RICE CULTURE IN TROPICAL ASIA

Edited by Tropical Agriculture Research Center of Japan
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C O N T E N T S

LIST OF AUTHORS

Dr. Shinjiro CHIKUBU	Utilization Division,	National Food Research Institute.
Dr. Terunobu HIDAKA	First Research Division,	Tropical Agriculture Research Center.
Dr. Toshihiko HINO	First Research Division,	Tropical Agriculture Research Center..
Mr. Chukichi KANEDA	Crop Research Division,	Central Agricultural Experiment Station.
Dr. Satoru MOTOMURA	Soil and Fertilizer Department,	National Institute of Agricultural Sciences.
Dr. Akio OSADA	Faculty of Agriculture,	Utsunomiya University.
Mr. Masaru SEKI	Forest Protection Division,	Forest Experiment Station.
Dr. Katsuo SUGIMOTO	Second Research Division,	Tropical Agriculture Research Center.
Mr. Fumio YAZAWA	Soil and Fertilizer Department,	National Institute of Agricultural Sciences.

CHAPTER ONE

RICE VARIETIES IN TROPICAL ASIA

Chukichi Kaneda

INTRODUCTION

Rice growing areas now extend beyond 45°N in the Ukraine, Rumania and Hungary, and as far as 35°S in Australia. Rice was originally a tropical plant and became a cultivated crop in the eastern parts of India and Burma*. Rice varieties in tropical Asian countries have very diversified characteristics. Cultivated rice belongs botanically to *Oruza sativa L.* In some areas of the African continent, *Oryza glaverrima* Steud., which differentiated independently from *O. sativa*, is also cultivated.

Local or native rice varieties, which have been developed and differentiated through a long history of adapting to various environmental(including artificial) conditions, are however facing extinction due to the recent dissemination of improved varieties and rapid changes of technology. Thus collection and conservation of useful germplasm as essential material for the future of plant breeding is urgent (Chang et al., 1972). Germplasm would be useful only after the proper evaluation of the characteristics of each variety.

In recent years there has been outstanding progress in the breeding of rice in tropical rice-growing countries. Many improved varieties have been released, and seed exchange among countries is active, resulting in the successful introduction of the varieties of one country recommended as new varieties for others. The variety IR 8 is a famous example. IR 20 and IR 22 were also adopted in many countries as recommended varieties. C4-63, which was bred in the Philippines, was recommended in Burma and Indonesia and extended the acreage of cultivation in other countries like Malaysia.

Rice varieties in the tropics are readily degraded due to their genetics and external environmental conditions. Therefore, not only plant breeders who are responsible for varietal improvement, seed increase, introduction and evaluation, but also workers in areas of agronomy, plant protection, soil chemistry, etc., must be concerned about whether the varieties they plant are maintaining their own original characteristics.

This chapter describes how characteristics of rice varieties are expressed, how to survey and record these characteristics and properly identify the varieties, and also how to multiply the seeds while preventing degradation of the varieties.

1-1. CLASSIFICATION OF VARIETIES

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* Some scientists insist that areas from Thailand to southern China should be included as places of origin of cultivated rice.

1-1-1. What is a "Variety?"

"Variety" of crops is originally not related to a group of botanical classification, but a unit of grouping for agricultural use. A variety is distinguished from other groups on any of the bases of morphological, physiological, chemical and other characteristics of agricultural importance; also, its characteristics can be maintained by its usual way of reproduction.

In practice, mixing or contamination, and degradation;occur to varieties due to various causes (cf. 1-4) during cultivation. As a result, a mixture of several varieties can often be seen in farmers fields. Recently, the word "cultivar" has been used without mentioning a level of purity, which is usually assumed in a "variety." "Cultivar" is therefore applicable to local rice varieties planted by common farmers in the tropics. However, recommended varieties newly disseminated after intensive seed improvement are also called cultivars.

1-1-2. Differentiation of Varieties and Bases of Classification

Sine rice was first cultivated by mankind, many varieties have differentiated in various directions. It is estimated, for example, that more than 4,000 indigenous varieties exist in Bangladesh, and 3,500 in Thailand, more than 2,000 in Japan, 1,700 in Taiwan, and over 1,000 in Burma (Chang, 1972).

Classification of different varieties is possible only after we can identify varietal difference of characteristics which have been brought about during the long course of differentiation of the crop. Differentiation of varieties can be realized through the progress of technology in cultivating the crop. Japanese farmers in the eighth century knew rice varieties only as waxy or non-waxy, and early or late. In the ninth and twelfth centuries, varieties were identified by their quality and other agronomic traits. It was in the sixteenth or seventeenth century that varieties were identified by overall characteristics such as maturity, pigmentation, hairiness, culm stiffness, or yield (Matsuo, 1959). Diversity of varieties of a crop can also be attained by the technology level of the crop cultivation as well as the geographic distances from the gene center of the crop.

Standards of classifying varieties are quite various. For classifying rice varieties of the whole world, the most popular starting point is the grouping by *indica* and *japonica* which is based on the growing regions, fertility of hybrids between varieties, morphologic, and physiological characteristics, and so on. Variation of the characteristics of *indica* is so diverse compared to that of *japonica*, that a group of *javanica* is often separated from *indica*. Japanese plant breeders and geneticists often use the three types A, B, and C. Type A varieties are mainly distributed in Japan, Korea, Taiwan, North and Central China, Europe and California; Type B in the Philippines, Indonesia, Europe, southern USA, Central and South America; Type C in Asian countries south of Central China (Matsuo, 1952).

From the standpoint of water requirement, indigenous rice varieties in tropical Asia can be grouped into (1) upland rice adapting to upland and rainfed fields in low precipitation regions, (2) lowland rice adapting to average rainfed fields to water-logged fields, and (3) deep-water rice and floating rice adapting to water as deep as five meters or more.

Varieties within a region are usually grouped by maturity, crop seasons, or grain type. In Cambodia, for example, "hatif", "mi-saison", "saison" and "tardif" are variety group names for early, medium, late, and very late varieties, respectively (Yada, 1968); in Uttar Pradesh in India, "kwari", "kartiki" and "aghani" are group names for early, medium and late varietis, respectively (Rao, 1972). Rather common group names are "aman," "aus" and "boro." Aman varieties are photoperiod sensitive and are grown in the monsoon season in Bangladesh and many states of India. Boro is spring (maturing) rice grown in the Assam and Bengal regions from November to April, and aus is autumn rice grown from April or May to August or September.

Indonesian varieties are usually grouped into bulu and tjereh. The general characteristics of bulu are: long-awned, low tillering and thick culmed, lodging resistant, short-grained and hard shattering, short period of seed dormancy, and so on. Many of these traits are also peculiar to *japonicas* and Type B varieties. Characteristics of tjereh, which belongs to Type C, are contrasting to those of bulu.

Genetic relationships based on the hybrid fertility among aman, aus, boro, bulu, tjereh and Japanese varieties are shown in Table 1-1 by Morinaga (1968).

Table 1-1 Fertility of the 15 inter-type combination hybrids of six main Asian ecotypes.

	Ordinary Japanese	Aus	Aman	Boro	Tjereh
Ordinary Japanese					
Aus	+				
Aman	−	++			
Boro	−	++	+		
Tjereh	−	++	++	++	
Bulu	+	+	−	+	−

Fertility : ++ 70% and over + 30 to 70% − less than 30%

Judging from the genetic relationships based on the cross-fertility, "ecospecies aman" includes aman, boro and tjereh. Cross-fertility of "ecospecies japonica" is low when crossed with "ecospecies aman," but rather high when crossed with "ecospecies aus" and "ecospecies bulu." "Ecospecies aus" produces highly fertile hybrids with "ecospecies aman," and aman and tjereh. These results obviously agree well with our experience in practical breeding work.

Many high-yield varieties bred in recent years are semidwarf in contrast to those traditional tall varieties susceptible to lodging. Dwarfism would be a new category applicable to the classification of tropical rice varieties.

1-2. CHARACTERISTICS AND EVALUATION OF VARIETIES

1-2-1. Characteristics of Varieties

When you know which group a variety belongs to, it is possible, to some extent, to have a rough idea of the characteristics of the variety. However, varieties belonging to the same group are quite similar in some characteristics but can be discriminated from each other by others.

Characteristics of varieties are inheritable. A single or a few major genes control qualitative characteristics, and a number of minor genes (polygenes) control quantitative characteristics. Qualitative characteristics are generally least affected by environmental factors such as temperature, soil moisture, and soil fertility. Thus stable expression of qualitative characteristics is valuable for judging whether the variety you are growing is genuine or not. On the contrary, quantitative characteristics are variable according to the levels of soil fertility, moisture, temperature, and so on. No proper value of any quantitative characteristic can be given to a variey, but can be discussed only in connection with growing conditions or in contrast with the data of other varieties. Besides, the order of the varieties in a given characteristic may be reversed depending on the environmental conditions. Quantitative characteristics therefore cannot be used for identifying varieties, especially under different environments. Many of the agronomically important characteristics are quantitative.

Plant characteristics of rice are exemplified as follows:

(1) Morphological characteristics

(a) Qualitative characteristics

Pigmentation of plant parts: leaf sheath, leaf blade, leaf margin, internode, node, hull, apiculus and awn, stigma, pericarp, etc.

Presence or absence of plant organs: ligule, auricle, hairs on leaf and hull, and other plant parts, glume length, length and amount of awns, threshability.

Panicle types: club, lax or open, and intermediate.

Grain shape, grain size: long-slender, short-bold, etc.

Grain appearance: degree of white core, white belly, translucency, etc.

Chemical characteristics of grains: waxiness, amylose content, alkali solubility, aroma, etc.

(b) Quantitative characteristics

Plant height, culm height, panicle length, grain number per panicle, grain weight, sizes of leaf blade, panicle count, stem thickness, etc.

These characteristics are affected by no only natural environmental conditions but cultural techniques such as seeding rate or level of plant protection, and others.

(2) Physiological and ecological characteristics

(a) Resistance to diseases, insects, low temperatures, drought, soil problems, submergence, lodging, and others.

(b) Others: maturity, seed dormancy, etc.

Physiological and ecological characteristics are of great importance in controlling the local adaptability of the variety. Judgment and evaluation of the characteristics is, however, not possible at a glance but should be made through all the growth stages. Resistance to different problems can be considered as rather stable, though varietal reactions to diseases might change by region due to different strains of causal agents of the diseases. Growth duration or maturity may vary greatly depending upon the environment, especially temperatures and day length (cf. 1-3 below). Characteristics stated in (1)-(b) also vary according to the changes of growth duration. Therefore these characteristics can also be considered as ecological characteristics.

1-2-2. Checking and Recording Characteristics

Characteristics of varieties are tested and recorded for two important purposes. The first is to identify the variety properly and keep its purity at the necessary level. The second is to judge the agronomic utility of the variety on such points as yield, local adaptability, and so on. For the first purpose, qualitative characteristics should be checked, and for the second purpose, quantitative, physiological and ecological characteristics are tested.

