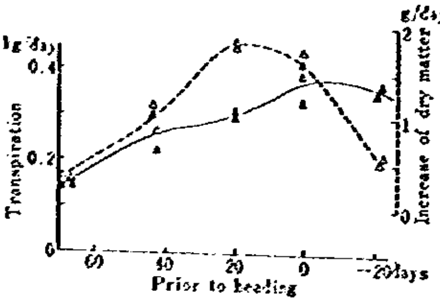

Fig. 4-19 Changes in transpiration and dry matter production per hill (Variety : Bahagia, Malaysia)[11)]

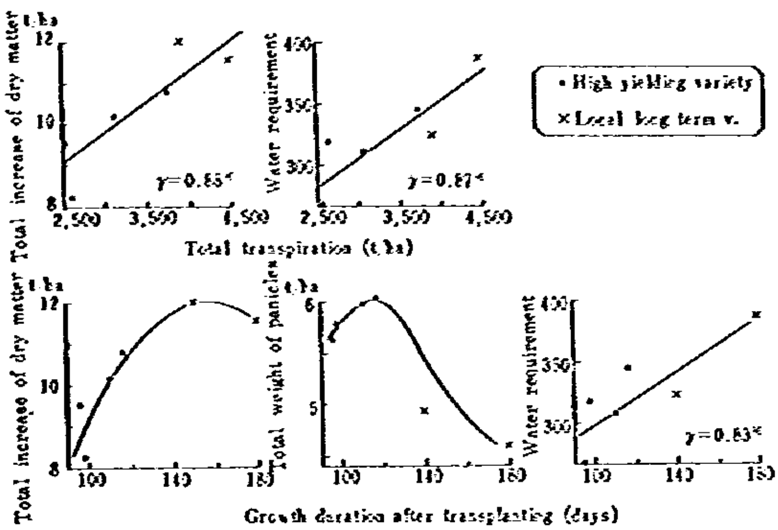

Fig. 4-20 Relation of total transpiration to total dry weight and water requirement, and relation of growth duration to total dry weight, total panicle weight and water requirement (Malaysia)[11)]

T is increasing with additional transpiration from emerged heads, the apparent photosynthesis or total dry matter production is not contributed from heads owing to active respiration in the heads in this stage. This phenomenon is a characteristic of paddy population having a high rate of transpiration in the heads. This unbalance is especially noticable in local long-term varieties.

As shown in Fig. 4-20, a positive correlation is seen between total transpiration and total dry matter production. Since varietal difference is less in T/day, the longer the growing period of the variety, the longer the cumulative figures of T and total dry matter production (Murakami, 1966; Sugimoto, 1971).

Transpiration needed to produce one gram of dry matter is called "water requirement" or "transpiration coefficient," and this value in lowland rice is about 300 (20 and 30). Since water requirement (WR) equals

Table 4-13 An estimation of the water consumption in the culivation of Bahagia by providing with standing water from sowing to harvest (Malaysia)[19]

Period	Item	Off season (Mar. 15 to Aug. 4)	Main season (Sept. 1 to Jan. 11)
From sowing to transplanting	Evapo-transpiration (Em/day) × (No. of days)	mm mm* 8.3×25=208	mm mm* 5.1×25=128
Prior to transplanting	Water required for pudding and levelling, and maintaining field at saturated moisture condition for 5 days	mm 190	mm 150
From transplanting to harvest	Evaporation (Em/day) × (No. of days) × (E/Em)	mm mm 5.9×117×0.55=380	mm mm 4.6×107×0.55=271
	Transpiration (Em/day) × (No. of days) × (T/Em)	mm mm 5.9×117×0.65=449	mm mm 4.6×107×0.65=320
	Percolation (Perc./day) × (No. of days)	mm mm 1×117=117	mm mm 1×107=107
From sowing to harvest	Total (Growth duration)	mm inches 1,344=53 (142 days)	mm inches 976=38 (132 days)

*irrigation requirement for nursery which is about 1/30 area of paddy field.

but off-season cropping, starting at the end of dry season, needs some irrigation water during the first half of the growing period in addition to rainfall. Out of total rainfall, the part maintained in the paddy field is called "effective rainfall" but the method of calculating it is not yet settled in tropical areas (van't Woudt, 1967). In Japan, it is estimated by neglecting amounts of rainfall less than 5 mm per day and the excess of any rainfall above 50 mm; 80% of the total rainfall within a range of 5-50 mm is regarded as effective rainfall.

The amount of water consumption minus effective rainfall can be regarded as "needed amount of irrigation water," but the actual amount of irrigation water needed is estimated as 30% more than the above amount, counting conveyance loss through the canal from the water source to the field.

4-2-10. Dry Matter Production and Necessary Water Amount

While photosynthesis goes on during the daytime, transpiration goes on day and night. However, 90% of the transpiration water is consumed during the daytime in connection with photosynthesis (Naito, 1969). Since both physiological reactions are carried out in the tissues of leaf blades through stomata utilizing solar energy, they are intimately related to each other (Naito, 1969; Tanaka, 1971). As seen in Fig. 4-19. A parallel relationship is recognized between T/day and dry matter production/day at every stage of plant growth. It can be regarded that the more the vigorous growth stage is, the greater the amount of dry matter produced, except at the end of the growing period when an unbalance is seen between increasing T and a reduction in dry matter production (Naito, 1969; Sugimoto, 1971). This phenomenon is due to the fact that, while the value of

Table 4—14 Result of water requirement (transpiration coefficient) determined in some Asian countries[11]

Country Author	Variety	Season	Measurement period	Transpira. coefficient	Season	Measurement period	Transpira. coefficient	Method of culture
			days			days		
Ceylon[11] Murakami	P. P	Wet season 1965	79	305	Dry season 1964/65	79	445	Pot
	Murenza 307	″	79	312	″	81	380	″
	H 4	″	105	336	″	116	452	″
	M 302	″	103	311	″	121	490	″
	Podiwee a-8	″	135	435				″
	Ptb-16	″	136	449				″
	Remadja				″	128	530	″
	Sigadis				″	128	570	″
Malaysia[11] Matsushima	Pebifun	Main season 1960/61	87	491	Off season 1960	96	453	Pot
					Off season 1961	90	439	″
	R. China 4	″	121	611				Pot
	Scrup 50	″	154	766				″
	IR 8	Main season 1967/68	92	254	Off season 1968	93	291	Pot
		Main season 1968/69	91	257				″
	Mahsuri	Main season 1967/68	107	243	Off season 1968	119	319	Pot
		Main season 1968/69	104	274				″
Country Author	Variety	Season	Measurement period	Transpira. coefficient	Season	Measurement period	Transpirs. coefficient	Method of culture
			days					
Korea Sato	Ginbozu	Normal season 1932—38	90	265 (171—327)				Field
Korea Tsubooti	Rikuu 132	Normal season 1933	59	258				Field
	Kamenoo	″	59	303				″
	Odashiro	″	59	331				″
	Nakateginbozu	″	70	319				″
	Tamanishiki	″	80	260				″
	Kokuryomiyako	″	80	276				″
	Omachi	″	90	299				″
Japan Tamai *et al.*	Yachikogane	Very early season 1958	118	290				Pot
		Early season 1958	105	322				″
		Normal season 1958	—	351				″
Japan Hasegawa	Fujisaka 5	Early season 1957—58	111	285				Pot
		Normal season 1957—58	111	291				″
		″	96	281				Field

Country Author	Variety	Season	Measurement period	Transpira. coefficient	Season	Measurement period	Transpirs. coefficient	Method of culture
			days					
Korea Sato	Ginbozu	Normal season 1932--38	90	265 (171--327)				Field
Korea Tsubouti	Rikuu 132	Normal season 1933	50	258				Field
	Kamenoo	"	50	303				"
	Odashiro	"	50	331				"
	Nakateginbozu	"	70	319				"
	Tamanishiki	"	80	269				"
	Kokuryomiyako	"	80	276				"
	Omachi	"	90	290				"
Japan Tamai *et al.*	Yachikogane	Very early season 1958	118	290				Pot
		Early season 1958	105	322				"
		Normal season 1958	—	381				"
Japan Hasegawa	Fujisaka 5	Early season 1957—58	111	285				Pot
		Normal season 1957—58	111	291				"
		"	96	281				Field
Japan[19] Kato *et al.*	Yachikogane	Normal season 1962	101	310				Field
		Normal season 1963	108	305				"
Japan Ishikawa and Nishio	Norin 17	Early season 1956—59	105	393				Field
	Mihonishiki	Normal season 1956—59	112	338				"
	Norin 37	Late season 1956—59	81	231				"

rate of transpiration vs. dry matter production (photosynthesis), it can be calculated by the equation Transpiration amount/increased amount of dry matter = WR, and it shows the water efficiency per unit dry matter production. Therefore, the WR value may change with difference of soil, fertilizer applications and cropping seasons which relate to it. This value is reduced during the middle growing stage when the increasing amount of dry matter comes to be large; on the other hand, it is enlarged at the late growing stage when the increasing amount of dry matter is small compared with T (Murakami, 1966; Naito, 1969; Sugimoto, 1971). A small value of WR means the water is utilized efficiently for dry matter production.

Table 4-14 shows the water requirement data determined in various Asian countries covering tropical, subtropical and temperate areas (Matsushima, 1962; Murakami, 1966; Naito, 1969; Sugimoto, 1971). The WR values were, in most cases, within the range of 260-500. In tropical areas, the WR value increased in proportion to the growing duration but in temperate areas this relation was not clear. Wu (Horiuchi et al., 1971) reported in Taiwan, a subtropical area, cases of both an increase in WR with growing duration and a reduction of WR in high-yield varieties. However, IRRI stated that the ratio of ET vs dry matter production had a definite value throughout the growing period and also showed a smaller varietal difference (IRRI, 1967).

In the case of pot culture, it must be noticed that the WR value may be larger than in the field, since in the former case, transpiration is affected by advection energy in addition to solar energy (Naito, 1969). Water acquirement values in the tropics are generally larger than those in temperate zones, and one of the reasons is that long-term varieties are grown. When varieties having almost the same growing duration are compared, this value is not always larger than that of temperate zone.

Water requirement values in tropical and subtropical areas are increased in proportion to the growing duration, so it is clear that water efficiency for dry matter production in local long-term varieties having long growth duration is lower than that of high-yield varieties having short growth duration (Matsushima, 1962; Murakami, 1966; Sugimoto, 1971; Wu, 1969). Moreover, dry season cropping makes larger WR value than rainy season cropping does (Murakami, 1966; Sugimoto, 1971).

Generally, dry matter production has a tendency to increase according to growing duration. However, as shown in Fig. 4-10, it stops increasing beyond a certain number of growing days. Moreover, since the grain/straw ratio is lower the longer the duration of growth, the weight of heads reaches a maximum at about 115 days after transplanting (Sugimoto, 1971). This suggestion coincides fairly well with the result of Vergara et al., in IRRI (1966). It can also be concluded that the optimum growing duration to gain maximum grain yield would be about 140 days including the nursery period, and this estimate also coincides fairly well with the conclusion mentioned in Chapter 4-2-7.

Summarizing the above, in local long-term varieties, compared with high-yield varieties, dry matter production, especially grain production, does not follow an increase of transpiration and therefore, their water requirement increases remarkably and results in remarkably inferior water efficiency to dry matter production. In the case of using limited irrigation water, the superiority of high-yield varieties having 4-4.5 months of growing period is clear both in grain production and water efficiency.

4-2-11. Water Management and Surface Drainage in the Middle Stage

Water for lowland rice cultivation brings nutrients, it helps make nutrients in the soil usable, and is effective also in checking the growth of weeds. Moreover, lowland rice is the most fruitful staple food crop in very deeply flooded swampy lands in the rainy season in Monsoon Asia where no other useful crop can be cultivated.

Under flooded conditions, however, water accumulates material and silt from the soil which may generate noxious gases and this causes damages to plant growth, especially root development (Tanaka, 1971). Therefore, continuous flooding of paddy fields is not ideal. This is especially true when high-yield varieties are to be introduced, at which time drainage facilities should be under consideration together with irrigation facilities. Good irrigation and drainage water control makes it easier to introduce machinery and to apply fertilizers and agricultural chemicals, and thus introduce modern rice cultivation technology dominated by short-stemmed varieties, shallow flooding and heavy fertilizer application. The majority of rice growing areas in tropical Asia, however, have no field canals and no drainage facilities throughout a district; therefore, areas where individual paddy fields are able to control drainage and water are very limited.

In swampy areas, water in paddy fields is difficult to control, and sometimes water depth is more than 30 cm, and many fields grow rice without manuring. As seen in Fig. 4-21 (Sugimoto, 1965A; Sugimoto, 1971), high-yielding varieties show yield depression in proportion to the water depth and this depression is larger in IR 8 than in Bahagia, while local varieties show less response to water depth except plots that are not manured; maximum yield is apparent in plots with a water depth of 10 cm.

Common to every variety and water depth, fertilizer application results in yield increase. Top-dressing is more effective than basal dressing in high-yielding varieties, while this tendency is not clearly shown in local varieties. Common to all the treatment plots, positive correlations are seen between yield and yield components of total numbers of heads and spikelets. The less the water depth the better in high-yielding varieties, while about 5-10 cm is optimum for local varieties. Results in local variety are shown in Table 4-10 which also shows the maximum yields at the shallower water depth of 6-13 cm among various water depths (Matsushima, 1962). The plots which were kept flooded (stagnant) showed greater yields than plots under water which was moving either horizontally or vertically. This seems to be due to the fact that local varieties have considerable tolerance to poor soil conditions.

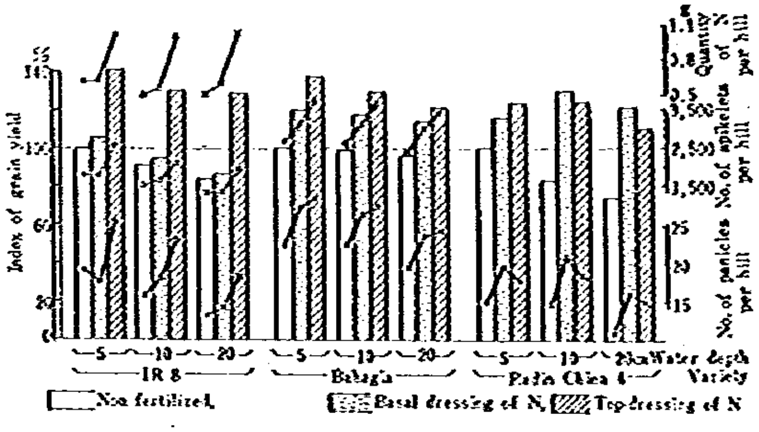

Fig. 4-21 Relation of water depth and fertilizer application method to grain yield and yield components (Frame test, Malaysia)

Table 4-15 Effect of water-depth and water-movement on grain yield (g/tank) (Variety : Radin China 4, Main season, Malaysia)[11]

Depth \ Movement	Stagenant	Horizontal	Vertical	Mean
0 cm	495			
6 cm (Mid-drying)			663	
6 cm	695	665	655	672
13 cm	671	665	624	653
26 cm	613	614	569	599
Mean	660	648	616	

Table 4-16 Effect of drought at different growth stages on grain yield and yield components (Variety : Radin China 4, Pot test, Malaysia)[11]

Treat. period (Days from heading)	No. of panicles	No. of grains per panicle	% of ripened grains	Wt. of 1,000 grains	Grain yield	Index
			%	g	g/hill	%
1 (-92)	15	156	87	21.4	49.8	86
2 (-80)	12	183	88	21.3	41.3	87
3 (-68)	16	157	90	21.7	47.4	100
4 (-56)	19	133	83	21.5	41.3	93
5 (-44)	18	156	89	21.0	45.9	96
6 (-32)	18	134	85	20.3	40.6	85
7 (-20)	17	164	74	19.5	39.5	83
7·8 (-14)	20	129	59	19.5	27.2	57
8 (-8)	20	122	50	20.0	23.1	49
9 (+4)	15	144	75	19.2	31.9	67
10 (+16)	16	137	86	21.2	39.1	82
11 (+28)	16	130	84	21.7	37.3	78
Control	18	159	83	21.2	47.6	100

Matsushima's findings (1962) on drought resistance are shown in Table 4-16. The stage most susceptible to drought is the reduction division stage (14-18 days before heading) and the heading stage and spikelet differentiation stage are second; this response is caused by the lowering of the rate of grain ripening due to non-fertilization. Soil drying does not affect yield during the so-called non-productive tillering period from the active tillering stage (68 days before heading) to the late tillering stage (44 days before heading). These results coincide rather well with various results obtained in Japan.