In the first case, for example, when we want to confirm whether a variety or a test line introduced from another country or region is the genuine one; or when we have to judge whether variety "A" was mistaken for variety "B" in the procedures of seeding or transplanting; or when, after many years' culturing of a variety, some offtype plants are seen in the field and it is necessary to identify the genuine plants in the field when gathering seeds, we need to refer to the record of characteristics of the variety. In Japan, all rice varieties are released by experiment stations with publications on the history, morphological and ecological characteristics, adapted area, and precautions for growers.

When we continue cultivation of a variety without referring to the record of its characteristics, especially when the personnel in charge are shifted and do not know any of the special characteristics of the variety, we may sometimes grow a quite different variety without knowing it. Varieties, especially traditional ones in tropical countries, most of which lack the original records of characteristics, are liable to this kind of mistake.

Rice catalogs of important varieties throughout the world, edited by FAO in the 1950's, are quite helpful as a reference for characteristics. Publication of supplements for the catalogs has now been discontinued. The last supplement was No. 9, issued in 1959.

"Catalog of rice cultivars and breeding lines in the world, collection of the International Rice Research Institute" published in 1970 contains various characteristics of about 10,000 varieties and lines collected from almost all the rice-growing countries of the world. More than 40 characteristics were tested and the data were arranged by a computer. The catalog is an essential reference book for those working with rice, especially those concerned with foreign varieties. The total number of collected varieties and lines at IRRI reached 23,000* in 1972 (IRRI, 1970-1973). Publication of the second volume of the catalog is eagerly awaited.

Besides IRRI's rice catalog, "A monograph of rice varieties preserved by Taiwan Agricultural Research Institute" (Taiwan Agricultural Research Institute 1964) is a good reference book on characteristics of traditional rice varieties in tropical countries. As for Indian varieties, a catalog by the Indian Council of Agricultural Researches (ICAR 1971) containing more than 5,700 varieties will be helpful.

In IRRI's rice catalog, all the collected varieties with the variety name are arranged in a series (Fig. 1-1). When we compare the characteristics of these varieties, we find a great difference among those stocked in different countries, and understand how varieties are apt to change or to be mishandled. It becomes obvious that we have to be cautious in handling rice varieties. For example, five accessions of Norin 22, a Japanese lowland rice variety, collected at IRRI were all considered as *japonica*, but one accession had open type panicles, very long ligules, red kernels and easy-shattering grains. Its seedling height was too tall to consider it as a variation due to the difference of crop season (Table 1-2). Therefore, this accession must be a variety other than Norin 22, though it has been grown for many years as Norin 22 in the country of seed source. To avoid this kind of danger in using and keeping varieties under a mistaken name, information on characteristics of varieties is essential.

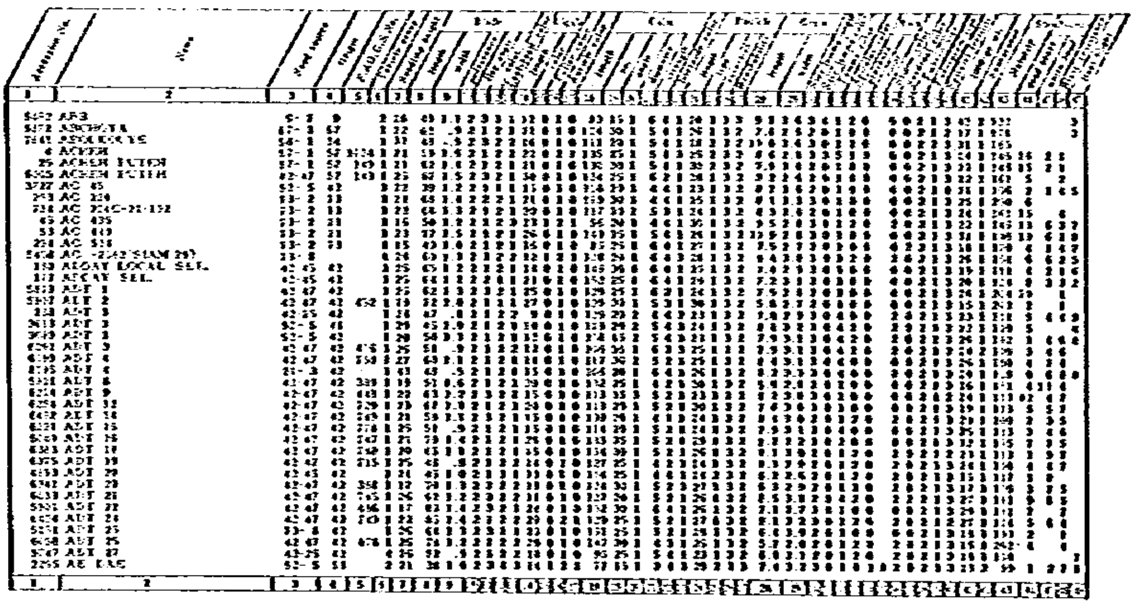

Fig. 1—1 A sample page of IRRI's "Catalog of Rice Cultivars and Breeding Lines in the World Collection".

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*In 1974, 35,000 according to "Research Highlights for 1974," published by IRRI.

Table 1-2. Characters of different accessions of the rice variety Norin 22 tested at IRRI (modifield from [11])

IRRI Acc. No.	FAO O.S. No.	Variety group	Seed-ling ht.	Ligule length	Panicle type	Thresh-ability	Apiculus cloor	Pericarp color
424	1313	jap.	17	6	compact	tight	colorless	colorless
6852	---	"	33	22	open	shatter.	"	red
7397	---	"	22	9	compact	tight	red	colorless

To know whether the variety being grown is genuine or false, it is necessary to check the qualitative characteristics which are almost free from environmental effects. For this purpose, the following characteristics should be observed and checked at different growth stages. The grading system used here is primarily in accordance with that used in IRRI's rice catalog (IRRI 1970). Characteristics with an asterisk (*) are especially important for marking.

(1) Characteristics to be checked at the seedling stage:

(a) Leaf color: 1. Light green 2. Green 3. Dark green
4. Purple leaf margin 5. Purple trace 6. Purple

*(b) Leaf sheath color: 1. Green 2. Purple trace 3. Purple

(2) Characteristics to be checked at the early tillering stage:

*(a) Leaf sheath color: Purple trace which was not evident in the seed beds becomes much clearer sometime after transplanting. Hills or plants with or without purple trace sheath color can easily be identified. Before the fields grow too thick, observation and recording of this trait must be finished. The first roguing of offtype plants is quite important at this stage in seed multiplication fields of *indica* varieties.

*(b) Ligule length: Generally short in *japonica* and various sizes in *indica*.

(c) Plant height, sizes of leaf blade, leaf angle, leaf color, number of tillers, etc.: These characteristics should be checked in the earlier stage of tillering, for varietal difference of time of ear initiation (or duration of basal vegetative growth stage) may have so great an affect so as to render the data almost meaningless. Tillering habit is a rather stable trait, and can be used for checking.

(3) Characteristics to be checked at the flowering stage:

(a) Date of heating: Dates of the first heading, 50% heading, and preferably full heading; and the uniformity of heading within the plot.

*(b) Panicle type: 1. Open 2. Intermediate 3. Compact
4. Clustering

1. and 2. can be distinguished sometime two weeks after heading. 4. is rarely seen in cultivated varieties (Photos 1-1 and 1-2).

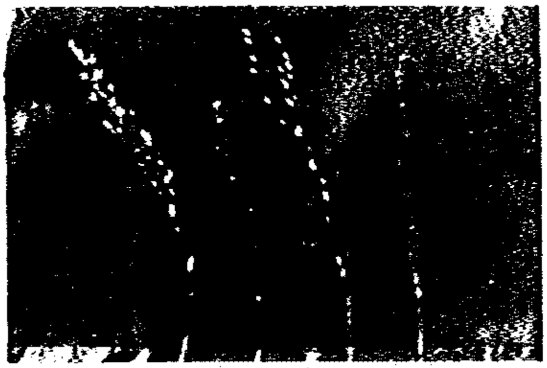


Photo 1-1. Panicle types, from left: club (compact), lax (open), intermediate.

Photo 1-2. Deformed panicles. Nodes are present in portion above line in lower portion of photo. The "clustered" type is shown on the left.

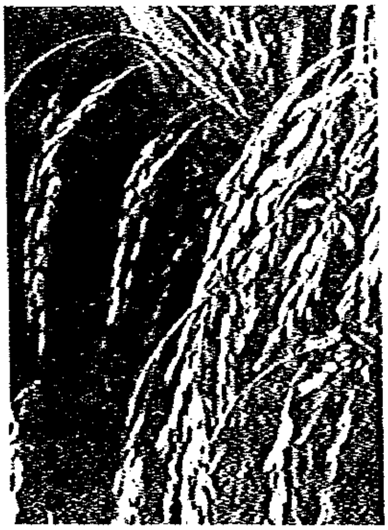


Photo 1-3. Panicle type of Pankhari 203. Note the long glume.

*(c) Apiculus color: 0. Colorless 1. Red 2. Purple

Some varieties change their apiculus color from flowering to maturity. Check it just after heading, and then at maturity (cf. footnote).

*(d) Stigma color: 0. Colorless 1. Purple trace 2. Purple

(Footnote) In Japanese rice, for example, the chromogen gene C^{Br} and the activator gene A produce pink apiculus at heading but change it to colorless at maturity; the chromogen gene C^{Bp} and the activator gene a produce colorless apiculus at heading but brown at maturity (Takahashi, 1957).

(e) Presence and length of awns: This trait is not always stable against environmental conditions, and can be seen as an ecological characteristic. Varieties with almost no awns sometimes manifest several long awns under conditions not yet very clear.

*(f) Glume length: 1. Short (less than 1.5mm) 2. Medium (1.6 - 2.5mm) 3. Long (more than 2.6mm)

Long glume is usually seen only in some traditional varieties like Pankhari 203, an Indian variety famous for its resistance, gene *Glh 1*, to green leafhopper (Photo 1-3).

(4) Characteristics to be checked at maturity

*(a) Flag leaf angle: 1. Erect 2. Intermediate 3. Horizontal 4. Descending

Flag leaves are erect in many varieties at the heading stage, but become horizontal (and then descending) at maturity. Observation of this trait should therefore be made within seven to 10 days after the full heading.

(b) Culm angle: 1. Erect (less than 30°) 2. Intermediate 3. Spreading (more than 60°)

Old indigenous indica varieties, standing erect during the earlier ripening stage, often spread culms as the ripening advances. Recording must therefore be conducted at maturity.

(c) Panicle exsertion: 1. Enclosed 2. Partly exserted 3. Exserted

Only some very old traditional varieties have panicles enclosed inside the sheath. Many improved semidwarf *indica* varieties grown at low temperature, or plants infected by some diseases such as "tungro" in the tropics or "dwarf virus" in the temperate zones, often produce enclosed or partly exserted panicles.

*(d) Lemma and palea color: 1. Straw 2. Gold to brownish 3. Brown spots on straw 4. Brown furrows on straw 5. Reddish 6. Purple 7. Black

Grades 3. and 4. are often mistaken for damage by some diseases and insect pests. Pigmentation becomes clearer as ripening proceeds. Recording should be done at least two weeks after heading, or at maturity.

*(e) Apiculus and awn color: Check whether the color has changed from that of the flowering stage.

*(f) Pericarp color: 0. Colorless 1. Brown speckle 2. Red 3. Purple

Take sample grains fully matured. As shades of color vary by variety, grades can be more finely divided according to the purpose of your experiment.

*(g) Waxiness: As freshly harvested grains of waxy varieties appear non-waxy, brown rice samples should be dried to around 14% moisture content. For strict identification of waxy rice, a cross section of brown rice is stained with KI-I solution. Grains stained brown are waxy, and purplish blue ones are non-waxy.

Besides the above-mentioned characteristics, such quantitative characteristics as culm height, panicle length, culm thickness, panicle count, grain fertility, maturing time and so on can be referred to. Grain shape and threshability are rather stable traits, though a tropical, medium-easy shattering variety may exhibit easier shattering when it ripens in cooler climates.

1-3. IMPROVEMENT OF RICE VARIETIES

1-3-1. Varietal Improvement

Methods of varietal improvement in the tropical countries are many and various. In some countries, introduction of new varieties and breeding lines, and testing their adaptability, is the main breeding program. In other countries, pure line selection, hybridization or even mutation breeding are the means of varietal improvement. "Seed improvement" is referred to the state of maintaining as high purity of varieties as possible.

Steps in rice breeding are: (1) finding or creating variation, (2) selection of the most desirable plants, (3) breeding of a practically homogeneous pedigree line, and (4) seed multiplication of the line for dissemination.

Finding and selecting better plants in the variation of the existing variety is "pure line selection," which has been generally practiced until recent years in many tropical rice-growing countries. Traditional local varieties are, for various reasons, low in purity, and have mixed lines. Thus, this method of breeding is effective to some extent. From a variety in Bengal, Kataktara was selected and its superior characteristics were noticed in 1915. In 1921, it was designated as the first recommended variety for the aus crop. Aus varieties Surjamukhi and Charnock were released as recommended varieties in 1927 (Alim et al, 1962). In the Philippines, pure line selection was initiated by Jacobson and his group, and Apostol (Senora II) was selected. Since then many varieties including Wag-wag and Elon-elon have been selected (Cruz, et al, 1956); (Torres, et al, 1956). After World War II, re-selection of the then existing recommended varieties, which had been degraded during the hostilities, was undertaken. In Malaysia, pure line selection was initiated several years later than in the Philippines. Seraup Kechil, Seraup Besar, Mayang Ebos, Siam 29, and so on, are the fruits of that project (Samoto, 1970). In Thailand, the history of rice breeding is rather new (since 1950), and almost all of the presently recommended varieties are the results of pure line selection (Parthasarathy, 1972).

In pure line selection, variation and combination of characteristics are limited only to the extent of existing ones. For very sharp improvement of certain characteristics, such as pest resistance, quality and maturity, or for combining merits of several different varieties into one variety, pure line selection is not effective.

Varietal improvement by introducing foreign varieties and breeding lines, and testing adaptability to the own environment has been successfully conducted in many countries. The Philippines first attempted variety introduction from Japan in 1902, and thereafter succeeded in the introduction of many varieties such as Ramai, Ketan Koetoek, Malagkit Sungson, etc. from then French Indo-China; Seraup Besar 15, Seraup Kechil 36 from then Federated Malay States; and Fortuna from U.S.A. (Cruz et al, 1956). After World War II, Peta, Intan, Tjahaja and others were introduced from Indonesia and are still widely cultivated (Cada, 1956). Peta became a parental variety of IR 8, IR 262, C4-63, and many new improved varieties. All these three Indonesian varieties, together with Bengawan and Mas which were later introduced, are sisters from the cross, Tjina x Latisail, made in Indonesia. Both parents of the cross were, again, introductions to Indonesia from abroad. Tjina, introduced in 1914 from China to Jogjakarta, was widely grown in Indonesia. Latisail is a "transplanted aman" variety of Assam with short grains and high yield.

Introduction of Taichung (Native)1 and Dee-geo-woo-gen into India and the Philippines was of historical importance. Because of great success in elevating rice yields in the tropics owing to T(N)1, this variety and its semidwarf parent, D-g-w-g, have been used vary often as parents for the breeding of new semidwarf tropical indica varieties. The growing areas of these are expanding year after year because of their high yield.

In the Philippines, rice breeding by hybridization was started in 1920. Raminad Str. 3 (Quezon rice) is a product of the cross, Ramai x Inadhica, made in 1928-29, and was released in 1938 (Torres et al, 1956).

In 1911, when a rice improvement program was started in Dacca in British India (including India, Pakistan and Burma), the hybridization technique had already been adopted, though only for the purpose of genetic studies. Crossing for breeding was initiated in 1917. From early crosses, several famous aus varieties such as Dular (Dumahi x Larkoch) and Pusur (Pukhi x Surjamukhi) were produced. Daudin is an aman variety of an earlier cross aimed at combining the good grain quality of Daudkhani and the wide local adaptability of Indrasail (Alim et al, 1962).

The first *indica-japonica* hybridization in tropical countries was probably made in Burma in 1928, using D17-88, Shinriki, and Aikoku (Parthasarathy, 1972). Extensive hybridization between *indica* and *japonica* varieties was started in 1951 in India as the FAO "Indica-Japonica Rice Hybridization Project." The recommended varieties produced from this project in member countries are Malinja (Pebifun x Siam 29) and Mashuri (Taichung 65 x Mayang Ebos 80) of Malaysia, Adt 27 (GEB 24 x Norin 8) of India, and Norelon Str. 340 (Norin 1 x Elon-elon) of the Philippines (Cada et al., 1972; Parthasarathy, 1972; Umali, 1972).

The active and successful breeding programs of IRRI in the 1960's stimulated hybridization breeding in many countries and resulted in many improved high-yield varieties. International cooperation in rice breeding also stimulated worldwide exchange of germplasm among different countries for efficient use in their breeding programs.

Figs. 1-2, 1-3, and 1-4 present genealogical relationships of fertilizer responsive, high yield, newly recommended varieties in the tropical rice-growing countries. From the figures, it is obvious that plant introduction played a very important role. They also indicate how significant the contribution was of the variety Dee-geo-woo-gen, developed through the breeding of IR 8 and Taichung (Native) 1, both fertilizer responsive and high yielding. All of the semidwarf indica varieties so far bred have the same dwarf gene originating from Dee-geo-woo-gen. Recent report says, however, that another dwarf gene was found in a variety, Chen-chu-ai, introduced from Mainland China to the Philippines (IRRI, 1973). It is worth noticing whether this variety will be a good donor of dwarfism in relation to its association with other important characteristics such as resistance to disease, insects and other problems, or grain shape and quality.

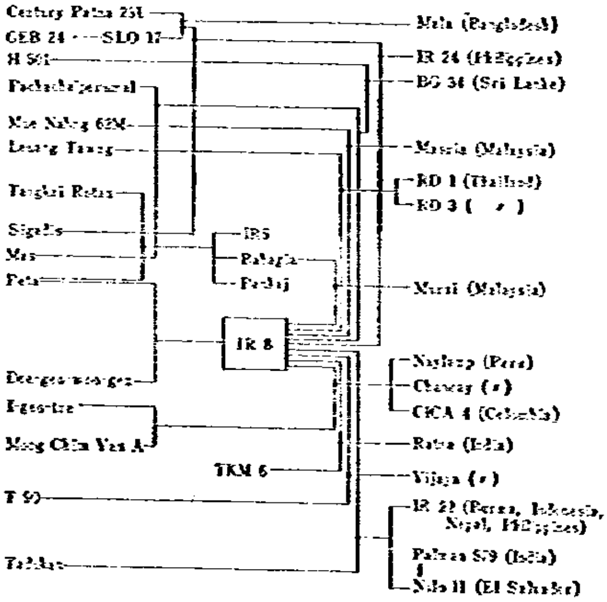


Fig. 1-2. Genealogical chart of new recommended varieties related to IR 8.

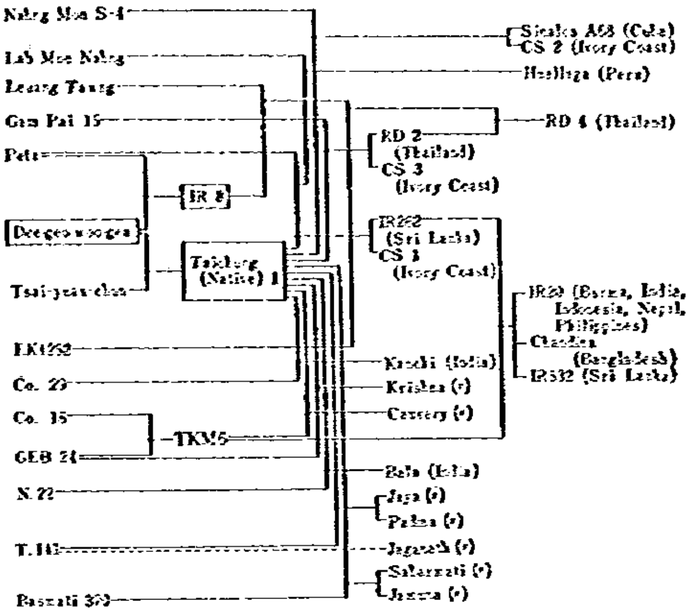


Fig. 1-3. Genealogical chart of new recommended varieties related to Taichung (Native) 1.

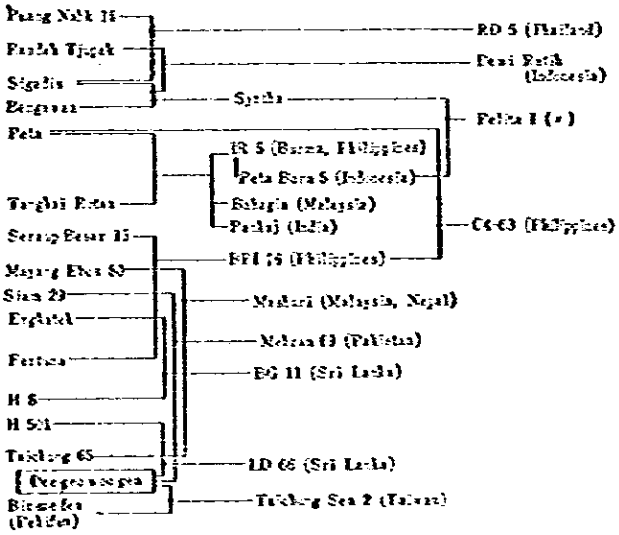


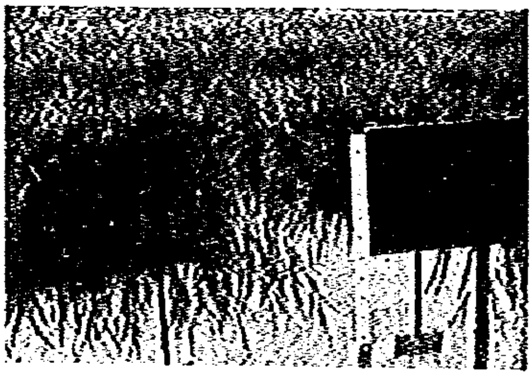
Fig. 1-4. Genealogicalchart of new recommended varieties related to Dee-geo-woo-gen and others.