The productive tillers can be obtained around 32 days after transplanting irrespective of the length of growing period or variety (Sugimoto, 1968). Almost all the tillers developed thereafter are non-productive. In Japan, mid-summer drainage is generally practiced; after enough active tillers appear, the field is drained and dried for 10-14 days in mid-summer around the maximum tillering stage to check non-productive tillering and to improve other factors as well.

Table 4-17 shows the author's findings (Sugimoto, 1971) in Malaysia. A greater yield increase can be seen in plots drained for 12 days and 18

Table 4—17 Effect of mid-season drainage on grain yield (Variety : IR 8, Malaysia)[11]

Treatment	No. of panicles per m^2	No. of spikeletes per m^2	% of ripened grains	Wt. of 1,000 grains	Grains yield	Index	
		$\times 10^4$	%	g	t/ha	%	%
1. Control Non f.	213	2.0	43	28.3	2.76	100	
2. 〃 Fertilized	290	2.7	60	29.4	4.80	174	100
3. 6 days drain Non f.	224	1.8	45	28.5	2.58	94	
4. 〃 Fertilized	285	2.6	58	29.3	4.42	161	92
5. 12 days drain Non f.	213	2.0	54	28.8	2.99	109	
6. 〃 Fertilized	314	2.6	67	30.0	5.22	189	109
7. 18 days drain Non f.	238	2.0	55	29.3	3.22	117	
8. 〃 Fertilized	318	2.7	60	29.5	4.73	172	93
9. Intermittent irr. Non f.	221	2.1	45	28.3	2.70	93	
10. 〃 Fertilized	301	2.7	59	29.3	4.74	172	99

Table 4—18 Effect of intermittent irrigation on grain yield and yield components in wet and dry season (Variety : Bahagia, Alor Star, Malaysia)[11]

Irrigation method	Nitrogen application method	No. of panicles per m^2	No. of spikelets per m^2	% of ripened grains	Wt. of 1,000 grains	Grain yield	Index	Net irrigation water
	kg/ha		$\times 10^4$	%	g	t/ha	%	mm
Flooding	102[a)] 136[b)]	156 162	2.1 2.4	81 79	25.6 25.6	4.39 4.70	100 107	360
Intermittent	102[a)] 136[b)]	167 171	2.2 2.5	80 77	26.1 24.9	4.64 4.79	106 109	238
Flooding	102[b)] 136[a)]	183 203	2.4 2.7	77 80	26.7 27.4	4.96 5.93	100 120	451
Intermittent	102[a)] 136[b)]	186 207	2.3 2.5	83 79	26.8 27.4	5.01 5.34	101 103	193

Note : Intermittent irrigation was introduced one month after transplanting,
a) ½ nitrogen applied basally and
b) ⅗ nitrogen applied basally.

days than in controlled plots and those drained for six days. This means the effect of soil drying helped improve the grain ripening rate and grain weight. The six-days-drained plots showed insufficient soil drying and plots with intermittent irrigation for 19 days showed no response on yield increase.

Mid-season drainage for 10-20 days from 35 days after transplantation not only saves water (140 mm/18 days) but also increases yield to some extent.

As seen in Table 4-18, Nishio (H. Takahashi, 1971) stated that intermittent irrigation one month after transplanting did not show any effect on yield increase in the dry season although some effect was seen in the rainy season. However, it saved a considerable amount of "net irrigation water" in both seasons, with an especially notable saving of water in the dry season. Yield increase response to heavy application of fertilizers was more remarkable in the dry season cropping than in that of the rainy season. As shown in Fig. 4-13, intermittent irrigation had some effect on yield increase (Motomura, 1973). Kanareugsa (and Chantratarakul, 1973) also recognized the effect of intermittent irrigation on yield increase as seen in Table 4-19. They recognized the effect of increased application of nitrogen on yield increase and decided the optimum application rate to be 100 kg/ha, but there was no effect from phosphorus.

Summarizing the above, mid-season drainage and intermittent irrigation clearly help to save irrigation water but their effect on yield increase may be up to about 10%. There are many experimental results which show no effects from them. Mid-season drainage and intermittent irrigation have two effects, that is, on the one hand, both help to lighten the soil from heavy reduced conditions by means of drying, but on the other, both may cause loss of soil nutrients by denitrification. Both are promising technologies for high-yield varieties which have the weak point of susceptibility to root rot under worse conditions. One point is that both may help the soil giving durability for introduction of harvester or combine. In alluvial plain paddy fields, as in Thailand and Malaysia, however, drainage is difficult in individual fields and large scale drainage facilities over a wide area is essential to adequate drainage.

4-2-12. Lodging

Elongation of various organs, increase of dry weight and their relationship fairly coincide with the results of "Aichiasahi" obtained in Japan at the heading stage (Seko, 1962). As seen in Figs. 4-22 and 4-23, the elongation processes and increase of dry weight of leaf-blades, leaf-sheaths, panicles and internodes develop along Robertson's growth curve until they reach the maximum (Sugimoto, 1965A; Sugimoto, 1968). As for these organs, except for increase of dry weight of Bo (panicle), the organs whose maximum growing time (elongation and increase of dry weight) coincides with those of the others are given the marks shown in Fig. 4-24. These marks correspond to each other as follows:

$$B_0 : S_1 : N_2,\ B_1 : S_2 : N_3,\ B_2 : S_3 : N_4,\ B_3 : S_4 : N_5$$

That is, certain regularity can be seen in each organ. Besides, the relation between elongation and increase of dry matter is as follows. Generally, at around the time that the elongation rate of a certain organ reaches the maximum, the increase of dry weight of said organ is accelerating. Then, at around the time the rate of increase of dry weight reaches the maximum, its elongation is approaching the end. Both developments proceed regularly and alternatively rising from lower organs to upper (Seko, 1962; Sugimoto, 1965A; Sugimoto, 1968).

The elongation rate of every organ is naturally affected by nutrients both inside and outside the rice plants and environmental factors at the heading stage, but the principal elongating period of every organ is definite in respective organs. Both *indica* and *japonica* rice grow with a certain regularity, and it can be seen that synchronous elongation and a corresponding increase of dry weight take place in every organ in correlation with each other. This knowledge can be utilized to diagnose morphology of rice plants and to clarify the mechanism of lodging explained hereafter.

Table 4—19 Effect of drainage on grain yield in relation to various rate of nitrogen and phosphate fertilizers (Variety : RD 1, Thailand)[19]

Treatment	Rate of P_2O_5 (kg/ha)	Grain yild(t/ha) Rate of nitrogen (kg/ha) 0	25	50	75	100	125	Average
Intermittent drainage	37.5	5.4	5.9	6.1	6.7	7.4	7.1	6.4
	112.5	5.3	6.0	6.8	6.9	7.1	7.0	6.5
Average (1)		5.4	6.0	6.5	6.8	7.0	7.0	6.4
(1)/(2)		1.06	1.06	1.01	1.07	1.07	1.05	1.06
Control	37.5	4.8	5.6	6.1	6.2	6.5	6.6	6.0
	112.5	5.3	5.6	6.3	6.5	6.6	6.8	6.2
Average (2)		5.1	5.6	6.2	6.4	6.5	6.7	6.1

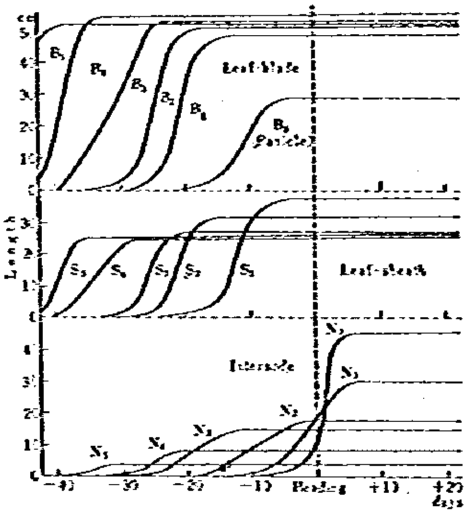

Fig. 4-22 Elongation process of the organs (Variety : Radin China 4, Malaysia)[17,19]

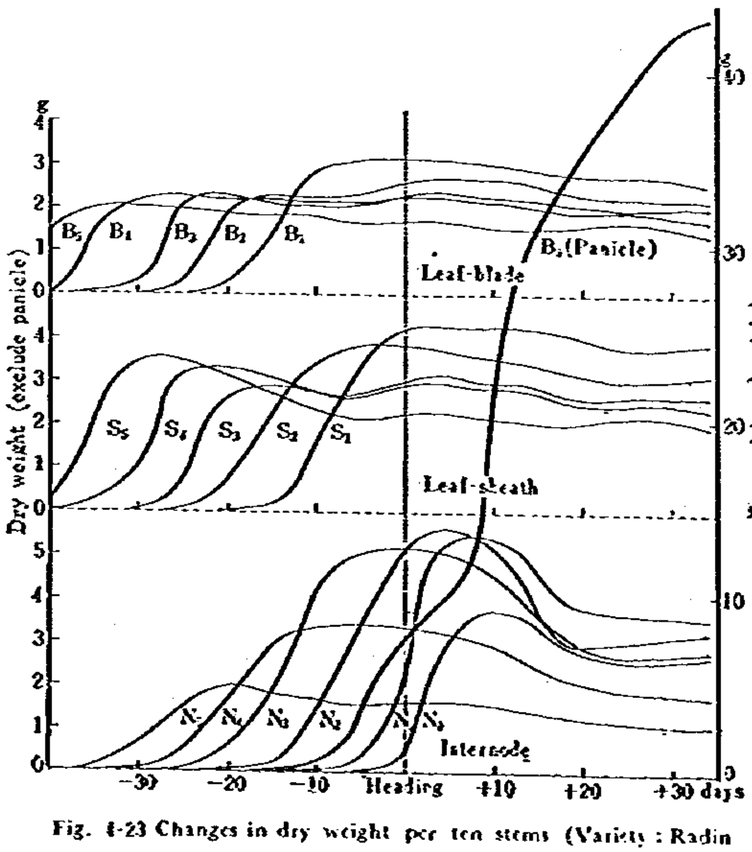

Fig. 4-23 Changes in dry weight per ten stems (Variety : Radin Chin 4, Malaysia)[17,19]

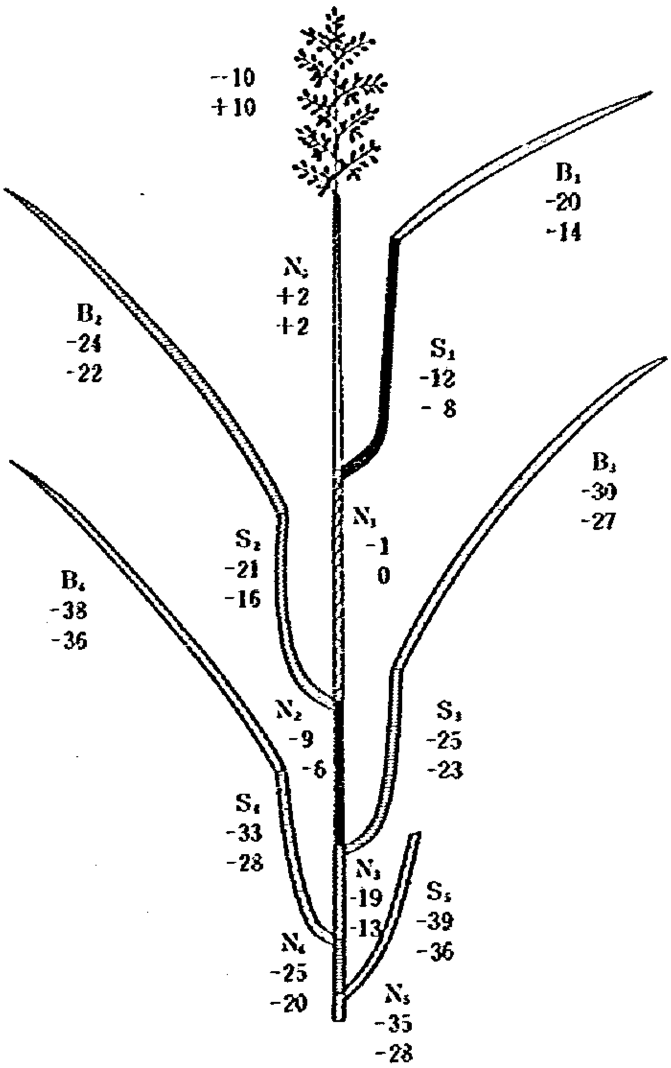

Fig. 4-21 Illustration showing the process of elongation and dry weight increase of each organ (Variety : Radin China 4, Malaysia)[37,39]
Notes : Upper figures : Peak date of principal period of elongation, Lower figures : Peak date of principal period of dry weight increase. Figures indicate the number of days before or after heading.

There are four types of lodging, that is, (a) lodging by breaking of internodes at the lower part of culms, (b) lodging by buckling and bending at the basal culm above ground level, (c) falling of the whole plant caused by upheaval of roots, seen in most cases of direct sowing culture, and (d) by gradual bending following the rupture of culm tissues. This is limited to open or spreading type growths of *indica* rice.

In paddy fields of IRRI, (b) is most common and this is due to the brittle or senescent culms usual in *indica* rice (Chang, 1964). In Malaysia, many cases of (a) are also found. Lodging is a complicated phenomenon and related to a delicate balance between the following three factors: (a) inherited straw strength, (b) effect of environmental factors on rice plant characteristics combined with straw strength and bending moment, and

(c) influence of outside factors, mainly such physical ones as wind, rain and the falling over of neighboring plants.

Local varieties generally have extremely long culms, and thus the lodging phenomenon can be seen, even without manuring, in fertile fields. Lodging-resistant varieties are those in which lodging occurs later. By the development of IR 8, the lodging-susceptible characteristics of *indica* types have made great strides in improving resistance.

The author's investigation in Malaysia (Sugimoto, 1965A; Sugimoto, 1968) showed, Fig. 4-25, that culms of the lodged rice plants were more elongated than those of the standing plants and the breaking happened at the internodes, mostly about 15 cm above ground level, the majority at N_3 and N_4 but partially also at N_2 and N_5. These internodes were generally more elongated and spindly than those of standing plants. Thus, an increase in the load of tops higher than the said part of culms, with panicle grain ripening, above the breaking strength of the said part of culms, results in lodging, breaking the part of culm. This is the mechanism of lodging.

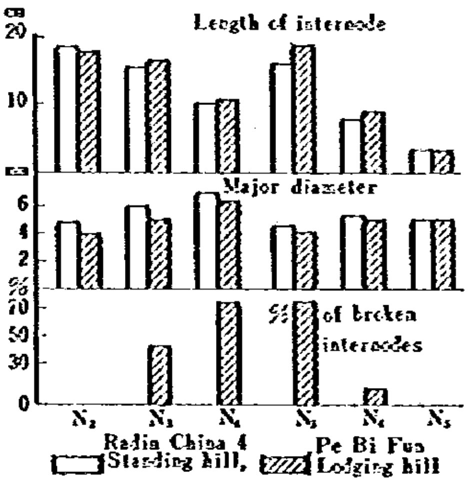

Fig. 4-25 Morphological difference between normal hill and lodging hill (Malaysia)[15,19]

As seen in Fig. 4-26, common to all the plots, the breaking strength of the weak part of culms rose at one point, showing its peak at the dough ripe stage (two weeks after heading) then dropped down. The bending moment, which is the product of length multiplied by the fresh weight of shoot above the said internodes, also increased rapidly after heading, showing its peak at the dough ripe stage then came down. In the case of lodging by breaking, the grade of breaking strength of the said culm is called "index of lodging" (IL) and calcuated as:

$$\frac{\text{Bending moment}}{\text{Breaking strength}} \times 100 = \text{IL (Seko, 1962)}$$

It can be understood that the larger the IL, the easier the lodging. This index figure will increase after the heading and come up to the maximum

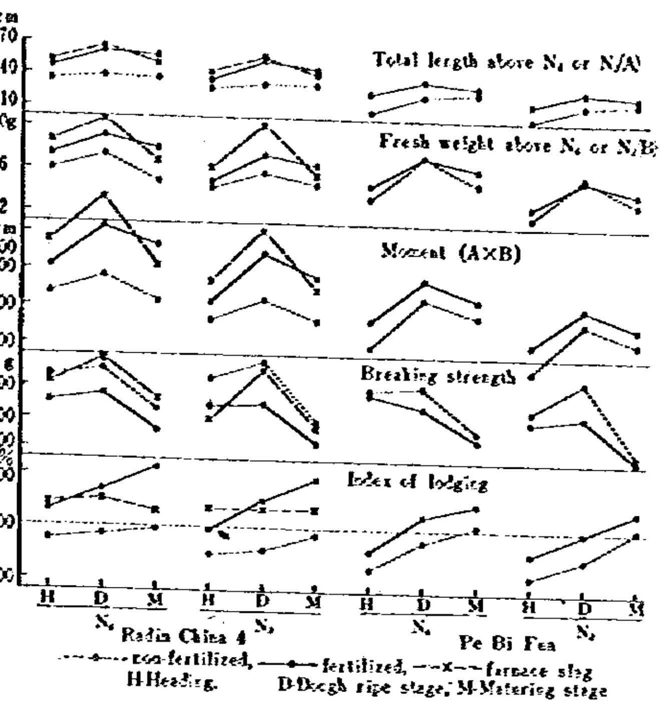

Fig. 4-26 Changes in index of lodging after heading (Malaysia)

at the maturity (Fig. 4-26). This transition fairly coincides with actual increasing of lodging risk during the ripening period (Sugimoto, 1965A; Sugimoto, 1968).