1-3-2. Factors Conditioning Adoption of Varieties

There are several important factors which determine whether a variety or a breeding line in one country can be extensively grown in other countries or regions. Information regarding such factors in a country will help one understand the outline of characteristics of commercial varieties, or of breeding lines to be disseminated in the country. Therefore, it is useful to have a knowledge of such factors for the evaluation of varieties and germplasm introduced from other countries.

(1) Technology of rice culture -- a main factor conditioning plant type of rice varieties in the region

Until some ten years ago, extensive farming was dominant in most tropical rice-growing countries. Farmers harvested rice from plants surviving damage by various diseases, insect pest, weeds, and other problems. Under this farming system, a variety with fast germination and vigorous growth on poor soils, and one which could compete with weeds, would be more commonly used. In the region, tall, leafy, vigorous varieties with long panicles, are predominant. In the monsoon season, vast areas are covered with water from less than one meter to several meters deep in some countries. In these regions, deep-water rice or floating rice varieties, which can elongate their stems as the water depth increases, are predominant (Photo 1-4).



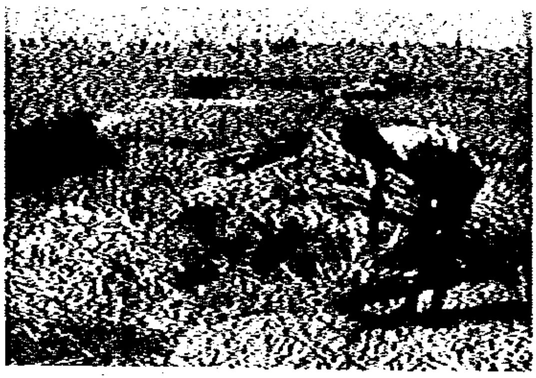


Photo 1-4. Selection tests of floating rice at the Hantra Rice Experiment Station, Thailand. In this area water depth is 130cm; IR 8 and C4-63, which cannot grow where water depth exceeds 80cm, cannot be cultivated here.

Photo 1-5. Traditional method of threshing, near Kathmandu, Nepal. Hitting the ground three or four times is enough to virtually complete threshing.

In the U.S.A., Australia, and in Surinam in South America, where large scale mechanized direct-seeding culture is conducted on vast farms, B type varieties with quick seedling growth, low tillering, stiff strawed and lodging resistant, prevail.

From the standpoint of harvesting, the U.S. varieties which are non-pubescent, thick-culmed and lodging resistant, are well adapted to harvesting by combines. Their descending leaves at maturity, which is the common characteristic of U.S. varieties, may also be suitable for combines. In the high elevations of tropical countries, tall, low tillering, and long panicle varieties are grown. These varieties are safer for the lower temperatures of the growing season, and suitable for harvesting by picking panicles.

The method of threshing is also a factor for deciding on the adoption of varieties. Hitting the ground with the panicles, or the like, is the general practice in tropical countries (Photo 1-5), and easy shattering varieties are preferred. When a non-shattering variety is to be released, a new system of technology for growing the variety must be adopted at the same time. The case of Nepal is a good example. Introduction of "ponlai" (*japonica*) varieties from Taiwan was quite successful in drastically increasing rice yields in Kathmandu. The dissemination of ponlai varieties was possible, however, only when coupled with the introduction of pedal threshers.

(2) Socio-economic conditions -- a main factor conditioning profitability of varieties

In this case, profitability denotes the level of yield increase of the rice variety against the input of labor, fertilizers, insecticides, and so on. In Japan, the limited cultivating area and high population, together with the overwhelming significance of rice in daily diets, stimulated work to increase yield by intensive farming, using modern technology. Under such conditions, rice varieties need not compete against weeds nor be resistant to insects and diseases, but fertilizer responsiveness is necessary for efficient production of "sink and source" of photosynthesis, and also for efficient transportation of the product of photosynthesis from leaves to grains. Thus Japanese rice varieties have become short-culmed and responsive to nitrogen application for higher yields.

In tropical rice-growing countries, on the contrary, chemical fertilizer supply and water control is far from satisfactory, and diseases and insect pests are rarely controlled. Under these conditions, the most important factor to ensure a safe harvest of rice must be vigorous plant growth, ability to compete against weeds, disease and insect resistance, etc. Therefore, varieties have generally been tall and leafy, susceptible to lodging, and low in response to nitrogen application. To cope with the food crisis brought on by the population explosion in recent years (after World War II), many tropical countries started to introduce and recommend short-culmed and fertilizer responsive varieties, and the area planted to semidwarf improved varieties has been increasing.

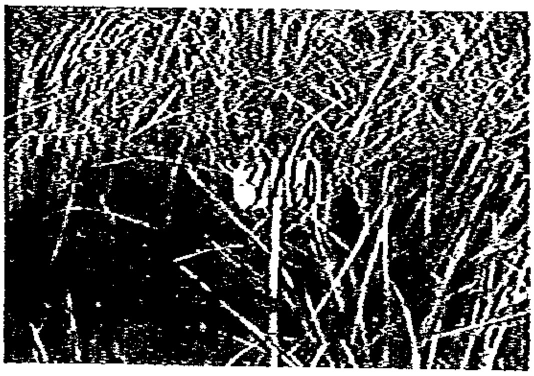
(3) Food custom and rice marketability -- a main factor conditioning grain and cooking quality

Taking an overall view of rice markets, the major factors of rice quality are grain shape and amylose content. Both characteristics are quite specific to locality, depending upon growing countries or marketing systems. Varieties which are not suited to the category in the country cannot be recommended nor be commercial varieties.

Rice varieties are grouped into waxy (amylose 0%) and non-waxy (amylose around 15 to 30%); and non-waxy varieties are divided into high, medium, and low amylose classes. Cooked rice is dry for high amylose varieties; soft and moist for low amylose varieties. Intermediate amylose varieties are soft immediately after cooking, but become dry and fluffy when cooled. In Northern and Northeastern Thailand, and in a part of Laos, people grow waxy rice almost exclusively. In the lowlands of tropical rice-growing areas, intermediate- to high-amylose varieties are predominant. At high elevations and in the mountainous areas of the tropics, or in middle and high latitude areas, low amylose or waxy varieties dominate. For example, out of 12 varieties we collected in a small town (1,300m elevation) in Mountain Province of the Philippines, four were waxy, six were low amylose, and two were medium-low amylose varieties. For people who prefer low amylose rice, high amylose varieties are of poor quality, and *vice versa*.

As for grain shape, it is the same story. In Japan, for example, long grain rice is called "foreign rice" and is disliked as lacking taste. In areas, where both long and short grain varieties are grown, short grain is "course" while long grain is "fine" and esteemed. Grain quality is especially important in rice exporting countries, and long grain varieties fetch a much higher price. Due to the recent advances in hybridization breeding, a combination of long grain and low amylose is not rare, and now the relation between grain shape and eating quality is not linear any more.

Beside the above two characteristics, specific rice such as scented rice or rice for Japanese "sake" wine are produced in rather limited areas. In Pakistan, for example, Basmati, a fine, superior quality scented rice (Photo 1-6), is produced in the Punjab areas (centering around Lahore City), and the Sind area of the lower reaches of the river Indus is not suited for Basmati because rice there fails to be aromatic. Sind is rather famous for cultivation of high-yield varieties with bold grains like IR 8 (Photo 1-7).



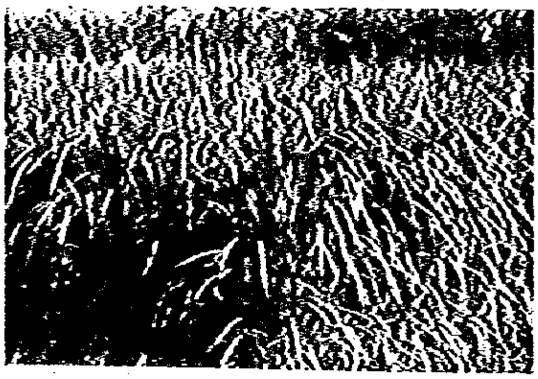


Photo 1-6. Basmati 370, a typical example of scented rice. With long stalks, long panicles and fine grains, it topples over easily.

Photo 1-7. Kangni 27, widely grown in the Sind area of Pakistan. Because of its short grain characteristic it has been replaced by IR 8 at a rapid rate.

(4) Limitation of climatic elements -- Factors conditioning growth duration of rice varieties

The growth duration of a rice variety is determined by the magnitude of the two developmental phases -- the vegetative growth phase and the reproductive phase (cf. Chapter 2, Physiology of the Tropical Rice Plant). The latter is almost equal in all varieties under the same environmental conditions.

The vegetative growth phase is divided into the basic vegetative growth phase and the photoperiod sensitive phase. Out of the climatic factors affecting these two phases, temperatures influence both, and daylength has an effect upon the photoperiod sensitive phase and controls days from seeding to ear initiation.

In the tropics, temperature is no limiting factor to growth duration, and rice varieties are classified by the degree of photoperiod sensitivity into (1) photoperiod sensitive, (2) weakly sensitive, and (3) non-sensitive varieties. Aman, tjereh, and floating rice are strongly sensitive, and come to heading only in the season of a certain daylength within rather smaller variation of daylength in the year. These varieties are called season-fixed or seasonal. Raminad Str. 3, a Philippines, a strongly photoperiod sensitive variety, flowers from the end of November to December irrespective of the time of seeding from January to August at Los Baños (Vergara, 1970). This is because the critical daylength of this variety is around 12½ hours.

On the other hand, in high latitudes, the daylengths in the rice growing season are between 12 and 15½ hours (at around 35°N), and the critical daylength of most photoperiod sensitive varieties is between 14 and 15 hours. When we grow these varieties in the tropics, the natural daylength is always short enough to affect the photoperiod sensitivity of those varieties throughout the growing season. Therefore, as soon as the basic vegetative growth phase is fulfilled, panicle initiation starts and results in very short growth duration. Table 1-3 shows the reaction of a Japanese late variety Hoyoku, which is very early in the Philippines. It needs longer duration in the wet season than in the dry season when the daylength is shorter. (Fig. 1-5)

On the contrary, in the case of Raminad Str. 3 grown at a higher latitude (e.g. 35° N), the natural daylength is shorter than the critical daylength of this variety only after October, when air temperatures are too low for normal heading, flowering or maturing. (Fig. 1-5)

Photoperiod non-sensitive varieties in the tropics reach heading almost at the same time after planting regardless of the seeding time; hence they are non-seasonal or duration-fixed varieties. Improved varieties in recent years are mostly in this group. Table 1-3 shows that IR 8, T(N) 1 and others flower almost at the same duration in both the wet and the dry seasons.

Two varieties of the same growth duration in the tropics are sometimes quite different in response to lower temperature conditions. When they are grown in hill areas of the tropics, or in the subtropical or

Table 1-3. Days to heading of some selected varieties at the two location—in the tropics and in the temperate zone.

Variety	Origin	at Konosu, Japan	at Los Banos, Philippines	
			Dry season	Wet season
Hoyoku	South Japan	118	57	67
T (N) 1	Taiwan	106	81	82
IR 8	Philippines	120	93	90
IR 22	"	143	81	83
IR 24	"	110	81	85

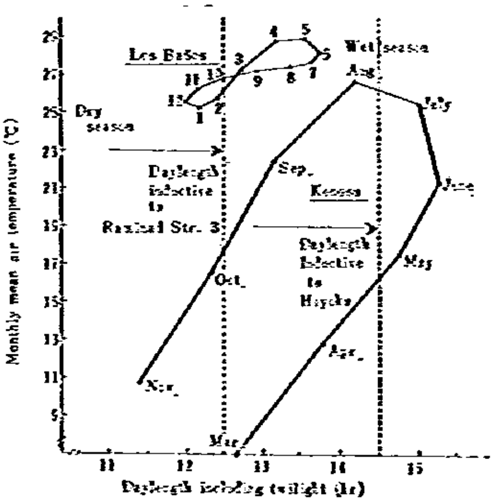


Fig. 1-5. Photperiod-thermograph at two different locations, in the tropical and in the temperate region, in relation to the photoinduction of panicle formation of two rice varieties.

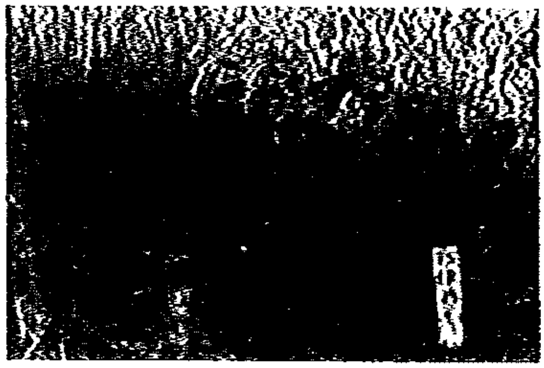


Photo 1-8
Example of the difference in regional adaptability of varieties; these are IR 22 and IR 24, which mature at the same time in the plains in the Philippines. The IR 22 has headed but IR 24 has just flowered.

Table 1-4. Resistance to lower temperatures in some improved indica varieties, Taichung Agric. Impr. St., 1972.)

Variety	% surviving hills after 3 replanting	Variety	% surviving hills after 3 replanting
T (N) 1	100	Jaya	12
T (N) 2	100	Vijaya	0
IR 20	0	Jaganath	3
IR 22	9	Ratna	29
IR 24	57	Padma	55
C 4-63	0	Cauvery	52
BPI 121-407	0	Bala	64
RD 1	0	Krishna	95
RD 3	9	Sabarmati	57
RD 2	0	Jamuna	100

Original number of hills planted : 42 per variety.

temperate areas, great difference can be found in their growth durations. This is considered to be due to the difference of the sensitivity to lower temperatures between the two varieties. In other words, the minimum critical temperature for normal growth and development may differ in the two varieties. Days from seeding to heading of T(N) 1, IR 22, and IR 24 at Konosu shown in Table 1-3 discloses that the heading of IR 22 is much delayed (Photo 1-8).

The difference of the sensitivity to lower temperatures between IR 22 and IR 24 is also shown in Table 1-4. The data denotes percentages of surviving hills of different improved *indica* varieties after several cold waves in February and March, 1972, at Taichung Agricultural Improvement Station, Taiwan. Each variety was planted in a plot of 42 hills (single plant per hill). A cold wave of minimum temperature 7.3° C which set in from the transplanting day (mid February) on, and others (late February, min. 7.8° C; and early March, min. 2.6° C) killed many plants. Missing hills were replanted with spare seedlings as long as there were any remaining. In late March, the percentage of surviving hills was checked. Taichung Native 1, and Taichung Sen 2 came to 100, while all recommended semidwarf varieties from the Philippines and Thailand, except IR 24 and IR 22, were completely killed. Two groups of the reaction were observed in Indian varieties; one over 50% and the other less than 30. All the varieties of the former group were derivatives from crosses including T(N) 1 as a parent, while the latter group varieties were not related to the Taiwan indica, except Jaya. Taichung Native 1 is considered to be a donor with low temperature tolerance, or wider local adaptability to Indian varieties.

1-4. MAINTAINING UNIFORMITY OF VARIETIES, AND SEED MULTIPLICATION

1-4-1. Causes of degradation of varieties

While we continue to grow a particular rice variety year after year, we sometimes find offtype plants with characteristics different from the original ones. The causes are various. When the mixing of offtype plants is so serious that roguing cannot be effective in refining the variety, we call it degradation of the variety. A farmer in Mindanao in the Philippines told the author that he had to renew rice seeds at least once in three years, even in a newly released variety, to keep a good yield level. Generally speaking, degradation of rice varieties in the tropics is so rapid that we must be careful to maintain the original characteristics of a variety.

The most important causes of degradation of varieties in the tropics are mechanical mixing of seeds and natural crossing. Other causes are segregation of characteristics of newly bred varieties, or natural mutation, though this does not occur frequently.

(1) Mechanical mixing of seeds

The greatest cause of degradation of varieties in the tropics is mixing-in of different varieties grown in the same field. In farmers' fields, sometimes three different types of plants are found in a single hill.

Chances of mechanical mixing exist in cultivation practices such as in the seedbeds, transplanting and threshing. Mixing of this type can be prevented to some extent by taking precautions. The most serious chance of mixing, however, is shattering of grains at the maturing stage or at the harvest. These grains remain in the fields and germinate in the next drop season to grow as offtype plants. Unlike *japonica* varieties, most *indica* varieties are easy shattering, and in an extreme case (of IR 8), more than 70% of the grains were blown down to the fields before the harvest by a typhoon.

In addition to their easy shattering, many *indica* varieties are seed-dormant for a long time. Seed dormancy contributes to a higher rate of mixing of so-called volunteer plants, for it prevents early germination of grains dropped in the fields. Mixing of volunteer plants in such a way is quite usual compared to *japonica* varieties, and mechanical mixing of different varieties is almost inevitable, if roguing and other procedures are not observed.

(2) Natural crossing

Rice is a self-pollinating crop, but it is pollinated to some extent by other plants under natural conditions. When this is done by other varieties, it is called natural crossing or outcross. Varieties originating from outcross are not rare. The Philippines varieties, Buenketan and Milketan, are found from natural crosses between nonwaxy varieties Buenavista and Milagrosa, respectively, and a waxy variety, Ketan Koetoek (bulu), introduced from French Indochina (Serrano, 1956). SLO 17, one of the ancestor varieties of IR 24, was selected from an outcross of GEB 24 in India (Ghose et al., 1960).

The rate of outcross of a plant varies depending upon the position in the field -- whether from central or outer marginal parts within a population of a variety. When a waxy variety is fertilized by a non-waxy pollen, the endosperm of the waxy variety changes into non-waxy by a phenomenon called "xenia," and through observation of brown rice grains, the percentage of outcross is calculated on the spot. A survey by the Kyushu Agricultural Experiment Station in Japan disclosed that varietal difference was found in the rate of incidence of xenia (Kyushu Agr. Exp. Sta., 1973; Table 1-5).

Table 1-5. Varietal difference of outcross percentage in two waxy japonica varieties, Kyushu Agr. Expt. St., Japan

Year	Date of heading	No. plants tested	No. grains observed	% non-waxy grains
		Saikai Mochi No. 113		
1969	Sept. 10	10	7,299	0.01
1970	7	11	11,958	0.65
1971	8	12	15,111	0.03
		Saikai Mochi No. 133		
1969	Sept. 8	5	1,359	0.46
1970	6	15	12,518	0.59
1971	7	12	13,299	1.65

Among Indonesian rice varieties, bulu are especially liable to be outcrossed. When different varieties are row-planted side by side, the outcrossing percentage within the bulu variety group was 6 to 13 times that within the tjereh group, and average outcross percentage of bulu x tjereh was 28 times more than that of tjereh x bulu (Kojima et al., 1962).

Rice varieties are in danger of being degraded when they are planted near wild species of rice. Oka (1964) estimated the outcross rate of glutinous varieties to be 44% in northern Thailand on the basis of the percentage of non-glutinous wild rice plants (Oka, 1964). The outcross percentage of Indian semi-wild rice was 10 - 20, intermediate to those of wild rice and cultivated rice. One of the causes of a higher outcross rate of cultivated rice by wild rices is the much longer anther of the wild species. Against 1.8 $\pm$ 0.03mm of IR 8 anthers, *Oryza perennis* subsp. *balunga* had 4.5 $\pm$ 0.06mm, and *O. sativa* f. *spontanea* had 4.1 $\pm$ 0.08mm of anther lengths (Athwal and Virmani, 1972).

When naturally outcrossed hybrid plants are unnoticed and harvested for seeds, many offtype plants of various forms will come out in the next crop. This is a quite important difference from mechanical mixture, and even plants of normal appearance may be hybrid plants. Therefore it is necessary to grow and check the following generation to certify the purity of the original variety.

(3) Segregation and random drift

Rice varieties are not necessarily homogeneous for all traits. In particular, traditional and local varieties of tropical countries, or even new improved varieties, are not highly homogeneous. Of course, there is some merit in stopping further pedigree selection when agronomic characteristics are practically uniform.

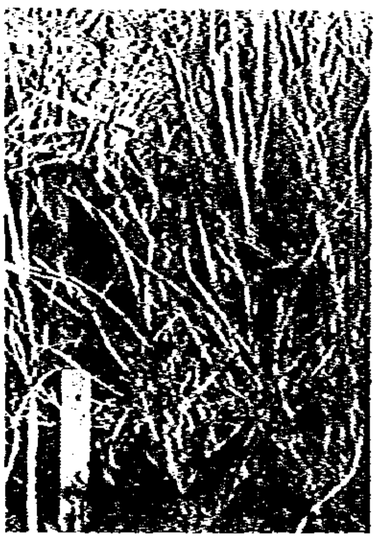


Photo 1-9. Extreme example of intravarietal difference.

When a variety having such genetically heterogeneous but practically (seemingly) uniform status is grown in a quite new environment, previously masked differences of characteristics among individuals may appear. Such cases are often observed when, for example, a variety bred in the plains area of the tropics is brought up to the highlands or to high latitude areas. Photo 1-9 shows intravarietal difference of characteristics of C4-63 (G), which is widely grown in tropical Asian countries. When this variety was introduced to Japan and grown at Konosu, the difference of heading dates between early and late plants was almost one month. Similarly, many *indica* varieties introduced in the same year (1972), such as RD 2, Ratna, Bala, and so on, exhibited intravarietal variance of some traits.

The above-mentioned are examples of notable changes of characteristics. As for polygenes controlling qualitative characteristics, they are in most cases heterogeneous, and during the course of cultivation year after year, they segregate without notice into many different genotypes, and it is probable that a variety has evolved new genotypes within itself. In addition, the effect of "random drift" may cause a more remarkable change in the characteristics of a variety. It is a rather common idea in Japan that a rice variety must have genetically homogeneous and uniform traits, and so all plants are equal for use as seeds. Based on this idea, harvesting of only a few plants for use as seeds for the next crop, might cause unconscious plant selection of some specific types.