The critical point of lodging risk is regarded as 200 in Japan (Seko, 1962). In Malaysia, even in unfertilized plots, IL reaches 200 at maturity, and in fertilized plots, IL 200 is shown from the heading stage to the dough ripe stage. Therefore, general rice culture there has notably high risk of breaking lodging as early as panicle emergence.

In local varieties having low fertilizer response, high yield generally cannot be promised without slight lodging. At the same time, lightening the lodging connected with top-dressing seems to be the key to yield increase. Application of calcium silicate or 2,4-D is sometimes effective in inhibiting lodging, but this countermeasure is not yet definitive (Sugimoto, 1965A; Sugimoto, 1968). The beginning of the principal elongation period of N_4 and N_3 is about 28 and 23 days before heading, respectively and initial elongation starts several days prior to that (Sugimoto, 1965A). High temperature and too luxuriant growth not only promote elongation of internodes but also reduce breaking strength if there is surplus nitrogen in the plants or the soil, and these seem to be main factors in lodging.

Ota in Sri Lanka (1964) clarified that the degree of lodging was noticably affected by the time of top-dressing as seen in Fig. 4-27. He pointed out that top-dressing at the reduction division stage (eight weeks after transplanting) didn't affect elongation of N_4 and N_3, which is related to lodging, but strongly affected yield (also see Table 4-4).

The raindrops that attach themselves to the plant body during rainfall are equivalent to 30-60% of the weight of the plant body itself, so the bending moment acting on the base of culm is increased 20-50% by rain water. Therefore, the loading from the wind in squalls at the ripening period is enough to cause lodging (Koritaka, 1968). Another outside factor is this: since the later part of the growing period is generally in the dry season, many paddy fields may be without rain water from the heading stage. In this case, rice plants run into a forced maturity due to high temperature and insufficient moisture, reducing the turgor pressure of culms thereby reducing breaking strength, and this eventually increases lodging.

In local long-term varieties, the prolonged lag vegetative phase promotes internode elongation irrespective of young panicle differentiation and development. This phenomenon naturally results in multiplying the number of elongated internodes and produces elongated internodes of more than 5 cm at the base of culms,down to N_5. Comparatively, in short term IR 8, there are not more than N_3 elongated internodes, that is, two internodes less than shown formerly by the author's examination. The smaller the number of elongated internodes above ground is, the shorter the culm length becomes, because of the reduction in bending moment value. This line also increases lodging tolerance.

4-2-13. Harvesting and Threshing

Under the high temperature conditions of the tropics, rice plants mature earlier than under the comparatively low temperature condition of the temperate zones and grains are completely ripe approximately 30-35 days after heading. In local varieties, a great part of field plants are lodging at maturity. However, since the majority of *indica* rice varieties have dormancy of grains, the panicles get almost no viviparity damage even if they get wet.

On the other hand, tropical rice, in most cases, matures in the dry season. So the grains are liable to be overmature due to high temperature and dryness. The over maturing results in checked grains and deterioration of grains; therefore, it is better to reap earlier.

Reaping is performed by hand with a sickle in most countries. Generally, reaping involves high cutting at about one-half of plant height in Thailand, Malaysia, the Philippines and other places. In Indonesia and part of Malaysia, there is a method of picking ears only. The plant stumps are left for buffalo feed, but sometimes they are burnt to prepare for the next cropping. Burning effectively kills the insects in the stumps.

Harvested rice stems are dried for a few days in the field without bundling. There are two ways of threshing. In the one, stems are held in the hand and the ears are beaten against the ground or the inside of a pail; in the other, in India and Pakistan, piled stems with their ears are trod out using cows or buffaloes. *Indica* rice can be easily threshed by the above methods because of its high shattering characteristic.

In this way, however, since all the work from reaping to threshing is done in the field, as in Malaysia, the loss of ripened grain is estimated by Sato (1961) to be 5%. As seen in Table 4-20, Horiuchi et al. (1971) showed that the rate of loss from reaping to threshing is 2-3%. This case also shows that the greater the over-maturity is, the greater the loss of ripened grain becomes. Therefore, reaping should not be delayed.

Table 4-20 Amount of grain loss and its percentage to the grain yield (Variety : Bahagia, Kedah, Malaysia)[1]

Season	Time of harvesting	Harvesting process: Cutting	Harvesting process: Gathering	Harvesting process: Threshing	Grains attached to the threshed stalks	Total grain loss	Total ripened grain yield
Main season 1969/70	27 days after heading	g/m² 1.32 (0.40%)	g/m² 0.72 (0.22%)	g/m² 2.33 (0.70%)	g/m² 0.83 (0.25%)	g/m² 5.25 (1.57%)	g/m² 331.1
	34 〃	2.23 (0.57)	1.12 (0.29)	6.72 (1.73)	0.76 (0.20)	10.83 (2.79)	388.4
	41 〃	2.97 (0.84)	1'93 (0.54)	5.33 (1.50)	0.91 (0.27)	11.14 (3.14)	354.5
Main season 1970/71	30 〃					6.40 (1.68)	382.2
	55 〃					5.10 (3.03)	167.2

High-yield varieties have short culms, half as long as local varieties, and most of them also have low shattering. Some farmers do not use these high-yield varieties because of the hard work involved in harvesting them, i.e., they have to reap with bent bodies at high atmospheric temperature, and threshing is a long, arduous task.

4-3. Literature Cited

CHAPTER FIVE
DISEASES OF THE RICE PLANT

Toshihiko Hino

Among the world's rice diseases, almost all those caused by viruses and mycoplasma-like microorganisms have limited geographical distribution; such diseases as rice tungro disease, rice orange leaf disease, and rice grassy stunt disease appear in South and Southeast Asia; rice yellow mottle disease in Africa; rice hoja blanca disease in North and South America. Also, virus diseases reported in Japan, such as rice dwarf disease, rice stripe disease, rice streaked dwarf disease, and rice necrosis mosaic disease, are distributed only in Japan or in regions near Japan. On the other hand, most fungus diseases, such as rice blast disease, rice brown spot disease, rice narrow brown spot disease, and rice bakanae disease, are widely distributed throughout temperate and tropical countries.

In the tropical zone, from the standpoint of temperature only rice can be cultivated throughout the year, and causal agents of disease also grow throughout the year. However, in some regions without irrigation fascilities, rice cannot be cultivated in a very dry season, and the causal agents have to survive until the next wet season by various types of overseasoning. In regions with irrigation facilities or in regions with enough rain throughout the year, rice is cultivated continuously and the causal agents are transmitted from crop to crop throughout the year.

In the tropical zone, as well as in the temperate zones, it is natural that the kinds and severity of rice diseases are different when rice plants are cultivated under different conditions, at high and low fertilizer levels, using new and native cultivation methods, with new and native varieties, etc.

As it is impossible to describe all the conditions of under which diseases occur in each area, only the kinds and diagnoses of rice diseases which occur in the tropical zone are described in this chapter. When details are necessary, references given at the end of this chapter should be consulted.

5-1. VIRUS DISEASES AND DISEASES CAUSED BY MYCOPLASMA-LIKE MICROORGANISMS

Some diseases hitherto suspected as virus diseases have recently been proved to be caused by mycoplasma-like microorganisms, such as rice yellow dwarf disease. Symptoms and methods of transmission of diseases cause by mycoplasma-like microorganisms are quite similar to those of virus diseases. As it is impossible to distinguish between these types of diseases without observation of causal agents by special equipment, they are described together in this chapter.

5-1-1. Rice Tungro Disease

Rice tungro disease was first reported in the Philippines in 1965. At present, similar diseases are widely distributed all over South and Southeast Asia, and are called by different names: Penyakit merah, Mentek, Yellow orange leaf, etc., as shown in Table 5-1. Among these, as Penyakit merah in Malaysia and Mentek in Indonesia have been known since the beginning of 20th century, these names were not used only for a disease but also for disease symptoms which include both virus disease and physiological disorders. For this reason, in Malaysia researchers are trying to use Penyakit merah only for the virus disease, and in Indonesia, Penyakit haban, a newly named virus disease, is being used as distinctive from Mentek. In India rice tungro disease is the commonly used name at present, though rice leaf yellowing disease was formerly used by some researchers.

Table 5-1. Virus diseases similar to rice tungro disease

Disease	Distribution
tungro disease	Philippines, India
Yellow orange leaf disease	Thailand
penyakit merah	Malaysia
mentek	Indonesia
penyakit haban	Indonesia
leaf yellowing disease	India

The tungro virus particle is spherical and 30-33 mμ in diameter. These particles were reported on rice tungro disease in the Philippines and on rice yellow orange leaf disease in Thailand.

The diseased plants are dwarfed, with yellow to yellowish orange leaves. The changes of color are more distinct on lower leaves than upper ones. These symptoms clearly appear when the plants are infected at a very early growing stage, e.g., the stage just after germination, or before and after transplanting. However, as these symptoms are similar to physiological disorders at the late stage of plant growth, it is very difficult to diagnose this disease as a virus disease only by observing the symptoms. Precise diagnosis required transmission tests or at least continuous observation from an early stage.

The disease is chiefly transmitted by green rice leafhopper, *Nephotettix virescens (=N.bipunctatus, N.impicticeps)*. The leafhopper, both numph and adult, transmits the virus just after it takes in juice from a diseased plant. The adults continue to transmit the virus generally for 2 days, with a maximum of 6 days. The numphs loose the virus after molting. Beside *N.virescens* mentioned above, *Nephotettix nigropictus (=N.apicalis)* and *Recilia dorsalis (= Inazuma dorsalis)* also transmit the disease, but these are not so important because transmission ability of these are not so important because transmission ability of these two is low and the population in the rice field is also low. Seasonal change of vector prevalence throughout the year is described in Chapter 6, Insects Injurious To Rice.

As to seasonal changes in disease prevalence, rice yellow orange leaf disease (= rice tungro disease) in Thailand, for example first appears at the beginning of the rainy season when the vectors migrate into rice fields. Fig. 5-1 shows the seasonal change in rice yellow orange leaf disease on rice fields where rice plants were transplanted on the 20th of every month. The vector migration into this field is shown in Fig. 6-9 in Chapter 6. In this field numbers of the vectors migrated at the end of June, and the disease was severe on plants transplanted on June 20. After this, both the amount of the vector migration and of the disease occurrence gradually decreased and fell to almost zero in the dry season. In general, rice yellow orange leaf disease is severe at the beginning of the rainy season and ceases in the dry season. When the rainy season begins late in the year, the disease occurs late.

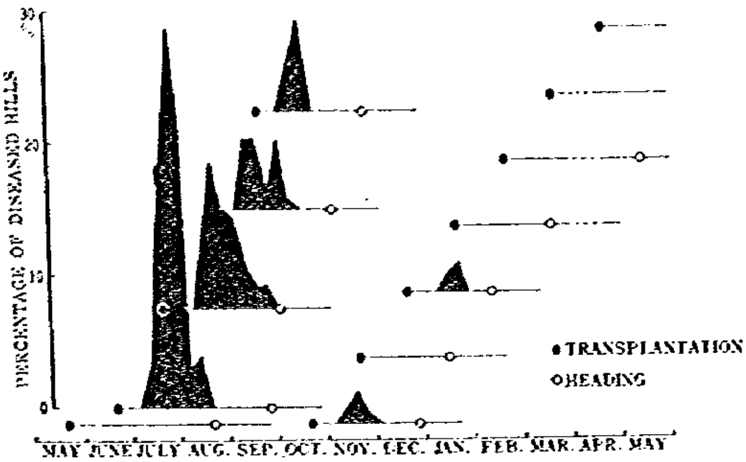

Figure 5-1. Seasonal change of Rice yellow orange leaf disease on rice variety RD-2 in Thailand (Hino, 1972).

The disease can be controlled by use of resistant varieties, though very little difference is seen among the diseases in different countries, the names of which are shown in Table 5-1. Tjiremas, Sigadis, etc., are resistant, and are also used for a source of resistance.

Effective insecticides are Sevin, Mipsin, etc. which can be used to control *Nephotettix* spp. However, rice tungro disease is more epidemic under field conditions when the vector population is very than in the case of rice virus diseases in Japan. Disease control by insecticide application is not considered to be effective unless insecticides with enough residual effect are applied over wide areas at the same time.

5-1-2. Rice Transitory Yellowing Disease

Rice transitory yellowing disease occurs only in Taiwan. The causal virus is bullet-shaped, 120-140 mμ in length and 96 mμ in diameter. Symptoms are almost the same as for rice tungro disease. The diseased plants are dwarfed, and leaves turn yellow from the lower to the upper ones. Formerly the disease was considered to be a physiological disorder and was included in suffocation disease. Later, when transmissiblity of the disease was proved, it was called rice transitory disease to separate it from physiological disorders.

Vectors are green rice leafhoppers, *Nephotettix nigropictus* and *N. cicticeps*. The vectors do not transmit the disease during the incubation period of 9-16 days, which is the period from acquisition of the virus from the diseased plants until becoming infectious. After the incubation period, the vectors transmit the disease continuously during their whole life. The rice varieties Wu-ku-chin-yu, Chun-lin-chung, Chutze, Hy-lu-tuen, etc., have been proved to be resistant.

5-1-3. Rice Orange Leaf Disease

Rice orange leaf disease is distributed in the Philippines, Thailand, Malaysia and Sri Lanka. The causal agent has not yet been identified. The disease is transmitted by the zigzag leafhopper, *Recilia dorsalis*. The transmission ability of the vector is not high, about 10%. The vector transmits the disease after an incubation period of 8-10 days. The symptom resembles that of the rice stem borer, *Chilo suppressalis*. Whole parts of the diseased plants turn orange-red and leaves roll toward the upper surface and become erect and straight as sticks. Most of the diseased palnts die. Resistant varieties have not been well investigated, but Peta was proved to be resistant in greenhouse tests. The above-mentioned rolling and erection of leaves are a conspicuous difference from rice tungro disease. Leaves of tungro-diseased plants do not become erect, but in most cases roll slightly toward thelower surface, and droop like those of healthy plants.

5-1-4. Rice Yellow Dwarf Disease

Rice yellow dwarf disease is widely distributed in both tropical and temperate zones. In Aisa, the disease has been reported in Japan, China, Taiwan, the Philippines, Thailand, Malaysia, Indonesia, India, and Sri Lanka. The causal agent is a mycoplasma-like microorganism and has been confirmed in Japan, Malaysia, the Philippines and Thailand.

The diseased plants turn bright yellow, dwarf and proliferate tillers. The period from infection to symptom appearance is very long, about one month even in young plants. In cases of infection at a late stage, symptoms are often lacking but appear on ratoons after harvest.

Vectors are green rice leafhoppers, *Nephotettix cincticeps, N. virescens,* and *N.nigropictus*. The vectors transmit the disease during their whole life after an incubation period of 30 days.

5-1-5. Rice Grassy Stunt Disease

Rice grassy stunt disease is distributed in the Philippines, Thailand, Indonesia, India and Sri Lanka. The diseased plants are dwarfed and proliferate tillers. Leaves turn dull yellow, short and narrow. Plants infected at an early stage produce no panicles. Symptoms resemble those of rice yellow dwarf disease. However, these two can be differentiated by the following symptoms; on yellowed leaves of grassy-stunt-diseased plants; on yellowed leaves of grassy-stunt-diseased plants, some green parts remain and brown dots often appear; on the contrary, on leaves of yellow-dwarf-diseased plants these symptoms do not appear.

Brown planthopper, *Nilaparvata lugens,* transmits the disease during its whole life after an incubation period of 10 days. The causal agent is considered to be mycoplasma-like microorganism, though this has not been proved yet.

5-1-6. Rice Hoja Blanca Disease

Rice hoja blanca disease is distributed in regions from northern South America to southern United States. The disease is caused by a virus. The diseased plants are dwarfed, and white stripes appear on the leaves, which finally turn wholly white. The diseased plants rarely produce panicles, and even if panicles emerge, the grians are mostly incomplete.

Vectors are *Sogatodes (Sogata) oryzicola* and *S.cubanus*. *S. oryzicola* transmits the disease mainly in rice fields, and transmits it from weed hosts to rice plants, or among the weed hosts, *Echinochloa colonum*, etc. The vectors transmit the disease during their whole life after an incubation period of 30 days. Furthermore, the virus is transmitted to the next generation of the vectors through eggs. Thus, the vectors which have become viruliferous by transoval transmission are considered to be the main population which spreads the disease in rice fields.

Resistant varieties are Gulfrose, Lacrose, Northrose, etc., bred in the United States, and also Peta, Bengawan, etc. of Asia origin.

5-1-7. Rice Yellow Mottle Disease

Rice yellow mottle disease is limited to the region near Lake Victoria, Kenya. The causal agent is a virus, which has different charactaristics from the viruses of other rice diseases mentioned above. The virus is transmissible mechanically and also by beetle vector, *Sesselia pussilla*. The virus is stable, keeps the infectivity in plant juice for 33 days at room temperature, loses it after heating at 80°C for 10 minutes, an is spherical in shape with a 32 mμ diameter.

The diseased plants are dwarfed and decrease tillers. Mottle with yellow stripes appears on leaves.

5-1-8. Remarks

Among the diseases caused by viruses and mycoplasma-like microorganisms in Japan, only rice yellow dwarf disease is also distributed in tropical and subtropical countries. The other diseases, rice dwarf disease, rice stripe disease, rice streaked dwarf disease and rice necrosis mosaic disease are distributed only in or near Japan, and are not distributed in tropical and subtropical countries.

5-2. BACTERIAL DISEASES

5-2-1. Rice Bacterial Leaf Blight Disease

Rice bacterial leaf blight disease is severe in many countries in Asia from Japan to India and Sri Lanka. The disease is restricted to Asia, and has not been reported in Africa, Europe, nor the Americas.

The disease shows two kinds of symptoms. One is the chronic symptom, which appears only on leaves and is commonly observed in both temperate and tropical zones. At first, leaf margins of the diseased plants turn yellow. Borders between yellowed and healthy parts show undulation. As the disease progresses, yellow parts turn whitish yellow to dull white. These symptoms resemble the natural death of leaves. On the diseased leaves, however, small bead-like bacterial masses ooze out from water pores at the leaf margins. Thus, by observing the bacterial oozes the diseased leaves can be distinguished from naturally dying leaves. Also, the disease can be disgnosed as follows: The end of the diseased leaf which shows clear symptoms is immersed in water as shown in Fig. 5-2. After a few minutes white streaming of bacterial ooze is observed to exude into the water from vascular bundles.

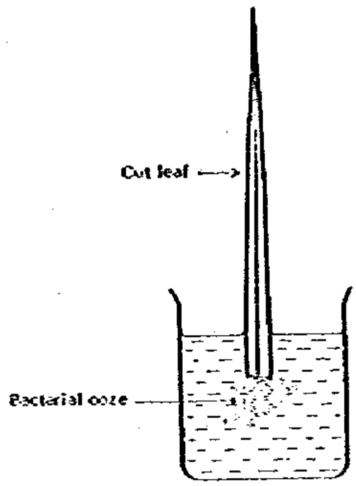

Fig. 5-2. Test for bacterial leaf blight. Cut end of infected leaf immersed in water showing streaming of bacterial ooze from vascular bundles (Pans Manual, 1970).

The other is Kresek, which is the acute symptom. Kresek occurs commonly in the tropics and rarely in a temperate zones. Usually about 20 days after transplanting, the diseased plants are dwarfed, wilted, and finally die. When the cut end of the basal part of the dead plant is pressed between the fingers, it exudes yellow sap, i.e., bacterial ooze. Or, when the cut end is placed in water, it exudes a white streaming of bacterial ooze, the same as the chronic symptom mentioned above. On leaf margins of the diseased plants small bead-like bacterial oozes can also be observed.

The disease is caused by *Xanthomonas oryzae*. The bacteria intrude into plant tissues through water pores at leaf margins or through wounds.

The bacteria winter on Gramineous weeds, *Leersia sayanuka*, etc., and are carried into paddy fields by irrigation water in Japan. In the tropical zone, the relationship between the bacteria and weed hosts, such as *Leersia* spp., has not been so well investigated that the ecological role of weed hosts is clear. However, from results obtained by bacteriophage analysis, the causal bacteria were proved to move into paddy fields in irrigation water. In the tropical zone, rice can be cultivated throughout the year, and it often grows from ratoons or dropped seeds even in the off-season. Wild rice sometimes grows near paddy fields. Under these conditions the causal bacteria seem to be able to develop their life cycle only on rice plants.

5-2-2. Rice Bacterial Leaf Streak Disease

Rice bacterial leaf streak disease is distributed in tropical Asia, e.g., southern mainland China, the Philippines, Thailand, Indonesia, Malaysia, India, etc. It has not occurred in Japan. Symptoms are: At first water-soaked type streaks several millimeters in length appear on leaf blades. Later, they elongate and turn brown. On brown-colored streaks a lot of yellow bead-like bacterial oozes are observed. In the case of the bacterial leaf blight disease mentioned in the previous section, yellow bacterial oozes appear chiefly at leaf margins. However, on bacterial-streak-diseased leaves, these oozes appear on the brown streaks on various parts of leaf blades.

The causal bacterium is *Xanthomonas translucens* f.sp. *oryzicola*. The bacteria are carried by wind and intrude through stomata. Also, they move in irrigation water, like the causal bacteria of leaf blight disease.

5-2-3. Rice Bacterial Grain Rot Disease

Rice bacterial grain rot disease has been reported only in the warm region of Japan. According to unpublished data of H.Tabei, the disease has also been found in Thailand and Sarawak. The causal bacterium is *Pseudomonas glumae*. The disease occurs only on grains, which turn partially or entirely greenish white to greyish brown. The diseased hulled rice grains are severely damaged and malformed. Even in case of severe infection, however, main and branch axes of panicles of the diseased plants remain green like those of healthy plants.

5-2-4. Other Bacterial Diseases

Beside the bacterial diseases mentioned above, rice bacterial stripe disease *(Pseudomonas alboprecipitans)* and some other diseases have been reported in the tropical zone. However, these are not important at present.

5-3. FUNGUS DISEASES

5-3-1. Rice Blast Disease

Rice blast disease is widely distributed all over rice cultivating areas in both the tropical and temperate zones. The disease occurs all through plant growth, from germination to ripening, and on all parts of rice plants, such as leavs, collars, nodes, panicle necks, grins, etc. Lesions are at first brown and elliptical, and sometimes coalesce into an irregular shape. Later, the center of the lesions turns dull grey. The diseased plants are stunted when the disease is severe. When more acute and severer, white lesions appear on young seedlings, usually in nursery beds and rarely in paddy fields. When nodes or panicle necks are attacked by the fungus, white panicles with dead grains are produced. The disease is apt to be severe when nitrogen fertilizers are applied abundantly or under humid conditions.

Rice blast disease is sometimes confused with the rice brown spot disease mentioned in the next section. However, lesions of the former are generally bigger than those of the latter. The most conspicuous difference is that at the margins of blast lesions necrosis progresses more in veins than in interveinal parts, as whoen in Fig. 5-3.

The disease is caused by *Pyricularia oryzae*. Conidiospores are pear-shape with two septa, colorless, 20-35 μ in length and 6-13 μ in width (Fig. 5-4). The fungus overseasons by mycelia or conidiospores on dried infected plant residues.

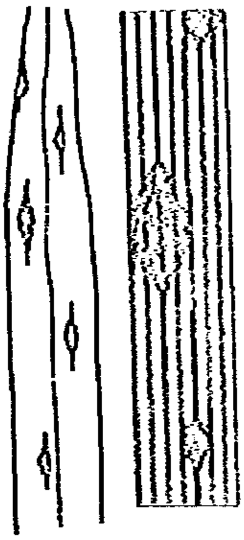

Fig. 5-3. Symtom of leaf-blast. The lesion appears along veins (Ono, 1947).

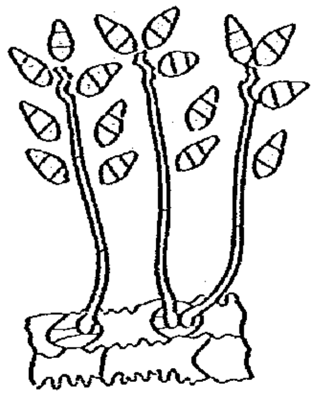

Fig. 5-4. *Pyricularia oryzae*, conidiospores and conidiophores (Ellis ; Ou, 1972).

Resistance of rice varieties to blast fungus can be clearly distinguished as of two types, true resistance and field resistance. The true resistance is racial resistance and means that a certain rice variety cannot be attacked by a certain strain of blast fungus. Field resistance is the degree of infection within a combination of suceptible varieties and compatible strains.

Resistance of rice varieties to blast disease often apparently fluctuate when it is tested in different localities, as shown in Table 5-2. Such different esults of resistance evaluation obtained in different localities is caused by different race communities existing in different localities. When a new rice variety is introduced, the race community easily changes to a new community which has strains more virulent to the new variety. Thus, when resistant varieties are introduced, it is necessary to evaluate resistance to blast, attaching more importance to field resistance, not to be confused with apparent resistance caused by a different strain community.

5-3-2. Rice Brown Spot Disease

Rice brown spot disease is distributed over all the rice cultivating areas of the world. The disease occurs over the whole growth span from germination to ripening, on all parts of plants, leaves, culms, panicles necks and axes, grains, etc. Lesions on leaves are circular to elliptic, brown with greyish brown centers, and generally smaller than those of blast disease. Lesions enlarge at first in interveinal parts (Fig. 5-5), contrary to those of blast disease (Fig. 5-3). The disease is prevalent on plants lacking nutrients, such as those grown in paddy fields with a low level of nitrogen fertilizer or in Akiochi fields, etc.

The causal fungus is *Cochliobolus miyabeanus*. The disease is also called Helminthosporium leaf spot, ecause the imperfect stage of the fungus is *Helminthosporium*. Conidiospores are brown with 6-11 septa, 80-140 μ in length and 14-22 μ in width. Conidiophores are also brown (Fig. 5-6).

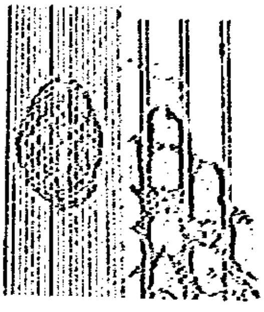

Fig. 5-5. Sympton of brown spot.
The lesion appears inter veins (Ono, 1953).

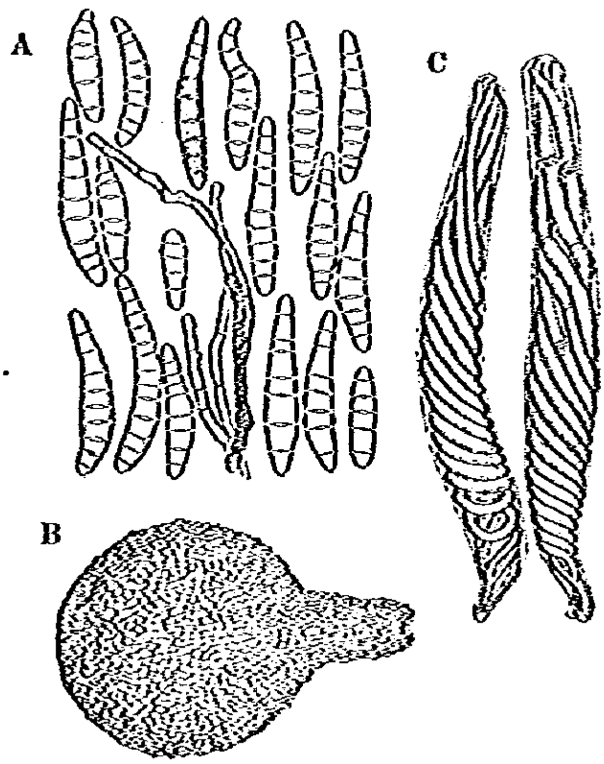

Fig. 5-6. *Cochliobolus miyabeanus.*
A, Conidiospores and comidiophores; B, perithecium; C, asci (Ito & Kuribayashi, 1927).

Table 5-2. General reaction to *P. oryzae* of selected varieties in various region indicating differences in physiologic race patterns (O=resistant, M=intermediate, X=susceptible.) (Ou, 1966)

Variety	General reaction in South asia	General reaction in Southeast Asia	General reaction in Temperate Asia
21 Aichi Asahi	O	X	X
111 Aimasari	O	X	X
113 Sasashigure	O	X	X
196 Taichung 170	O	XO	X
20 Norin 20	O	OMX	X
192 Chianan 2	O	OMX	X
193 Tainan 3	O	OMX	X
195 Kaohsiung 64	O	OMX	X
104 221/BCIV/1/45/3	O	XO	O
165 Peta	O	X	O
169 Raminad Str. 3	O	X	O
173 FB 86	O	XM	O
197 Taichung (Native) 1	O	X	O
56 59-334	XO	X	O
74 T 21	X	X	O
151 Patnai 23	XO	X	O
174 Tjere Mas	XO	X	O
175 C 22	X	X	O
11 Te-tep	OX	O	O
12 Tadukan	OX	O	OX
45 C 46-15	O	OM	O
59 Murungakayan 302	O	OX	O
218 Zenith	OX	OM	O
61 Fanny	X	X	X
62 Arlesienne	XO	X	X
83 T.K.M. 6	X	X	X

5-3-3. Rice Narrow Brown Leaf Spot Disease

Rice narrow brown spot disease is distributed all over the world except Europe. Lesions on the diseased leaves are brown, linear in shape, limited by veins, and usually narrower than one mm. Old lesions are greyish brown with brown margins (Fig. 5-7). The disease is apt to occur on plants lacking nutrients at low fertilizer level.

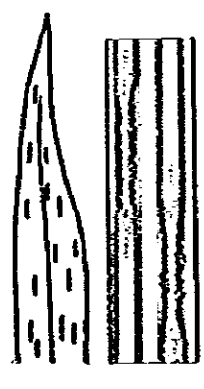

Fig. 5-7. Symtom of Cercospora leaf spot. The lesion is limitted inter veine(Ono, 1917).

The disease is caused by *Sphaerulina oryzina*. As imperfect stage of the fungus is *Cercospora*. the disease is also called Cercospora eaf spot. Conidiospores are colorless, 25.7-43.3 μ in length and 4.3-5.2 μ in width. Conidiophores are brown (Fig. 5-8).

Rice white leaf streak disease caused by *Ramularia oryzae*, resembles rice narrow brown leaf spot disease, and occurs only in Southeast Asia.

5-3-4. Rice Stem Rot Disease

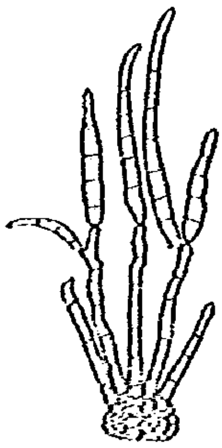

Fig. 5-8. *Sphaerulina oryzina*, conidiospores and conidiophores (Hata, 1918).

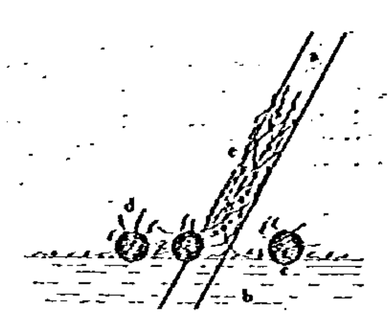

Fig. 5-9. Infection behavior of rice stem rot fungus. a, rice plant ; b, water ; c, sclerotia ; d, conidiospores ; e, appresoria (Ono & Suzuki, 1955).