(4) Spontaneous mutation

In an extreme example, spontaneous mutation is reported to occur at the very high rate of over 6% (Nagai, 1959). As a cause of degradation of tropical rice varieties, the significance of spontaneous mutation is much smaller than mechanical mixing or outcrossing.

The result of mutation of recessive genes controlling morphological characteristics into dominant genes can easily be found as an offtype. Mutation in the reverse direction can be noticed only in the next generation when recombinants of recessive homogeneous plants appear. But at this time, many heterogeneous plants are already included in the population. Therefore reselection of the original variety is needed following the method of pedigree line selection; e.g., the "ear to row method."

1-4-2. Maintenance of purity, and repurification

For maintaining a desirable level of purity of the varieties concerned, or for finding and roguing offtype plants, and for refining degraded varieties, the following will be checkpoints:

(1) Precautions in farming technology

Besides careful checking of threshing tools, bags, mats, and clothes, it is safer to use separate fields for each variety of seeds.

(2) Finding offtype plants

Plant a single seedling to each hill in fields for registered or certified seeds to effectuate checking and roguing at the stages of (a) heading, (b) maturing, and if possible, (c) early tillering. Characteristics efficient for checking were given in 1-2-2. An easy and rough judgment is possible by just observing uniformity of heading dates and plant height. It is especially easy to find early offtypes at the early stage of heading. Late offtypes are easily discovered at the stage of panicle drooping. These two stages are important for roguing. Remember that plants next to missing hills tend to grow taller and later (or earlier depending on soil fertility).

In India, extermination of wild rice species, *O. sativa fatua* is a great problem, for it causes easier shattering and yield reduction through outcrossing with cultivated rice. It is so hard to identify wild rice and to rogue it completely by the time of heading that preventing degradation of cultivated varieties is difficult. In the States of Bihar, Bombay, Madia Pradesh, Punjab, and others, breeding lines of purple leaf-sheaths or leaf-blades are grown to identify green leaved wild rice plants more easily and to rogue them from the earlier growth stages (Ghose et al., 1960).

(3) Precautions at harvest

After finishing roguing, attention must be paid to the possibility of outcross. Plants on the borders of the seed increase fields should not be harvested for seeds. For seed increase in a small plot, short three-row planting is more desirable than long single-row or two-row planting. When different varieties must be grown in small plots for seeds, alternate planting of early and late varieties would reduce the chance of outcross between the two neighboring varieties, and offsprings of the outcross can easily be found in the next season.

For selecting panicles of primary tiller, secondary or tertiary tillers, it is useful to refer to the heading dates of adjacent rows (plots). Considering the effect of random drift, harvesting 30 panicles from two hills is obviously less desirable than harvesting two panicles each from 15 hills, or one panicle each from 30 hills.

(4) Reselection and renewal of seeds

When offtype plants are found in fields for "foundation seed" or "registered seed" production, or when some sign of degradation of the variety is seen, several to some scores of plants are harvested by the hill (when a single seedling is planted to a hill) or by the panicle (when several seedlings are planted), and these are grown as pedigree lines of at least 20 to 30 plants each. When segregation is observed within a line, you may conclude that outcross had happened in the variety. Select those lines with no segregation and with the variety's own characteristics. Several plants of the selected lines are again used in the next season for certifying the purity of the lines.

For preventing degradation of varieties, yearly cultivation of "breeders seed" or "foundation seed" should avoided. The breeding institution sends the original seed of the variety as a "genetic stock" to the central institution for seed-stocks preservation, and also keeps the long term seed-stocks under dry and cool conditions for using to reproduce "foundation seed" and "registered seed" when necessary.

1-4-3 Seed multiplication

The rice seeds planted by farmers are produced through the series: "breeders seed" by breeding institutions, "foundation seed" multiplied from breeders seed (Photo 1-10), and then "registered seed," and finally "certified seed." The last is given to the farmers (Fig. 1-6).

International minimum standards for each of the three classes of rice seeds are proposed as shown in Table 1-6. Different kinds of regulations and rules are enacted for production, cleaning, and marketing of the seeds. Seed growers must have official seed certifying agencies perform field inspections or sample examination of seeds.

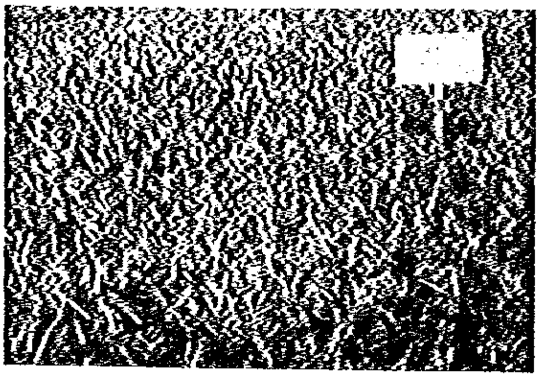


Photo 1-10
Cultivation example of intravarietal difference.

Photo 1-11
Tough stalk and panicle of Peta.

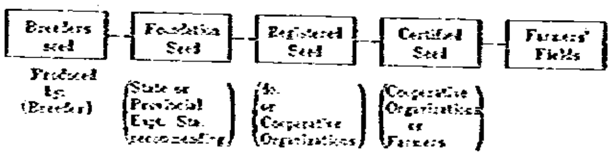


Fig. 1-6. System of seed multiplication

Table 1-6. International rice seed standards (minimum).

Factors	Foundation	Registered	Certified
Pure seed (minimum)	98%	98%	98%
Red rice (minimum)	0	1 per 5 kg	1 per 2.5 kg
Other varieties (max.)	0	0	2 per 0.5 kg
Innert matter (max.)	2.0%	2.0%	2.0%
Total weed seeds (max.)	0.05%	0.05%	0.1%
Total objectionable weed seeds	0	0	0
Germination rates (min.)	80%	80%	80%
Moisture content (max.)	14%	14%	14%

1-5. IMPROVED RICE VARIETIES IN TROPICAL ASIA

Rice varieties being grown in tropical Asian countries can be grouped into three according to their genealogical relationship. The first group is the semidwarf (improved) type and the derivatives from Dee-geo-woo-gen, IR 8 or Taichung (Native) 1. All these varieties are semidwarf to moderately short in height, non-sensitive or weakly sensitive to the photoperiods, diverse in grain shape and quality, and resistant to diseases and insect pests or lodging.

In contrast to this, the third group of varieties are traditional local varieties or pure lines from them. Their characteristics are quite diversified: from strongly sensitive to non-sensitive to photoperiods, with grain appearance and eating quality suited to local people (from very short to very long grains, and sticky to hard cooked rice). Some of them are tolerant to different kinds of problems in the environment. They are generally tall and leafy, lodging susceptible and low yielding.

The second group of varieties is intermediate in their characteristics and adapted to those areas where the first group of varieties is not suited. For example, semidwarf varieties are too short and unable to develop full yield where soil fertility is very low; and they are too early and too short to avoid yearly flood damage at maturity in deep water areas. Under such conditions, second group varieties are much more adaptable than the first group ones, with greater improvements in yield and better fertilizer response than the third group.*

In general, descriptions of the characteristics of the third group varieties are not available in publications internationally accessible. However, many of the varieties are described and can be referred to in the catalogs of IRRI, ICAR, and others. Therefore, the first and second group varieties are described. Most of this information is not recorded in the catalogs.

1-5-1. Varieties of Dee-geo-woo-gen derivatives

(1) IRRI varieties

<u>IR 8</u> (Dee-geo-woo-gen/Peta, released in 1966)

Dee-geo-woo-gen is a little taller but with stiffer straws at maturity than T(N)1. IR 8 combines of semidwarf and stiff straw genes of D.g.w.g. and the rather tough stalk of Peta (Photo 1-11), can endure nitrogen application of 150 kg/ha in highly fertile soil, and is high yielding. On the other hand, the variety needs large inputs of fertilizers and pesticides, is inferior in grain appearance and eating quality, and is unpopular in the markets. Thus it was destined, in most countries, to be replaced by more improved varieties. However, IR 8 played an important role as a "miracle rice," widely grown in many countries to motivate new technology of rice

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*Fertilizer shortage since 1972 and our reperception of the relative significance of fields out of control in irrigation water, such as upland, rainfed or deep flooded fields, have increased the importance of second group varieties.

cultivation for high yields, and also as one of the most used parent varities to produce many new semidwarf varieties.

IR 20 (Peta^3/T(N)1//TKM 6, released in 1969)

Release of IR 8 and IR 5 (cf. p. 32)contributed much in elevating yield level, but problems remained especially in grain appearance and eating quality. Filipino farmers earnestly desired the release of new, good quality varieties. The breeding line IR532-E576 was then released and was named as IR 20. In Bangladesh, it is called "Irrisail."

IR 20 is similar to IR 8 in maturity, plant height, and yield, but has slender and translucent fine grains. As its grain appearance is comparable to that of Wag-wag, a famous local fine grain variety of the Philippines, IR 20 is nicknamed "IRRI-Wagwag" or "New wagwag." Its resistance to disease is much better than that of IR 8 and IR 5, and it also inherits the stem-borer resistance of TKM 6 (Photo 1-12).

Due to its weak sensitivity to photoperiods, IR 20 flowers about 10 days earlier than IR 8 in the dry season (of shorter daylength), and almost at the same time as IR 8 in the wet season (of longer daylength). Culm length also varies by the season; it is almost the same height as IR 8 and lodging is slight in the dry season, and about 10 - 15cm taller than IR 8 in the wet season, tending to break at the culm base.

Irrisail is grown as a transplanted aman variety in shallow-water fields; its resistance to tungro virus and bacterial blight is satisfactory; and it has medium long fine grains and much higher yields (ca. 70%) than Latisail. Irrisail is popular in Bangladesh (Zaman et al., 1972).

Chandina, a boro and aus variety in Bangladesh, released in 1970, was originally IR532-1-176, a sister line of IR 20. As boro rice, it matures almost at the same time as Habiganj Boro VI, but is 80% higher in yield. As aus, it matures about a week later than Dular, but yields 65% more, with better grains than IR 8 or Purbachi (a variety introduced from China)(Zaman et al., 1972).

Photo 1-12

Photo 1-13
Plant types of IR 20 (left) and IR 22 (right) in dry season demonstration at IRRI.

IR 22 (IR 8/Tadukan, released in 1969)

When IR 22 was released together with IR 20, it was considered superior because of its much better lodging resistance with equal disease resistance. In grain appearance and quality it is similar to IR 20. Seasonal variation in culm height and stiffness is far less than IR 20, and much safer against lodging.

Information from farmers fields, however, showed later that IR 22 does not possess the wide spectrum blast resistance of Tadukan, and is susceptible to green leafhoppers and tungro disease. Therefore, IR 22 was not as popular among Filipino farmers as IR 20. In Nepal, where green leafhoppers and virus diseases are not serious problems, IR 22 is preferred. Photo 1-13 shows plant types of the two varieties at IRRI field in the dry season. A sister line of IR 22, IR579-48-1, is called Nilo 11 in El Salvador, and Palman 579 in India.