Rice stem rot disease is caused by two kinds of fungi, *Leptosphaeria salivini* and *Helminthosporium sigmoideum* var. *irregulare*. An imperfect stage of the former is also *Helminthosporium sigmoideum*. Sclerotia of the former are black, spherical, and 0.2-0.3 mm in diameter, and those of the latter are black, irregular in shape, and 0.1-0.2 mm in diameter. Symptoms caused by both fungi are almost the same. At first, greyish green lesions appear on the leaf sheath at water level at a late stage of plant growth. Later, the fungi reach the culm, cause decay in sheath and culm, and form black sclerotia. Thus the diseased plants are apt to be easily lodged.

Sclerotia can survive for a long time even under conditions unsuitable to fungus growth. After the rice harvest, sclerotia formed at the basal parts of plants remain in the fields, where they survive until the next rice cultivating season. In irrigation water, they move to attach themselves to rice plants, and penetrate into tissues of the plants, as shown in Fig. 5-9.

5-3-5. Rice Sheath Blight

Rice sheath blight is distributed in Asia, from Japan to India and Sri Lanka, South America, and Madagascar. At first, greyish green lesions appear on the leaf sheath at water level. Later, the lesions enlarge and turn brown with grey centers. When rice plants grow densely and have poor ventilation, the disease progresses rapidly. Under these conditions mycelia stretch through air along the plant surface and soon reach the upper parts of plants. Then, most lower leaves die and acute grey lesions are formed on upper leaves.

The causal fungus is *Pellicularia sasakii* which is also called *Corticium sasakii* in some countries. The fungus forms white or brown sclerotia on the surface of the leaf sheath. The sclerotia are 1-3 mm in diameter. Life cycle and way of infection are almost the same as in the rice stem rot disease mentioned in the previous section. Sclerotia formed in the previous cultivation move to rice plants by irrigation water and cause primary infection of the plants.

5-3-6. Rice Bakanae Disease

Rice bakanae disease is widely distributed all over the world. The disease can be observed during the whole growing period of rice, from germination to ripening. The most conspicuous symptom is plant elongation. However, when the disease is severe in nursery beds, the diseased plants show various symptoms, elongation, stunting, or death of plants. The diseased plants, both elogated and stunted, show wider leaf angles from the vertical and more yellow than healthy plants.

The causal fungus is *Givverella fujikuroi* and its imperfect stage is *Fusarium*. Microcodiospores are colorless, long and elliptical without septa, 6-15 μ in length and 3-5 μ in width. Macroconidiospores are colorless, crescent-moon-shaped with 1-5 septa, 20-50 μ in length and 2-5 μ in width (Fig. 5-10). The fungus forms a pinkish white mass of mold on the basal parts of the diseased plants in rice fields to produce conidiospores. Dispersed spores intrude flowers or grains to cause infection, and then latent mycelia in the grains overseason. Thus, the disease is transmitted through seeds to the next rice cultivating season. The fungus can survive in soil only for short time, and not until the next cultivating season, either in temperate or tropical zones. Consequently, the primary source of infection of the disease is seed transmission and this can be controlled by seed disinfection or by using healthy seeds.

5-3-7. Rice Stackburn Disease

Rice stackburn disease was once limited to the southern part of the United States. However, at present the disease is widely distributed

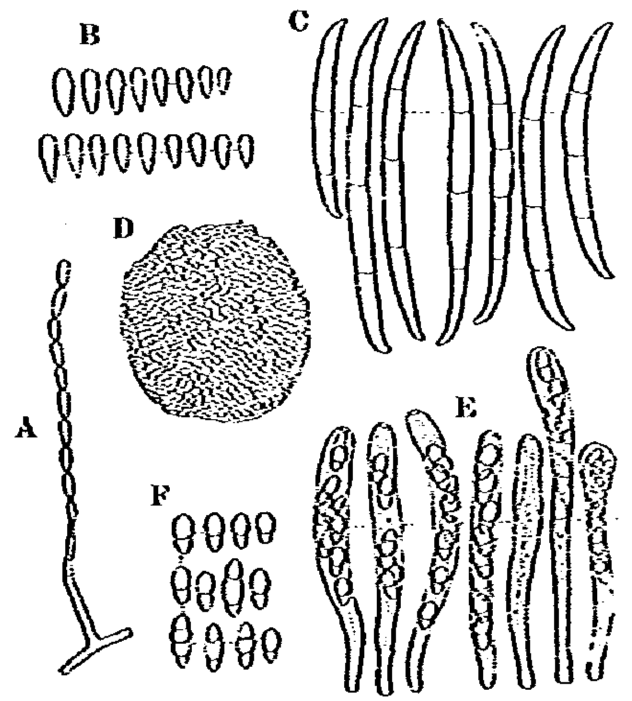

Fig. 5-10. *Gibberella fujikuroi*.

A, microconidiospores and conidiophore ; B, microcodiosphores , C, macroconidiospores ; D, perithecium ; F, asci ; F, ascospores (Ito & Kimura, 1931).

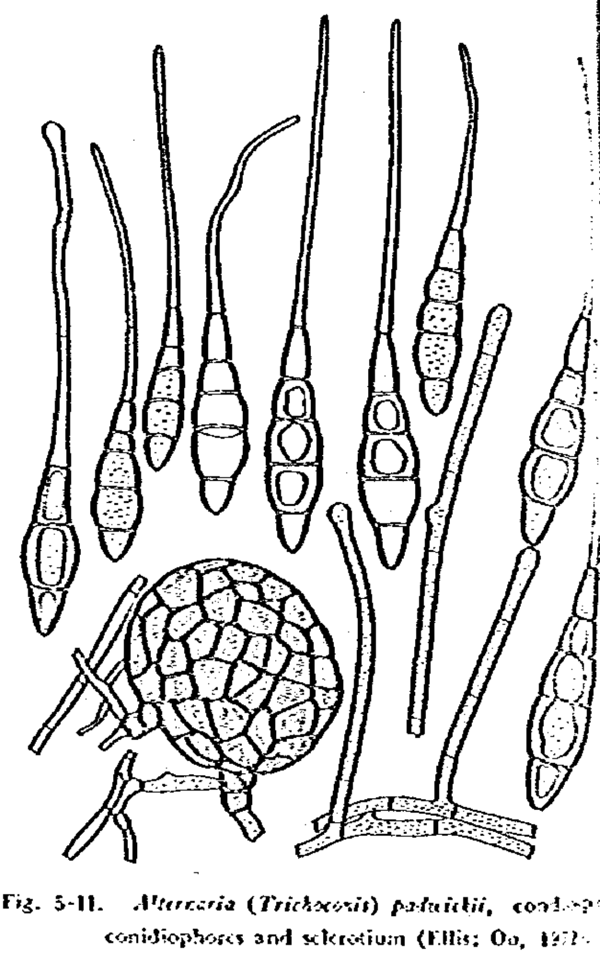

Fig. 5-11. *Alternaria (Trichoconis) padwickii*, conid... conidiophores and sclerotium (Ellis; Ou, 197...

through Southeast Asia, India, Africa, and South America. It has not bee found in Japan.

Lesions on the diseased leaves are brown and oval in shape. Later, the center of the lesions turns dull white, and small black sclerotia are formed there. Usually the lesions on leaves are not so many that they cause damage. Lesions are also formed on grains and cause some damage. When the diseased grains are used for seeds, seedlings die.

The causal fungus is *Alternaria padwickii*, also called *Trichoconis padwickii* Conidiospores are elongately fusoid with 3-5 septa, creamy yellow, 103.2-172.7 μ in length and 8.5-19.2 μ in width. Sclerotia are black, spherical and 52-195 μ in diamter (Fig. 5-11).

5-3-8. Rice Collar Rot Disease

Rice collar rot disease is distributed only in the central plain of Thailand. At first, brown lesions are formed at collar parts, i.e., the joint part of leaf blade and sheath. Later, the lesions enlarge to all the collar part and consequently the leaf blade falls down and dies. On the lesions small black dots, pycnidia, are formed.

The disease is caused by *Ascochyta oryzae*. In Japan the fungus can be observed on rice straws and is not hazardous to rice plants. Spores are linear-oblong with an indistinct septum, 15 μ in length and 4 μ in width.

5-3-9. Rice Sheath Blotch Disease

Rice sheath blotch disease was first reported in Japan, where at present it causes almost no damage. The disease is distributed in many countries in Asia, from Japan to India. Lesions are formed chiefly on the leaf sheath and are brown with a greyish brown center, where black small dots, pycnidia, are observed.

The causal fungus is *Pyrenochaeta oryzae*. Pycnidia are black and 0.2 mm in diameter. Spores are fusoid,

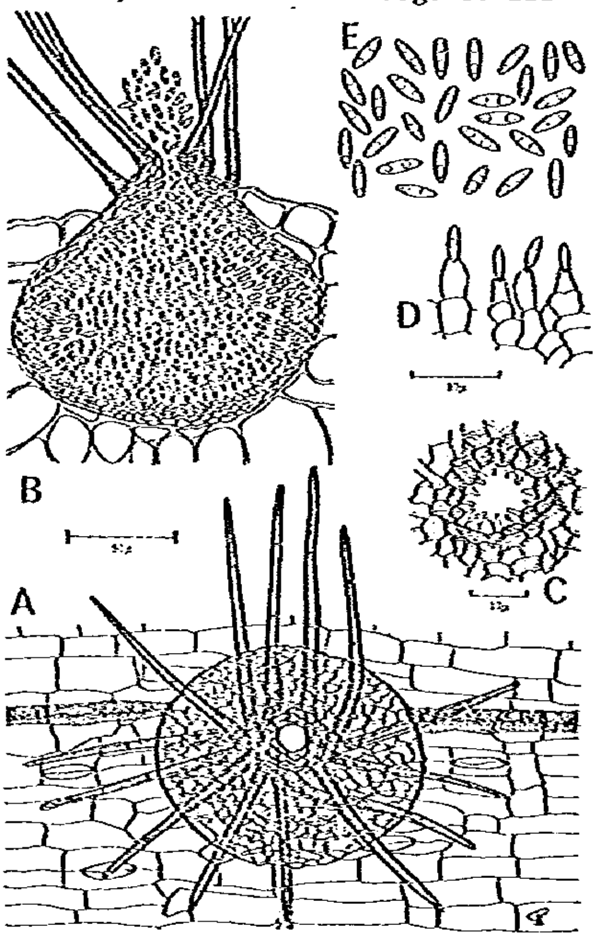

Fig. 5-12. *Pyrenochaeta oryzae*.

A, Pycnidium ; B, vertical section of pycnidium ; C, surface view of ostiole ; D, conidiophores ; E, conidia (Punithalingam ; Oe, 1972).

4-6 μ in length and 1.5-2 μ in width (Fig. 5-12). Beside the fungus mentioned above, *P. nipponica* is considered to take part in the disease. Pycnidia and spores of *P. nipponica* are smaller than *P. oryzae*.

5-3-10. Rice Udbatta Disease

Rice udbatta disease is distributed through India and the southearn part of mainland China. Panicles of the diseased plants are covered by mycelia in the leaf sheath at the booting stage, and then white stick-like panicles emerge. Later, white mycelia become hard to form sclerotium-like bodies, on which a lot of small black dots are formed. Symptoms rarely appears on flag leaf. The diseased plants are a little dwarfed.

The causal fungus is *Ephelis oryzae*, also called *Balansia oryzae*.

5-3-11. Other Fungus Diseases

Other fungus diseases distributed in the tropical zone are as follows. These diseases are also distributed in Japan.

Rice leaf smut, *Entyloma oryzae*
Rice leaf scald, *Fusarium nivale* and *Rhynchosporium oryzae*
Rice seeding blight, *Corticium rolfsii*
Rice false smut, *Ustilaqinoidea verens*
Rice kernel smut, *Tilletia horrida*
Rice scab, *Gibberella zeae*
Rice brown sclerotial disease, *Sclerotium oryzae-sativae*
Rice sclerotial disease, *S.hydrophilum* and *S.fumigatum*
Rice bordered sheath spot, *Rhizoctonia oryzae*
Rice reddish-brown sheath rot, *Helicoceras oryzae*
Rice net-blotch,*Cylindrocladium scoparium*

5-4. METHODS OF DISEASE CONTROL

(1) Diagnosis

In disease control, the kind of disease and the causal agent should first be clearly diagnosed. Diagnosis by symptoms observed in the rice field needs training and experience. In order to diagnose fungus diseases with certainty, microscopic observation of the causal agent is recommended.

(2) Elimination of Primary Infection Source

Considering the life cycle of the causal agent of the disease, the primary infection source should be eliminated.

In almost all diseases except those caused by viruses and mycoplasma-like microorganisms, the primary infection source is dried infected plant residue left from the previous cultivating season in or near rice fields. In the case of rice blast, brown spot, narrow brown spot disease, etc., spores formed on the infected plant residues of the previous cultivating season are carried into rice fields by wind, etc., and cause primary infection in a new cultivating season. Thus, infected plant residues should be removed from fields or surrounding areas as completely as possible.

In some diseases such as rice bakanae disease, primary infection is caused by seed transmission. Rice blast, brown spot, stackburn disease, etc. are transmitted both through seeds and by the wind from infected plant residues as mentioned above, and thus seedlings often die. In order to control seed-borne diseases, it is necessary to use healthy seeds collected in healthy fields or to treat seeds with fungicides.

Irrigation water carries causal agents of some diseases, such as bacteria of leaf blight and sclerotia of stem rot. It is necessary to clear fields in the area of upper streams of irrigation canals, eliminating the plant residues, ratoons, etc. infected in the previous cultivating season.

(3) Use of Resistant Varieties

Viral diseases, such as rice tungro, transitory yellowing, and hoja blanca disease, can be controlled by using resistant varieties. As to rice blast and bacterial leaf blight disease, use of field resistant varieties avoids severe damage, showing stable tolerance to all strains. In some diseases, such as bakanae, sheath blight disease etc., resistant varieties are difficult to obtain at present.

(4) Cultivating Methods

Rice blast disease is severe at high fertilizer leve, and brown spot disease at low level. Sheath blight scarcely ever occurs under well ventilated conditions. But, under densely painted and poorly ventilated conditions, it is severe and even flag leaves are finally damaged. As to virus diseases, damage is severe when plants are infected at an early stage and very slight when infected at a late stage. Thus, by means of combination with resistant varieties and cultivating methods, such as plant density, fertilizer level, cultivating timing, etc., many kinds of diseases can be avoided.

(5) Chemical Control

Many agricultural chemicals have been developed to control diseases effectively, Kasugamycin for rice blast, organic arsenate for sheath blight, carbamate for virus vectors, etc. Though organic mercury was once used to control blast and stem rot, it is not used at present because of its danger to human health. As to agricultural chemicals to control particular diseases, it is best to read the current literature on the subject, for agricultural chemicals are being developed constantly and rapidly.

However, the use of agricultural chemicals is a last resort. Considering the ecology of causal agents, disease should be controlled by combining various methods of ecological control mentioned in this chapter, so far as possible. After trials of these methods, agricultural chemicals should be applied as little as possible, aming at the period when the causal agent has the lowest population. Unless ecological control is considered, the controlling effect of agricultural chemicals over a long term cannot be expected to be economical, though an effect can be seen a short time after application.

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CHAPTER' SIX
INSECT INJURIOUS TO RICE

Terunobu Hidaka

The number of species and genus of insect pests which attack rice in tropical regions is not known. In Japan, more than 135 have been recorded. Although there have been some reports of studies undertaken in tropical countries on important pests, we have only fragmentary information on the bionomics of these pests. Thus we have gradually added to our information on the species, identification, distribution, life history (at least in part), occurrence, characteristics of damage, and natural enemies of these pests, but still know relatively little. Particularly concerning the conditions of occurrence of insect pests, we may note with considerable interest that surveys are being conducted every 10 days during the June-to-December monsoon season in the northeast rice-growing region of India. These efforts have been extremely valuable in predicting outbreaks of major insect pests, enabling preventive measures to be taken. To prevent the occurrence of pests, or kill them, insecticides may be used, resistant varieties may be cultivated, cultural practices may be modified, and natural enemies may be used, among other methods, but what is desired is to establish a system of integrated pest control based on an understanding of the bio-ecosystem of both the pests and their natural enemies. It is undoubtedly desirable to devise and adopt methods which reduce insect-caused damage to the extent that it is economically negligible, since it is impossible to exterminate all pests or all pests of a specific genus. It is particularly important to make progress in research which will enable us to make maximum use of natural enemies.

This chapter uses the latest information available to survey the species, distribution, life history, characteristics of damage, occurrence and other matters related to major insect pests which attack rice in tropical regions, and as a matter of convenience these pests have been classified here according to their feeding habits.

6-1. CLASSIFICATION OF MAJOR INSECT PESTS ACCORDING TO FEEDING HABITS

Because the larval and adult forms of insect pests impart damage to different parts of the rice plant, the following classification is used.

Group A. Larva which attack the leaf blade or sheath
Lepidoptera: stem borers; Diptera; gall midge, Leaf miner.

Group B. Larva and adults which suck sap from leaf blades or sheaths
Homopta: plant hoppers, leaf hoppers, leaf aphids,

leaf scale; Heteroptera: stink bugs, rice bugs; Thysanoptera: rice thrips.

Group C. Larva which eat leaf blades
Lepidoptera: army worms, leaf rollers, Styrid butterflies; Coloptera: leaf beetles; Orthoptera: grasshoppers.

Group D. Pests which eat roots
Coleoptera: plant weevils, root worms; Diptera: crane flies, mole cricket.

6-2. CLASSIFICATION AND BIONOMICS OF MAJOR INSECT PESTS

6-2-1. Group A

(1) Stem borers (Photo 6-1)

There are five principal species of stem borers which are pests: *Chio suppressalis* Walker (the rice stem borer;Photos 6-6 to 6-8); *Tryporyza incertulas* Walker (the yellow stem borer, Photos 6-2 to 6-5), *Chilo polychrysus* Meyrick (the paddy borer), *Tryporyza innotata* Walker (the white rice borer), and *Sesamia inferens* Walker (the pink rice borer). The host plants and distribution of these pests are as shown in Table 6-1. The yellow stem borer and white rice borer, in addition to being parasites on rice, also attack sugar cane, corn and other crops. All of these stem borers are widely distributed throughout tropical South-east Asia.

Table 6-1 Host plants and distribution of major stem borers (Hattori 1972)

Species	Host plant					Distribution												
	rice	sugarcane	maize	wheat	others	CHINA	JAPAN	FORMOSA	PHILIPPINES	INDONESIA	MALAYSIA	VIETNAM	THAILAND	BURMA	PAKISTAN	INDIA	CEYLON	Others
Chilo suppresslis	•					•	•	•	•	•	•	•	•		•	•	•	Ussuri, Korea, Hawaii, Spain
Chilo tumidicostalis		•														•		Nepal
Chilo partellus	•	•	•		•										•	•	•	Africa, Afganistan, Comores
Chilo auricilius	•	•	•		•			•	•	•			•	•		•	•	Nepal, Sikkim, Buthan, Sangir, Molucca
Chilo polychrysus	•		•			•			•	•	•		•			•		(Assam)
Chilo infuscatellus		•	•		•			•	•	•				•		•	•	Central Asia, Afganistan, Timor, Vulkan
Chilo sacchariphagus		•			•				•	•	•							Mauritius, Reunion, Madagascar
C. s. indicus	•	•			•											•		
C. s. straminellus		•			•	•	•	•										
Acigona steniells		•										•				•		
Tryporyza incertulas	•					•	•	•	•	•	•		•	•	•	•	•	
Tryporyza innotata	•								•	•								N. Australia
Tryporyza nivella		•				•	•	•	•		•			•		•	•	New Zealand, Africa
T. n. intacta		•			•					•								
Ostrinia furnacalis			•	•	•	•	•	•	•	•	•		•	•	•	•	•	Manchuria, USSR Korea, Australia, Micronesia, Solomon, Sikkim, New Guinea
Sesamia inferens	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	Korea

<u>Characteristics of damage cause by stem borers:</u> The larva eats soft tissues while burrowing through

the leaf sheath. This causes the leaf sheath of young rice plants to become yellowish brown, a condition known as discoloration of the sheath. If damage is extensive enough, the entire leaf withers; this condition is known as dead heart. Eventually the stem begins to form a hole where the larva made its entrance or exit from the sheath becomes visible. When the stem has been damaged before the milky stage of flowering the damage is assessed as being white head (Photo 6-9). Because all grains of white head rice are empty, there is no harvest. The foregoing is a common characteristic of damage caused by stem borers.

Occurrence of stem borers: The occurrence of stem borers varies greatly according to variety, location and year. Occurrence will also vary from month to month during the same year. As shown in Fig. 6-1, in Malaysia, the population density of both yellow stem borer and paddy borer are high in December. However, in Indonesia, there is no month during which it may be said that there is a peak in occurrence (Fig. 6-2).

Further, in Thailand, the stem borer which occurs most frequently is the yellow stem borer, followed by paddy borer, pink rice borer and rice stem borer, in that order (Table 6-2).

Life history: As shown in Table 6-3, there is little difference between the egg, larva, pupa and adult stages among five common rice borer species. Although the length of a single generation was found to be about 50 days for all five species, considerable variation in the length of a generation is to be expected, due to differences in the environmental conditions of the population. Seven or eight life cycles may be expected in the course of one year.

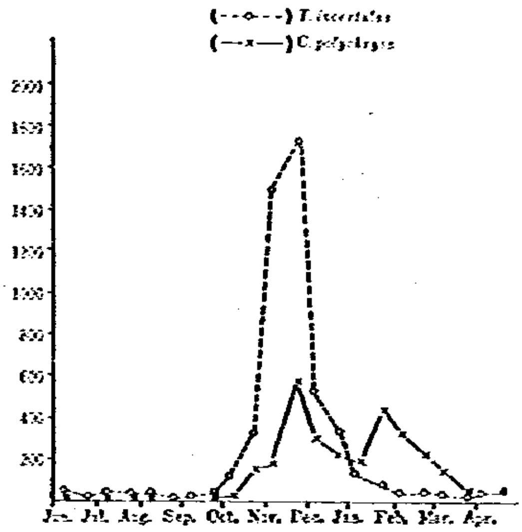


Fig. 6-1 Moth catches of *T. incertulas* and *C. polychrysus* at Sinpang Tiga Padi Test Station, Krian, (Singh 1972)

With the exception of the pink rice borer, all stem borers deposit egg masses on the upper surfaces of leaves and leaf sheaths. The pink rice borer deposits eggs between the leaf sheaths; the eggs thus are not visible. It is characteristic of the yellow stem borer that the eggs are covered by body hairs of the adult. Hatched larvae penetrate into the rice plant by making a hole, and feed primarily

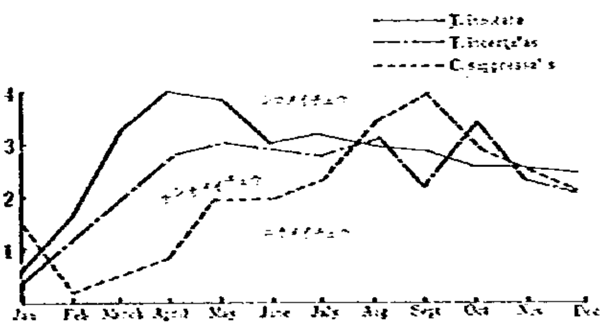


Fig. 6-2 Number of moths caught per month in kerosene light trap. (Cria Experimental Garden "Pusakanegara" Indonesia, 1970) (Soehardjan 1972)

Table 6-2 The percentage of various species of stem borers captured in light traps from 16 stations during 1965 in Thailand (Nishida 1972)

Localities	Total number of month	*T. incertulas*		*C. suppressalis*		*C. polychrysus*		*S. inferens*	
		Total	Percent	Total	Percent	Total	Percent	Total	Percent
1. Chumpae	133	49	36.8	4	3.0	80	60.1	0	0.0
2. Huntra	1,286	1,014	78.3	0	0.0	233	18.1	39	3.0
3. Khonkaen	4,134	3,403	82.3	42	1.0	413	10.0	280	6.5
4. Klongluang	7,474	6,822	91.3	11	0.1	459	6.1	183	2.4
5. Koksamrong	428	247	57.7	2	0.5	120	28.0	59	13.8
6. Kuangut	244	171	70.1	0	0.0	73	29.9	0	0.0
7. Nakompatom	211	183	86.7	0	0.0	15	7.1	13	6.2
8. Nakornsrithamraj	1,144	1,076	94.1	2	0.2	66	5.8	0	0.0
9. Pan	1,192	1,064	89.3	0	0.0	122	10.2	6	0.5
10. Pimai	328	328	100.0	0	0.0	0	0.0	0	0.0
11. Pitsanuloke	2,359	2,002	84.1	0	0.0	303	12.7	57	3.1
12. Rajburi	1,860	1,102	58.6	0	0.0	745	40.1	24	[illegible]
13. Rangsit	452	285	63.0	0	0.0	149	33.0	18	[illegible]
14. Sakolnakorn	6,602	3,735	56.6	0	0.0	2,852	49.9	31	[illegible]
15. Sanpatong	613	447	72.9	7	1.1	144	23.5	15	[illegible]
16. Surin	5,303	3,932	73.3	78	1.5	1,188	22.4	159	[illegible]
Total	33,818	25,826	—	146	—	6,942	—	896	—
Mean/Locality	2,113.6	1,614.1	74.7	9.1	0.5	433.9	22.3	56.0	[illegible]

Table 6-3 Comparison of the life cycles of the five common rice stem borers (Figures in brackets show the rang, units in days) (PANS Manual No. 3, 1970)

Species	Eggs	Larva	Pupa	Adult	Life cycle duration
Chilo polychrysus	4–7	30 (16–43)	6 (4–8)	2–5	26–61
Chilo suppressalis	5–6	33 (29–48)	6 (5–9)	3–5	41–70
Sesamia inferens	7 (6–10)	36 (28–56)	10 (8–11)	4–6	45–83
Tryporyza incertulas	8 (7–10)	49 (35–46)	8 (6–10)	4–5	52–71
Tryporyza innotata	4–9	19–31	7–11	4–5	30–51

within the leaf sheath. After five or six instars the larvae become pupae. Pupation takes place within the leaf sheath. The adult is nocturnal.

Insect natural enemies of stem borers: Many insect natural enemies of the stem borers are known to exist in the tropics. The relations between egg parasite and stem borers are shown in Fig. 6-3. About 20 species and varieties of egg parasite are known and many which have not been taxonomically classified are now being studied.

Fig. 6-4 and 6-5 show braconid parasite of stem borers in the Philippines and Thailand respectively. From both countries, more than six Braconidae parasitic on larvae have been recorded. There are, in addition, Ichneumonidae parasites (Fig. 6-6).

Because the above-mentioned insect natural enemies are highly effective, measures to ptoect them are necessary. In addition, stem borers can be eliminated by the use of resistant varieties and pest control employing insecticeds but such methods have not yet been established in the tropics.

(2) Rice gall midges, *Orseolia oryzae* (Wood-Mason)

This is an important species of pest which is distributed widely throughout southern Asia. It can be found in Thailand, India, Sri Lanka, Indonesia, Laos, Burma, Bangladesh, Cambodia, Nepal, Vietnam, the southern part of mainland China and in Africa, Cameroun.

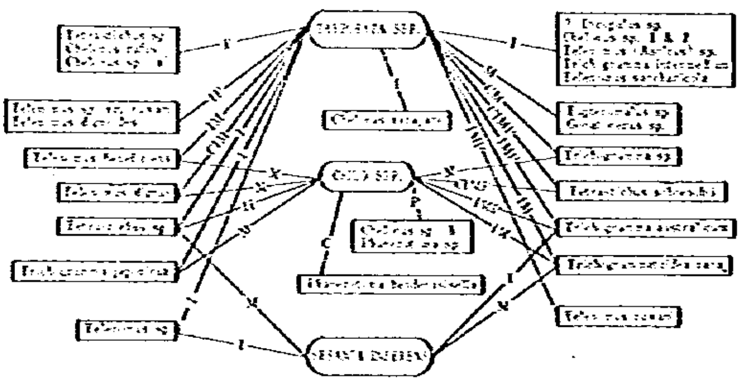


Fig. 6-3 Egg parasites of rice stem borers. (V.P.Rao, 1971)
I: India, C: Ceylon, M: Malaysia, P: Pakistan.
*The identity of these species from *Tryporyza* should be confirmed.

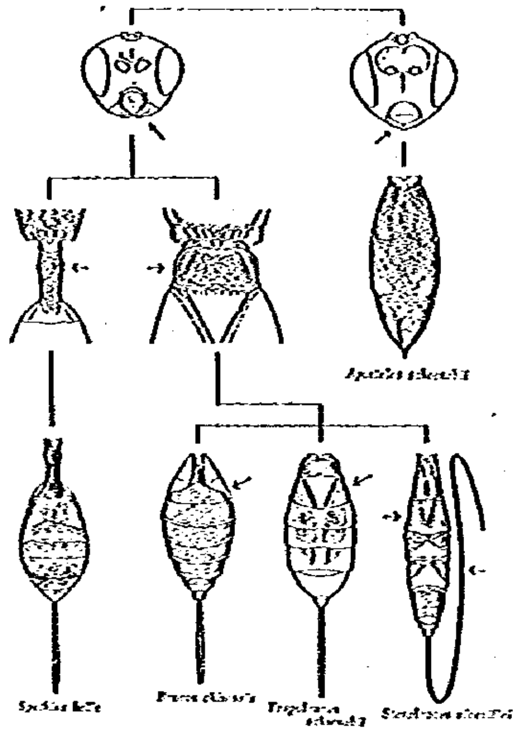


Fig. 6-4 Illustrated key to the braconid parasites of rice stem-borers in the Philippines (Chihisa Watanabe 1973)

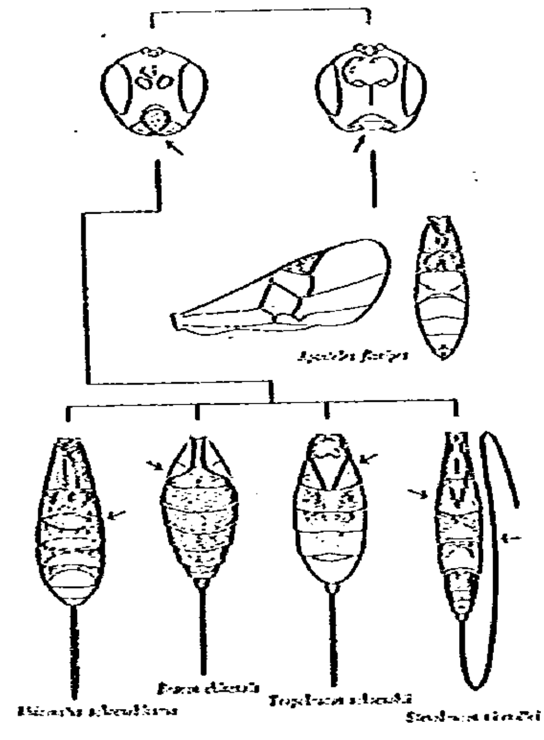


Fig. 6-5 Illustrated key to the braconid parasites of rice stem-borers in Thailand (Chihisa Watanabe 1973)

Ecology and life history: Adult rice gall midges (Photo 10) are nocturnal. The adults live for two or three days and one female lays 230 eggs on the leaf blade and sheath. The eggs have an incubation period of 3.5 days and the hatched larvae utilize the morning dew and move from the sheath gap to the plant stalk to feed. This feeding continues until they reach the growing point. The larva stage lasts about 14 days. Then, the larvae change to prepupa and the pupa (Photo 11) inside the base of the plant stalk. The pupa climbs up into the gall (Photo 12) for wing formation. From the vicinity of the spongy part of the gall, one half of the pupa emerges. It remains there in a fixed position while the wings form. The pre-pupa stage lasts for about 5.5 days and the pupa stage about 6.5 days. One generation requires approximately 30 days and there are 10 to 12 generations per year. During the dry season, rice gall midges occur in five species of host plants other than rice, i.e. wild rice, *Ischaenum aristatum, Paspalum distichum, Leersia hexandra* and *Echinochlora colonum* (photo 13).