IR 24 (IR 8/IR 127-2-2, released in 1971)

Following the improvements of yield, resistance to diseases and pests, and grain quality in semidwarf *indica* rice varieties, the next request by the Filipinos was improvement of eating quality. All the IRRI varieties released up to then were of high amylose content, and cooked dry and fluffy, unlike the soft and moist rice of C4-63 or Intan that are preferred by the Filipinos.

IR 24 (former pedigree line No. IR 661-1-140-3-2) is a little earlier, slightly shorter than IR 8, and the yield is equal to, or greater than, that of IR 8 (Photo 1-14). Grain shape and appearance is medium long and slender like IR 20 and IR 22, having low amylose content. It cooks soft as the Filipinos prefer.

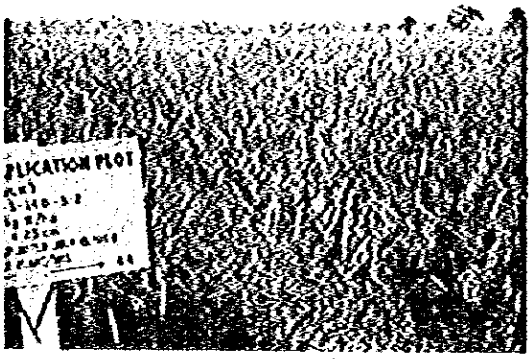
Owing to its cooking quality, IR 24 is not as widely grown as IR 20 or IR 22 in other countries. Resistance to low temperatures is, however, remarkable, and seems to adapt it to the high altitudes of the tropics or to the temperate regions. It is resistant to green leafhopper, but resistance to blast or bacterial blight is not sufficient. The male parent of IR 24, IR 127-2-2, is a cross between a line of Century Patna/SLO 17 made in Texas, U.S.A., and Sigadis of Indonesia.

(2) RD varieties of Thailand

RD stands for Rice Department. Until recent years, rice in Thailand had long been bred through pure line selection; RD 1 is the first commercial variety bred by hybridization.

RD 1 and RD 3 (Jackson et al., 1969; Leuang Tawng/IR 8, released in 1969)

The female parent variety, Leuang Tawng is the only recommended variety grown in the dry season (January to May) in the Central Plains of Thailand. It is weakly photoperiod sensitive, but leafy; it tends to lodge, and is susceptible to blast and yellow orange leaf virus. Hybridization was performed in 1966 at the Bangken Rice Experiment Station for the breeding of photoperiod nonsensitive, fertilizer responsive, high yield, disease resistant and good quality rice varieties.



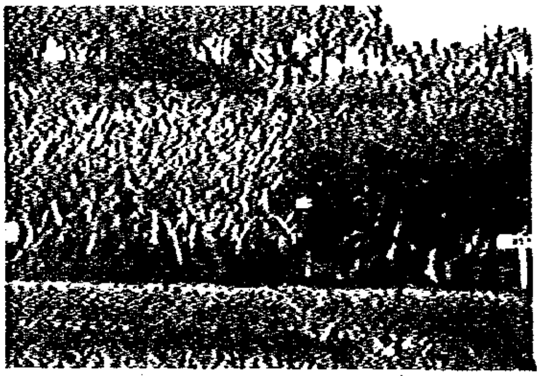


Photo 1-14. Plant type of IR 24 IR 24, at IRRI.

Photo 1-15. TN 1 (left) and RD 1 (right at an IRRI demonstration paddy.

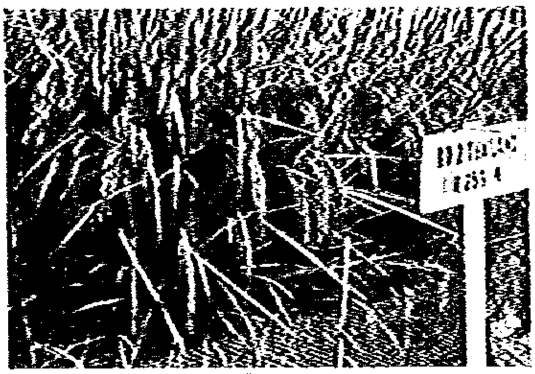


Photo 1-16. Plant form of the first improved indica variety, RD 2, at IRRI.

Odd numbers of RD are given to non-glutinous, and even numbers to waxy varieties. Both RD 1 and RD 3 are photoperiod nonsensitive and the growth duration is almost constant in both the dry and the wet seasons. RD 1 is about five to 10cm shorter than IR 5, and RD 3 is similar to IR 8 in height. Both have remarkably erect flag leaves, but panicles are not fully exserted. Besides the difference in plant height, RD 3 is also differentiated from RD 1 by its long flag leaves and brown hulls (Photo 1-15).

Both are resistant to yellow orange leaf virus and green leafhoppers, but susceptible to blast and bacterial blight. RD 1 also tends to show yellowing of leaves. Both, especially RD 3, are much shorter and much earlier than traditional varieties due to their photoperiod non-sensitivity, thus frequently incurring flood damage at harvesting time. Therefore, conditioning the present cultivating technology, the probable dissemination area of these two varieties is limited to places where irrigation water control is possible. RD 5 (cf. p. 32) was released in 1973 to fill the gap between RD 1 and 3 and traditional tall varieties.

<u>RD 2</u> (Gam Pai 15^2/T(N) 1, released in 1969)

Released together with RD 1 and 3, this is a waxy variety. The female parent variety, Gam Pai 15, is a waxy variety recommended in Northern Thailand, tall culmed and easy lodging; large grained and high yielding;

photoperiod sensitive and very late (Photo 1-16).

Hybridization was performed at IRRI, and F_4 seeds of IR 253 were sent to Thailand. Pedigree line selection has continued there since 1965. RD 2 is photoperiod non-sensitive and semidwarf, with long panicles of yellow hulls and colorless apiculus. Like Gam Pai 15, grains are medium long and bold, which makes it possible to tell it from RD 1. Disease resistance, especially to bacterial blight, is a weak point (Jackson et al., 1969).

RD 4 (BKN 17-1/EK1252//RD 2, released in 1973)

BKN 17-1 is a sister line of RD 1 and RD 3, and EK1252 is an Indian experimental line resistant to rice gall midge and other pests.

RD 4 is a waxy variety, resistant to rice gall midge as well as to green leafhopper and brown planthopper; about one week later and some 10cm taller than RD 2, and photoperiod non-sensitive. Its yield is almost equal to that of RD 2 where no gall midges infest the field, and as much as 50% more than that of RD 2 in fields with heavy gall midge infestation. Slender grains a little longer than RD 2, brown hulls, and purple culm bases make this variety easy to identify (Hamamura and Awakul, n.d.; Rice Division, Department of Agriculture, Ministry of Agriculture, Thailand, 1973).

(3) Indian varieties (Rao, 1973; Shastry et al., 1971).

Padma (T.141/T(N) 1, released in 1968)

Jaya (T(N) 1/T.141, released in 1968)

T. 141 is a tall, fine-grain variety selected from a local variety, Soruchinnamali.

Padma, bred by CRRI (Central Rice Research Institute), is similar to T(N) 1 in plant type, yielding fewer but better quality grains than T(N) 1. Padma is early maturing, but in 1970, several better quality varieties of the same maturity were released, such as Kanchi, Ratna, and Krishna. As bacterial blight resistance is not improved from T(N) 1, it is not safe to cultivate this variety in kharif season.

Jaya, bred by AICRIP (All-India Co-ordinated Rice Improvement Project), is quite similar to IR 8 in plant type but earlier by about one week in the tropics. Grain shape and appearance are also similar to those of IR 8, but cooking quality is claimed to be better than that of IR 8 in India. Bacterial blight resistance is better than that of T(N) 1. Being also resistant to green leafhoppers and tungro, Jaya can be called a coarse grain variety with wide adaptability.

Bala (T(N) 1/N.22, released in 1970)

The male parent variety, N.22 is an upland rice in Uttar Pradesh; early maturing and with white, medium grains.

Bala, bred by CRRI, is the earliest among Indian semidwarf improved rice varieties and is highly resistant to drought, and thus adapted to rainfed fields and to upland cultivation. Being low tillering, it is suited to direct seeding culture. For transplanting, closer spacing is needed. It is a coarse grain variety with inferior yield and quality compared to Cauvery (of the same maturity) under lowland conditions, but in uplands yields more than traditional varieties. Even in fields of severe drought, two tons per hectare can be expected.

The purple apiculus color inherited from N. 22 could be a marker characteristic of this variety.

Cauvery (T(N) 1/TKM 6, released in 1970)

Bred by AICRIP, and a fine grain and good quality variety of the same maturity as Bala. It is short-culmed and high tillering, lacking good responsiveness to nitrogenous fertilizers due to lodging susceptibility inherited from TKM 6. Having no resistance to diseases and insects, Cauvery is not adapted to fertile fields.

Sabarmati and Jamuna (T(N) 1/Basmati 370^5, released in 1970)

Bred by IARI. Basmati 370 is a scented rice variety with long and fine grains, grown in India, Pakistan and Nepal. It is tall and easy to lodge, thus it is hard to obtain high yields. Breeding of short-culmed and lodging resistant, high yielding Basmati was also tried by IRRI in cooperation with Pakistani breeders through backcrossing Basmati 370 with Taichung Native 1 (lines of IR 288, or IR 424).

Sabarmati is a success in combining a semidwarf plant type and good grain quality and aroma. At Konosu, Japan, its aroma could be detected at the tillering and flowering stages, and in brown rice.

Jamuna is similar to Sabarmati in maturity, plant type and grain shape, but has longer panicles and no aroma in rice. It is higher tillering and better in low temperature tolerance than Sabarmati (best among Indian short improved varieties, cf. Table 1-4). Both yield less than Taichung (N) 1 and IR 8.

Kanchi (T(N) 1/CO.29, released in 1970)

Bred in Coimbator. A coarse grain variety of the same maturity as Padma or Krishna, and a good yielder, lacking resistance to bacterial blight, green leafhopper, and tungro.

Krishna (GEA 24/T(N) 1, released in 1970)

Bred by CRRI: the former line No. is CR 1-6. The same maturity as Kanchi and about 15 days later than Bala; 10 days earlier than Jaya. Fine grains of a shape similar to Cauvery; very high tillering; lacks disease resistance.

Ratna (TKM 6/IR 8, released in 1970)

Bred by CRRI. TKM 6 is a slender grain variety with a wide range of resistance to diseases and insect pests, and also one parent of IR 20. Ratna is as early as Padma, and has fine grains of the TKM 6 type. Adapted to the rotation system of rice-wheat, it is good for the kharif season in Uttar Pradesh, Punjab, Hariana, and others. Moderately resistant to stemborers and blast.

Vijaya (T.90/IR 8, released in 1970)

Bred by CRRI. A fine grain variety which comes to maturity later than IR 8 by four to five days; yielding as much as IR 8, and fairly resistant to bacterial blight, resistant to green leafhoppers and tungro. Therefore, it seems to be adapted to all the states of India, especially to the northeastern states where tungro is rampant. Low temperature tolerance is insufficient, and it would be grown with some danger in the rabi season.