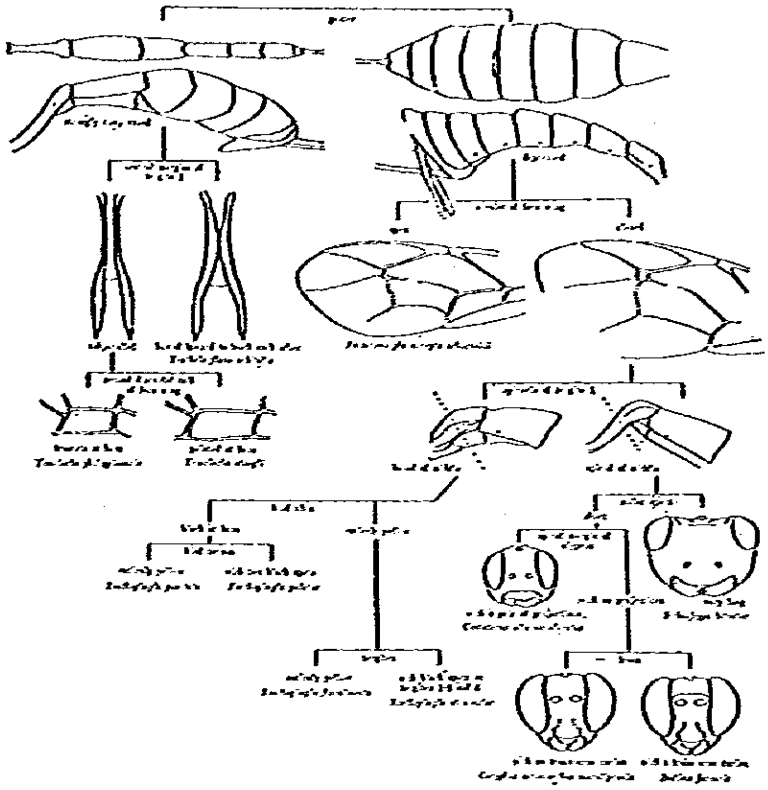
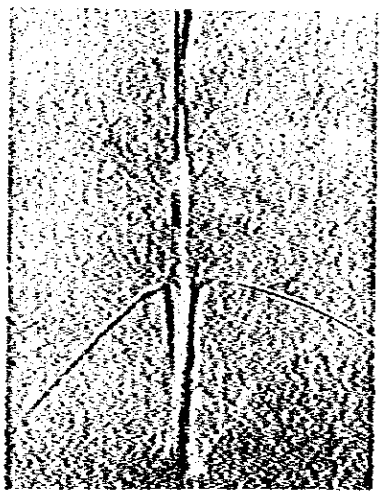


Fig. 6-6 Illustrated key to the ichneumonid parasites of rice stem-borers in southeast Asia. (Setsuya Momoi, 1973)



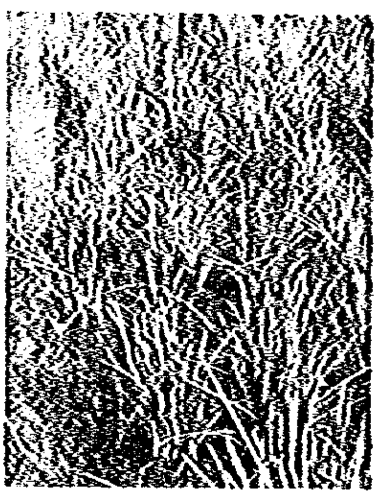


Photo 6-1 (Left): Gall developed in rice in Thailand directly after transplanting (Hidaka, 1972)

Photo 6-2 (Right): Rice damaged by rice gall midges in Thailand (Hidaka, 1972)

Occurrence of rice gall midges: This is shown in Fig. 6-7. The rice gall midges start to appear in northern Thailand from April and May and the population density reaches its peak in the last part of September. They die out in the middle part of November. The number of rice gall midges increases in the tillering stage and decreases remarkably from the primordium formation. The rainy season in August affects the increase of the midges. Rice gall midges also occur in the second crop of rice and in wild rice supplied with water throughout the year.

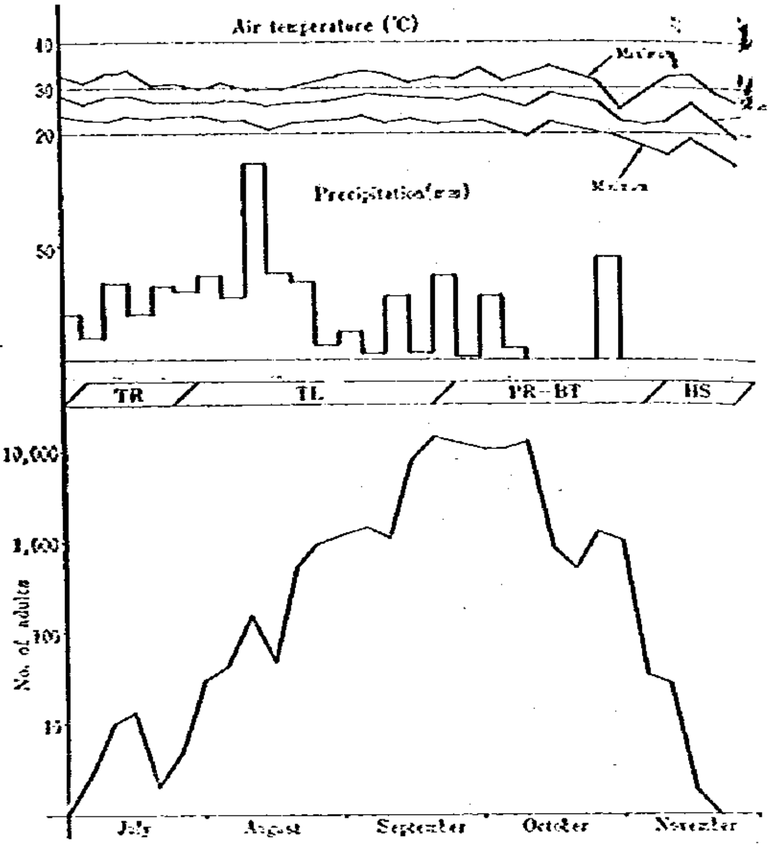


Fig. 6-7 Number of adults collected by the light trap at Pan, Thailand 1969 (Hidaka 1972) TR : Transplanting stage, PR : Primordium, BT : Booting, HS : Heading stage.

Characteristics of damage caused by rice gall midges: The larva of the rice gall midge feeds on the rice up to the growing point and the larval chamber is formed within one or two days. The gall caused by the feeding damage of the larva extends for less than 4 cm during the larva stage and cannot be seen from the exterior. In the pupa stage, however, the gall rapidly grows until it reaches about 30 cm in length. The gall, also known as an onion tube, is hollow and has a diameter of 3 - 4 mm. About four-fifths of the gall is in the leaf sheath and the remaining one-fifth in the leaf blade. Between the leaf sheath and blade, there is the spongy part of the gall. The damaged tillers (Photo 15) are split abnormally. The plants remain short, change to yellowish-brown and die. No ears are formed.

Control of rice gall midges: Control methods include the cultivation of resistant varieties, application of insecticides and utilization of early and late transplanting. In the northern and northeastern parts of Thailand, the RD_4 glutinous variety has appeared recently as a resistant variety. Among the insecticides, Diazinon granules are the most promising and it is sufficient to apply 2 kg of the active ingredients per hectare twice on the 14th and 28th days after transplanting. It has also been found that rice gall midge damage is less in the case of late transplanting in the last part of August than in cases of early transplanting.

6-2-2. Group B

(1) Leaf hoppers

The most important rice leaf hoppers in the tropics are *Nephotettix virescenes* (Distant) (Photos 35, 36 and 37), *N. nigropictus* (Stal) and *Inazuma dorsalis* Motschulsky (Photos 40 and 41). The distribution, host plants and vector viral diseases of the leaf hoppers are shown in Table 6-4.

Nephotettix malayanus and *N. parvus* occur in grasses such as *Leersia hexandra* although they are not found in rice.

Table 6-4 Important leafhopper and planthopper pests of rice (PANS Manual No. 3)

Name	Common Names	Host	Distribution	Vector of
Delphacidae	Planthoppers			
Sogatella furcifera	white backd plathopper	rice, millets maize, and other grasses	Throught the tropics Caribbean Brazil, South & Southeast Asia, Japan, Korea	
Sogatodes orizicola	rice delphacid	rice	Southern USA, Caribbean Islands, Central America,	Hoja blanca
Sogatodes cubanus		Echinochloa and other grasses	Southern USA, Caribbean Islands, Central America	Hoja blanca
Nilaparvata lugens	Brown planthopper	rice, grasses, sugarcane	South & Southeast Asia, China, Japan, Korea, Micronesia	Grassy stunt
Cicadellidae	Leafhoppers			
Laodelphax striatella	small brown planthopper	rice, wheat, millets, barley, sugarcane and grasses	Japan, Taiwan, Palearctic regions	Rice stripe Black-streaked dwarf
Nephotettix cincticeps	rice green leafhopper	cereals and weeds	Japan, Taiwan, Korea, Manchurian China	Dwarf, Yellow dwarf
Nephotettix virescens	rice green leafhopper	rice, wheat, barley, citrus	Japan, Taiwan, Indian sub-cotinent, Malaysia, Philippines, Thailand	Yellow dwarf Tungro, Penyakit Merah, Yellow orange leaf
Nephotettix nigropictus	rice green leafhopper	rice	South & Southeast Asia, Japan	Dwarf, Yellow dwarf, Transitory yellowing
Inazuma dorsalis	zigzag leafhopper	rice	South & Southeast Asia, Japan, Taiwan	Rice dwarf, Orange leaf

<u>Ecology and life history of leaf hoppers:</u> The banana-shaped eggs are laid in a single row inside the leaf sheath. The eggs hatch after seven days and the larvae pierce the young parts of the leaf sheath and blade and suck the sap. The larva stage (Fig. 6-8) is about 16 days with five instar stages. The adults have a life span of about 15 days and one generation covers approximately 30 days. Leaf hoppers occur throughout the year in the tropics. In areas where there is no rice in the dry season, they shift to weeds where they continue to propagate. As is evident from Table 6-4, leaf hopeers are important vectors for viral diseases.

<u>Occurrence of leaf hoppers:</u> Of the leaf hoppers occurring in rice, *N. virescens* accounts for over 85%. *N. nigropticus* is found only in small numbers. As can be seen from Figs. 6-9 and 6-11, the numbers of leaf hoppers increase in the period from June to August and the rice plants are susceptible to viral diseases during this time. A positive correlation

can be seen between the numbers of leaf hoppers and the outbreak rate of viral diseases. It has been found that the numbers of *N. virescenes* decrease from September.

Damage caused by leaf hoppers: The rice plants are not harmed so much by the leaf hoppers themselves but by the viral diseases for which they serve as vectors. For the characteristics of such damage, refer to the chapter on viral diseases.

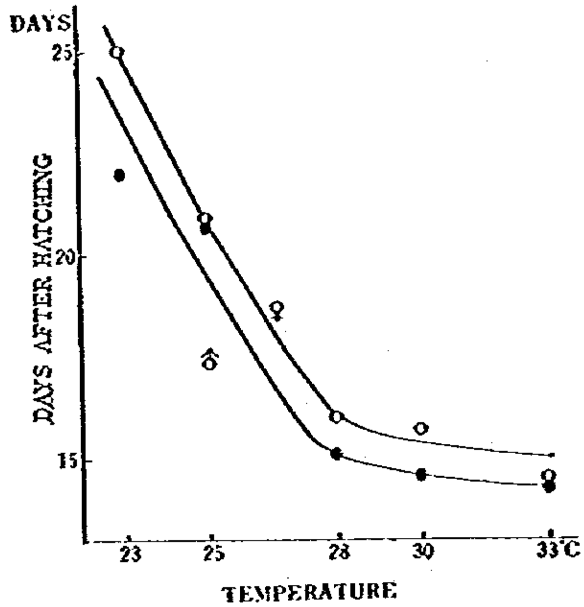


Fig. 6-8 Nymph period of *Nephotettix virescens* at different temperatures. (Hino, 1972)

(2) Plant hoppers

There are two species of plant hoppers which cause important damage in rice: the brown plant hopper, *Nilaparvata lugens* (Photos 42 and 43) and the white-backed plant hopper, *Sogatella furcifera* (Photos 38 and 39). Table 6-4 shows their distribution, host plants and vector viral diseases. The white-backed plant hopper is not a vector for viral diseases but the brown plant hopper serves as a vector for the grassy stunt viral disease.

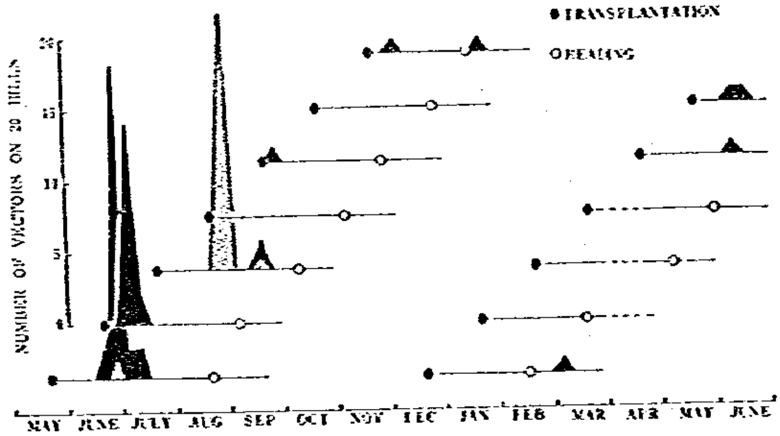


Fig. 6-9 Seasonal change of *Nephotettix* population in paddy field in Thailand (Hino, 1972)

Ecology and life history of the plant hoppers: The plant hoppers lay their eggs in a single row inside the leaf sheath. The eggs hatch after five to six days and the larvae feed mainly on the leaf sheath. The larvae pass through five instar stages and become adults after 15 to 16 days. The life span of the adults is approximately 14 days. Plant hoppers appear in a brachypterous form and the adults also pierce the rice plant with their stylets and suck the sap (Fig. 6-10). One generation lasts 25 - 35 days and grasses serve as hosts during the dry season.

Occurrence of plant hoppers: Both the brown and white-backed plant hoppers throughout the year in the tropics with peaks reached in February, May and August as can be seen in Fig. 6-11. However, in Japan the greatest numbers of plant hoppers fly in from the last part of June through July as is evident from Fig. 6-12. They are migratory insects which fly

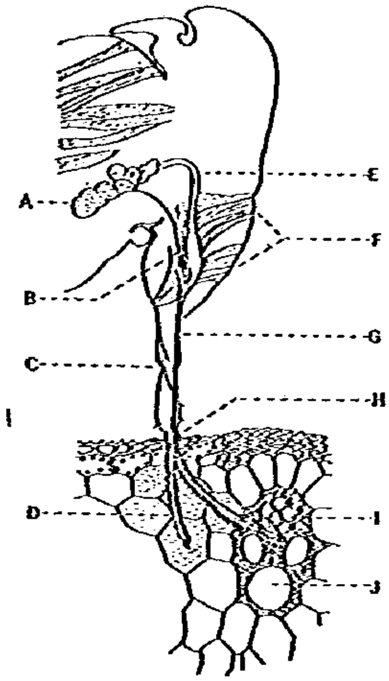


Fig. 6-10 Diagram showing the stylet insertion of the brown planthopper. A: Salivary glands, B: Salivary pump, C: Labium, D: Stylet sheath, E: Oesophagus, F: Pharyngeal dilator muscles, G: Stylets, H: Feeding mark, I: Phloem, J: Xylem. (Sogawa 1972)

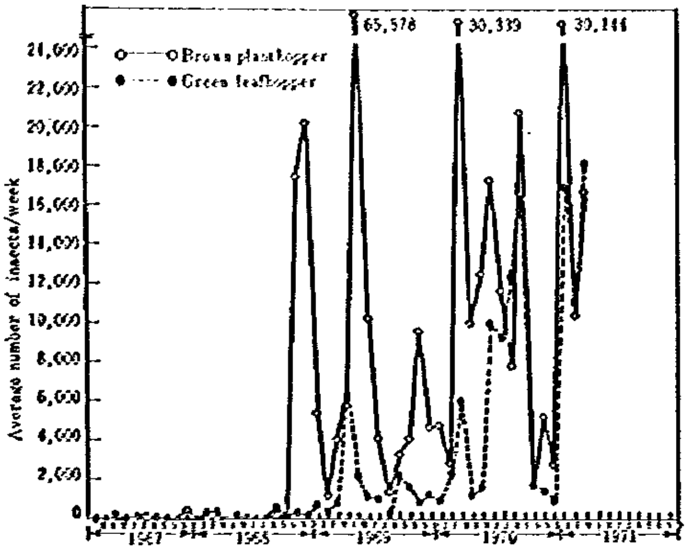


Fig. 6-11 Change in the abundance of adults of the brown planthopper and green leafhoppers as shown in light trap catches (IRRI, 1967 —1971). (Pathak 1972)

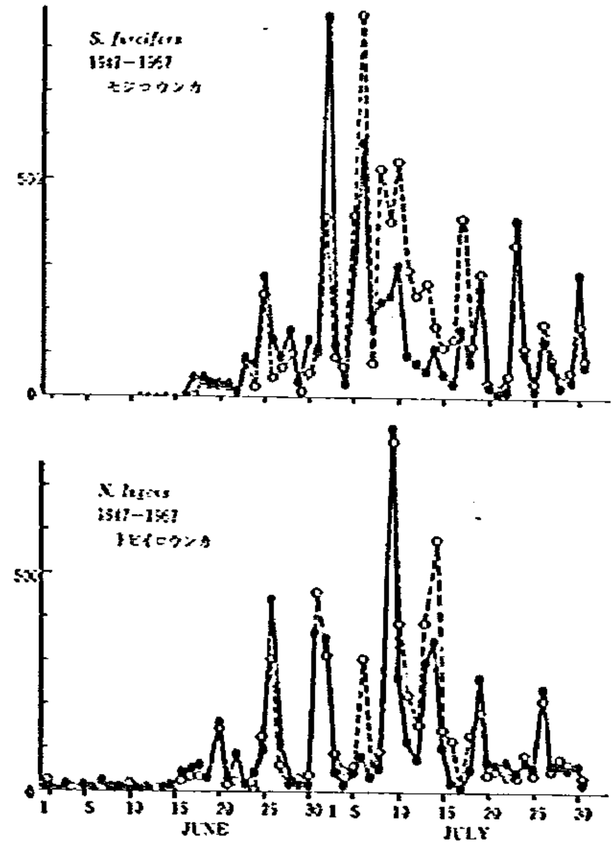


Fig. 6-12 Catches of *Sogatella furcifera* and *Nilaparvata lugens* by a light trap summed up for each calender data from 1947 to 1967 at Chikugo. (Kishimoto, 1972)

from continental China to Japan. In Japan, neither the brown nor the white-backed plant hoppers can survive the winter but in the tropics, 10 - 25 generations occur every year.

Characteristics of damage caused by plant hoppers: When the population of the larvae and adults in the rice stalks, increases their excretions adhere to the rice plant. In the tillering stage in particular, yellowing and dwarf plants occur. In years of high plant hopper occurrence, hopper burn appears and no harvest is possible. In the Philippines, the brown plant hopper is a vector for the grassy stunt viral disease but this has not been reported in Japan to date.

Control of leaf and plant hoppers: Resistant varieties have been used in recent research performed mainly by the IRRI. Table 6-5 gives a list of varieties resistant to *Nephotettix virescens* and the brown and white-backed plant hoppers. The Mudgo variety which is resistant to the brown plant hopper has been selected as the mating parent for the resistant varieties. Pankhari 203 has high resistance to *Nephotettix virescens*. Among these selected varieties, there are those which are resistant to stem borers, *Nephotettix virescens* and the brown plant hopper (for example, the IR20x{MudgoxLR8] variety). To introduce resistance to brown plant hoppers in Japanese rice, Kaneda (1971) has been selecting and growing brown plant hopper resistant varieties from crosses between Hoyoku and Judgo varieties. Fig. 6-13 shows the survival and development of first instar nymphs of brown plant hoppers

Table 6-5 List of rice varieties higly resistant to *Nephotettix virescens*, *Nilaparvata lugens* and *Sogatella furcifera* (Pathak, 1972)

Nephotettix virescens	*Nilaparvata lugens*	*Sogatella furcifera*
Ginmasari	Ptb 18	Pu San 1
Intan 2100	Ptb 21	Dahanala 2014
Peta 2892	Murangakayan 302	CI 5662-2
CO-9	Kosatawee	JBS 31
Guwea-gu-gi-goo	Sinnakayam	C 5-17
Pankhari 203	Sinnasuappu	Miao Tien-I-Li-Chan
PTB-21	PK-1	Tien-Lie
ASD-7	ASD 7	Pankhari 203
ASD-8	Babawee	SLO 12
D-204-1	Balamawee	B 76
Su-yai 20	CO 22	Colombo
Tilokachari	Dikwee	Mudgo
Jhingasail	Gangala	3-Month Variety
Godalki	Hathiel	Kaluheenati
DNJ 27	H 105	Sudhubalawe
DNJ 9	Kuruhondarawala	Vellailangayan
DS 1	MTU 15	ARC 5752
DM-77	Mudgo	ARC 6213
DV-29	Murunga 307	ARC 6563
DV-139	PTB 19	ARC 6624
IR-8	Seruvellai	ARC 6631
ARC 5752	SLO 12	ARC 6650
ARC 6006	Sudurvi 305	ARC 7251
ARC 6938	Thirissa	ARC 7331
ARC 5050	T 5	ARC 10214
ARC 6102	Vellaiangayan	ARC 10595
ARC 6162	Rather Heenati	ARC 10600
ARC 6180	Sinna Karuppan	ARC 10618
ARC 7059	Periamorungan	MTU 18
ARC 7302	Podikwee	HR 106
ARC 10229	Mahadikwee	SUDURVI 306
ARC 10243	Ovarkaruppan	
ARC 10281	Madayal	
ARC 10656	Palasithari 601	
ARC 10746	Murungakayan 3	
ARC 10804	Murungakayan 101	
ARC 10826	Murungakayan 301	
	Murungakayan 303	
	Hondarawala 502	
	Hondarawala 378	
	Murungakayan 104	
	M.I. 329	
	Pawkkulama	
	Tibiriwewa	
	Heenukkulama	
	Anadaragahawewa	

and *Nephotettix virescens* on various test varieties. The ASD7 variety has been found to be resistant to both the brown plant hopper and the

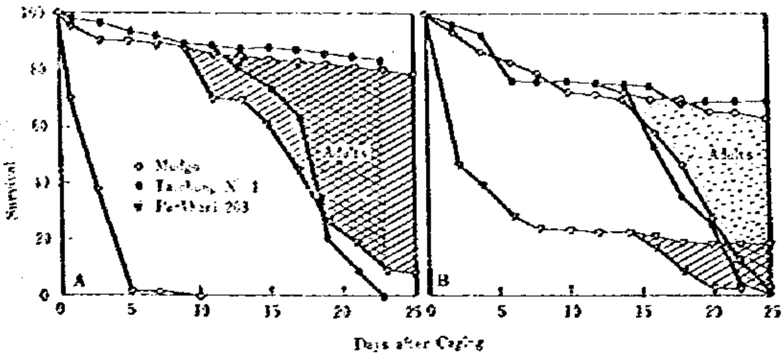


Fig. 6-13 Survival and development of first instar *Nilaparvata lugens* (A) and *Nephotettix virescens* (B) nymphs on 60-day-old plants of resistant and susceptible varieties. (A similar difference in insect survival on these varieties was also recorded in experiments using 15-, 45-, and 90-day-old plants.) (IRRI, 1968)

Insecticides must be applied once to the rice seedlings and twice around the 14th day after transplantation. A dosage of about 2kg of active ingredient per hectare is suitable. It is especially important to apply insecticides during the seedling and initial paddy periods in the case of plant or leaf hoppers which are vectors of viral diseases. In the case of emulsions, 1,000 - 1,500-fold dilutions are appropriate. Carbamate insecticides have proven effective in controlling plant and leaf hoppers.

(3) Stink bugs

The main stink bug species causing damage to rice are eight of the 14 species belonging to the genus *Leptocorisa* of the Coreidae family. There are also three species of the genus *Scotinophara* and *Nezara viridula* (Photos 16 and 17) of the Pentatomidae family. Table 6-6 gives a list of 40 species of stink bugs occurring in Japan (including the Ryukyu Islands). Table 6-7 is a list of the Leptocorisa species with their distributions.

Ecology and life history of stink bugs: The eggs of stink bugs are laid in masses (30 - 40) in the form of a barrel in the rice leaf sheaths and blades. The eggs of the Coreidae family are scattered in a flat form on the leaf blade. The eggs hatch after about seven days and the larvae insert their stylets into the soft parts of the leaf sheath, etc. to suck out the sap. There are five larval instars over a period of 20 to 30 days. The adults have a life span of 30 - 40 days. Species of the Coreidae family (Photos 19 and 20) also occur in plants other than rice such as sugar cane and soyabeans. *Nezara viridula* is widely distributed throughout the world. The adults are of four types depending on their color: G, O, F and R (Table 6-8) with the G type predominating. This species is similar to *Nezara antennata* but in Japan, there are many more *Nezara viridula*.

Occurrence of stink bugs: Stink bugs occur throughout the year. There are records of wide outbreaks of *Scotinophara* in India and Ceylon but none have been reported recently. *Leptocorisa* species occur mainly in eared rice plants. They occur during both the first and second rice crops and are particularly evident in the milky stage plants in paddy fields. The number of outbreaks per year and their peaks are not definite. *S. lurida* has four generations per year but during the dry season, the adults collect in small groups in weedy areas and the ridges between the paddies. The occurrence of *Nezara viridula* is shown in Fig. 6-14.

Table 6 6 List of Heteroptera occurrence on rice plant in Japan and Ryukyu Islands (Hasegawa 1972)

Pentatomidae
1. *Scotinophara lurida* (Burmeister)
2. *Lagynotomus elongatus* (Dallas)
3. *Aelia fieberi* Scott
• 4. *Eysarcoris fallax* Breddin
• 5. *E. guttiger* (Thunberg)
• 6. *E. lewisi* (Distant)
• 7. *E. parvus* (Uhler)
• 8. *E. ventralis* (Westwood)
• 9. *Dolycoris baccarum* (Linné)
• 10. *Palomena angulosa* (Motschulsky)
11. *Starioides degenerus* (Walker) (in Ryukyu Islands)
• 12. *Nezara antennata* Scott
• 13. *N. viridula* (Linné)
14. *Pygomenida bengalensis* (Westwood) (in Ryukyu Islands)

Coreidae
• 15. *Cletus pugnator* (Fabricius)
• 16. *C. punctiger* (Dallas)
• 17. *C. trigonus* (Thunberg)

Alydidae
• 18. *Leptocorisa acuta* (Thunberg) (in Ryukyu Islands)
• 19. *L. chinensis* (Dallas)
• 20. *L. oratorius* (Fabricius) (in Ryukyu Islands)
• 21. *Riptortus clavatus* (Thunberg)

Rhopalidae
• 22. *Aeschyntelus maculatus* (Fieber)
23. *Rhopalus sapporensis* (Matsumura)
24. *Stictopleurus punctatonervosus* (Goeze)

Lygaeidae
• 25. *Nysius plebejus* Distant, complex
• 26. *Cymus tabidus* Stal, complex
27. *Dimorphopterus pallipes* (Distant)
28. *Pachybrachius lateralis* (Scott)
• 29. *P. luridus* (Hahn)
• 30. *Togo hemipterus* (Scott)
31. *Graptopeltus albomaculatus* (Scott)
32. *G. angustatus* (Montandon)
• 33. *Neolethaeus dallasi* (Scott)

Pyrrhocoridae
34. *Pyrrhocoris tibialis* Stal

Miridae
35. *Adelphocoris suturalis* (Jakovlev)
36. *Creontiades pallidifer* (Walker)
37. *Lygus (Apolygus) nigronasutus* Stal
38. *Lygus (Orthops) disponsi* Linnavuori
39. *Stenotus rubrovittatus* (Matsumura)
40. *Trigonotylus ruficornis* (Geoffroy)

Note. • are the species causing Pecky rice.

<u>Damage caused by stink bugs:</u> The stink bugs feed on the young rice plants. The parts into which the bugs have inserted their stylets become white and dead hearts sometimes occur. The plants remain short and have a dwarfed appearance. The damage is especially bad in the ears during the milky stage and harvesting becomes impossible. Since the stylets pierce the rice gains in the milky stage and suck out everything, the grains become empty. When the insect damage occurs in the latter half of milky stage, spots appear and the rice quality drops.

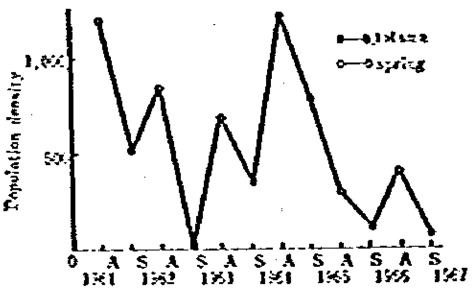


Fig. 6-14 Annual fluctuations in population density of adults of *Nezara viridula* before (autumn) and after (spring) hibernation in Japan (Kiritani 1972)

<u>Control of stink bugs:</u> Insecticides have been used for some time. The insecticides in the form of powders or emulsions are applied liberally to the base of the stalk during the adult flying periods or the larva hatching periods. Control of the damage cause by stink bugs during the milky stage requires considerable care because of

insecticide residues in the rice grains. The emulsions should be diluted 1,000 - 2,000-fold and the powders applied in concentrations of 30 to 40kg/ha. Effective insecticides include Diazinon, Sumithion and Lebaycid.

(4) Rice thrips

Seven species of rice thrips have been reported in the Far East and Southeast Asia. The most important among these are rice thrips, *Chloethrips oryzae*, and rice aculeated thrips, *Haplothrips aculeatus*. Table 6-9 shows the distribution, hosts and names of rice thrips species.

<u>Life history of rice thrips:</u> The egg are laid in the leaf blade tissue. However, the rice aculeated thrips have no ovipositor and lay their eggs on the surface of the leaves. The eggs hatch in there to four days and the larvae feed on the surface of the leaves which causes them to curl up vertically. The leaves remain in this condition until the adults appear. The larva stage is 10 to 14 days and the adults live for about 20 days. One generation lasts approximately 18 days.

<u>Occurrence and damage of rice thrips:</u> The main damage by rice thrips is to young seedlings. Since the larva are produced in large amounts, they cause considerable damage. The leaves become yellow and die (Photos 21 and 22). The leaves curl vertically to the inside. However, there is very little damage to the rice leaves after transplantation although rice aculeated thrips feed on the flowers during the blooming period. Both the larvae and adults cause damage to the rice.

Table 6-7 List of *Leptocorisa* species as a pest of rice plant with distribution. (Hasegawa 1972)

1. *Leptocorisa oratorius* (Febricius) (=*L. acuta* Distant, miss identification)
   Distribution : India, Ceylon, Nicobar Is, Pakistan, Bhutan, Burma, Thailand, Vietnam, Malaysia (incl. Sarawak and Sabah), Indonesia (Sumatra), singapore, Burnei, China, Formosa, Ryukyu Is, Celebes, the Philippines, Australia, Solomon Is.
2. *Leptocorisa acuta* (Thunberg) (=*L. varicornis F.*)
   Distribution : India, Pakistan, Burma, Bhutan, Vietnam, Thailand, Malaysia (incl. Sarawak and Sabah), Buruncei, Indonesia (Sumatra), Hongkong, China, Formosa, Ryukyu Islands, the Philippines, New Britain, New Ireland, Australia, Solomon Islands, New Hebrides, Fiji Island, Samoa Island.
3. *Leptocorisa chinensis* Dallas (=*L. nitidula* Breddin, *L. corbetti* Chaina)
   Distribution : Bhutan, Malaysia Thailand, Vietnam, Indonesia (Sumatra), China, Korea, Formosa, Ryukyu Is. Japan, the Philippines, Palau Is., Bonin Is.
4. *Leptocorisa biguttata* Walker
   Distribution : Malaysia (incl. Sarawak and Sabah), Burnei, the Philippines, Celebes, Halmahera.
5. *Leptocorisa tagalica* Ahmad (=*L. geniculata* Chaina)
   Distribution : Malaysia (Sarawak), Halmahera Is, the Philippines.
6. *Leptocorisa luzonica* Ahmad
   Distribution : Vietnam, Malaysia (Sarawak), the Philippines.
7. *Leptocorisa pseudolepida* Ahmad
   Distribution : Malaysia (incl. Sarawak), Burnei, India, Ceylon, Indonesia (Borneo).
8. *Leptocorisa costalis* (Herrich-Schäffer)
   Distribution : Indonesia (Java, Sumatra), Vietnam, Malaysia (incl. Sarawak and Sabah), Burnei, Thailand, Singapore, the Philippines.