(4) Varieties of Malaysia and Sri Lanka

Murni (Bahagia/Ria, released in 1972)

Hybridized and selected by the Bukit Merah Padi Experiment Station of West Malaysia. The female parent Bahagia is most widely grown as a double cropping variety with good quality and high yield, but is somewhat too leafy and too late. The erect plant habit, fertilizer responsiveness and shorter growth duration of Ria (IR 8) were intended to be incorporated in Bahagia.

Murni is intermediate between the two parents in plant height; is five to ten days earlier than Bahagia, and of good grain quality with long slender grains with light brown hulls; moderately resistant to blast (West Malaysia, MARDI and Division of Agric., 1972).

Masria (IR 8/Muey Nahng 62M, released in 1972)

The male parent is a photoperiod sensitive waxy rice recommended in Northern Thailand. All Malaysian waxy varieties had been too late with the same maturity (about 160 days) as Muey Nahng 62M to be adopted for the double cropping culture. To breed a short duration waxy variety, the Bumbong Lima Rice Research Station of West Malaysia introduced IR 789 from IRRI in 1969, and selected Masria. This is a weakly photoperiod sensitive waxy variety with short culms, erect leaves, and awnless medium short grains which can easily be shattered. Masria is moderately resistant to double cropping (West Malaysia, MARDI and Division of Agric., 1972).

BG34-6, BG34-8, and BG34-11 (Released in 1971)

These three varieties were selected from the cross, IR 8//Pachchaiperumal/Mas///H 501, in Ceylon. Before BG34-6 was released, IR262-43-8 had been adopted to replace H 7, a leading variety of the 3½ months duration variety group. As IR262 was too dwarf, BG34-6, which was about 20cm taller and had an almost equal yield, was then released to supplement IR262.

Pachchaiperumal had been the principal variety of three-month duration for the past 30 years in Ceylon. It is high yielding but is susceptible to lodging and blast. BG34-8 and BG34-11 are replacements for this local variety.

LD 66 (H 501/Dee-geo-woo-gen, released in 1971)

H 501 is a blast resistant, 4-months variety selected from the cross, G.E.B.24/Vellai Illankalayan, and had been recommended in the southwestern region of the island. LD 66 is resistant to bronzing disease, and adapts to problem soil areas of the wet zone (Weeraratne, 1970).

1-5-2. Other improved varieties

IR 5 (Peta/Tangkai Rotan, released in 1968)

The release of IR 8 effected a sharp yield increase which none of the traditional varieties could attain. However, it needed plenty of irrigation water, fertilizers and chemical pesticides to produce the best yield. IRRI then released IR 5 for farmers who are not favored with controlled irrigation water and are afflicted with diseases and insect pests. IR 5 is intermediate in plant height between IR 8 and the old local varieties. The same variety is called Peta Baru 5 in Indonesia. Bahagia of Malaysia and Pankaj of India (released in 1969) are sister varieties from the same cross.

IR 5 is five to 10 days later, about 30cm taller, and more resistant to blast, than IR 8, but little improvement was attained in grain quality. It has medium long grains but is of the bold type and has chalky kernels. Bahagia is better in quality. Pankaj has similar characteristics but is characterized by the latest maturity among Indian improved varieties, and is grown in the kharif season in regions where early varieties are not suitable due to troubles in maturing and harvesting.

C4-63 (Peta/BPI 76, released in 1968)

Bred by UPCA (University of the Philippines, College of Agriculture). The male parent BPI 76 is a variety of the Philippine Bureau of Plant Industry.

Plant height and maturity of C4-63 are similar to IR 5, but it is better in lodging resistance. It is non-sensitive to photoperiods, and resistant to green leafhopper and tungro. When released, the variety was still segregating in pigmentation of leaf sheath and apiculus. The present C4-63, which is sometimes called C4-63(G), has a green sheath and no apiculus color.

C4-63 has medium long and slender grains with a small white belly, coupled with intermediate amylose content. Its cooking quality is popular among Filipinos. It is also grown in a wide area from Indonesia to Burma.

RD 5 (Puang Nahk 16/Sigadis, released in 1973)

Being taller by 30cm and later by 20 days than RD 1, RD 5 approaches local rice varieties in plant height (almost equal to Nahn Mon S-4). RD 5, however, has erect leaves and is weakly sensitive to photoperiods. Its growth duration reaches 160 days in the dry season, affecting the planting of the main season crop. So RD 5 is primarily recommended for the main season. Non-chalky grains are similar in shape to those of RD 1. RD 5 yield is equal to, or greater than, that of RD 1. It also inherits the disease resistance of the male parent, Sigadis, against blast, yellow orange leaf virus, and bacterial blight. Owing to these improvements in plant height, growth duration, and disease resistance, RD 5 can cover almost 50% of the Central Plain of Thailand where RD 1 cannot be grown due to deep water. Culm bases and apiculus are purplish (Hamamura and Awakul, n.d.; Rice Division, Department of Agriculture, Ministry of Agriculture, Thailand, 1973).

Mahsuri (Taichung 65/Mayang Ebos, released in 1965)

This variety was born as an outcome of the International Rice Hybridization Program of FAO, and is perhaps the greatest success from the standpoint of growing area of varieties bred by the Program. Hybridized in India, and selected with the cooperation of Malaysian and Japanese plant breeders, the variety is now grown in Malaysia, as well as in India, Nepal and elsewhere. With such an international background, Mahsuri is adapted to the double cropping culture of Malaysia; is nearly non-sensitive to photoperiod, intermediate in height (15cm taller than Bahagia), with erect and narrow leaves and plant type similar to japonica varieties. Hull color changes to brown several days after heading. Grains are somewhat short but slender and translucent. Cooked rice is soft and moist. Its drawbacks are susceptibility to blast and small grain size (Chew, 1972; Samoto, 1970).

Pelita I/1, Pelita I/2 (IR 5/Syntha, released in 1971)

Bred in Indonesia. The male parent Syntha is a traditional plant type variety, selected from the cross, Bengawan^4/Sigadis, and released in 1963.

Both varieties are a little (two to three days) later than IR 5. Pelita I/1 is almost the same height as IR 5, and Pelita I/2 is about 15cm taller than IR 5. Due to their lower amylose content, both are better in table quality than IR 5. Resistance to bacterial blight and sheath blight were not improved beyond IR 5 (Harahap et al., 1972).

BG 11-11 (Engkatek/H 8, released in 1971)

An improved variety of medium plant height bred in Sri Lanka to replace H 4. According to experimental results obtained from 450 locations throughout the island, BG 11-11 yields less in direct seeding but a little better in transplanting than IR 8. Its yielding ability is much better than that of IR 8 at a lower level of nitrogen fertilizers (80 kg/ha). Kernels are so small as to be only two-thirds as large as those of IR 8.

The female parent, Engkatek, is a local variety of Salawak, with strong culms, strong photoperiod sensitivity, and extensive local adaptability (Weeraratne, 1970).

Mala (Century Patna 231/SLO 17)^2/Sigadis, released in 1971)

The former pedigree line number was IR272-4-1; selected from IRRI lines in Bangladesh for the aus and boro season crops. Mala is a non-seasonal variety which can be seeded anytime from November to May, but performs best when seeded between mid-November and mid-December, maturing in

150 days and harvesting seven tons/ha. When seeded in mid-April like the aus crop, it matures in 117 days and yields 6.2 tons/ha.

As plants are taller than IR 8 by more than 30cm, and almost as tall as C4-63, Mala lodges in fertile lands, though it is resistant to tungro and bacterial blight. It has medium fine grains and good quality.

1-6. LITERATURE CITED

CHAPTER TWO

PHYSIOLOGY OF TROPICAL RICE PLANTS

Akio Osada

2-1. PHOTOSENSITIVITY AND GROWTH DURATION CHARACTERISTICS BY VARIETY

2-1-1. Photosensitivity by Variety

There are many non-photosensitive varieties of rice in tropical Asia, but most rice plants widely grown there are photosensitive, in spite of the relatively little change in day length compared to the conditions in higher latitude zones. At different places in the tropics, many varieties which differ in photosensitivity have been developed over a period of many years, adapting to variations in the environmental conditions such as latitude (day length), water supply or temperature.

A typical instance can be seen in India where there are three rice crops, namely Aus, Aman and Boro (Fig. 2-1). Usually, temperature does not limit the growth of rice in the main rice cultivating areas in India, while rainfall limits it to a great extent, as most paddy fields are rainfed. Most rice is sowed when the monsoon rains begin.

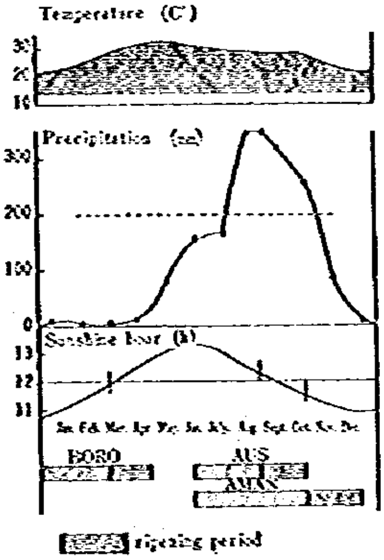


Fig. 2-1. Climatic conditions and rice growing season at Cuttack (Tanaka, 1958)
The shaded portion in the uppermost figure denotes temperature above 13°C, minimum for rice growth.

Both Aus and Aman crops are grown in the rainy season, but their photosensitivities are different. Aus varieties are non- or less-photosensitive and differentiate panicles under relatively long-day conditions, because they are often planted on the relatively higher land where the level of irrigation water goes down soon after the end of the rainy season and they must be harvested by that time, that is, in October or early November. Aman varieties are photosensitive. They are usually planted in lower land where water is stagnant even after the rainy season is over and harvested in December. Their panicles are formed under shorter-day conditions than those of the Aus crop. The area planted to Boro is very small, and this crop is cultivated in the dry season, starting in January, with the aid of artificial irrigation and the varieties used are, of course, non-photosensitive.

2-1-2. Growth Duration by Variety

(1) Variation in Growth Duration

There are considerable variations in the growth duration of indica varieties. For example, among the varieties grown in India, growth duration - the days from sowing to maturity - ranges from less than 3 to 7 or 8 months (Fig. 2-2).

Of course, growth duration of photosensitive varieties changes according to the sowing season. Fig. 2-3 shows the heading time of a Cambodian variety, Neang Meas, sown at half-month intervals throughout the year, from August to the following July (Sato, 1960). When sown between August and October, heading took place in December or January, despite the longer interval after sowing, because it is a "season-bound or seasonal variety". The later the sowing time, the shorter the period from sowing to heading. However, the interval to heading of plants sown in November and December was prolonged with delay in sowing time. Moreover, plants sown in January and later in the second year, flowered in late November or early December, and the time that plants sown early in January required to head was as long as 328 days.

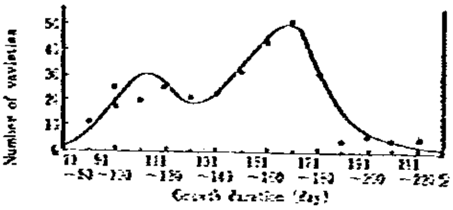


Fig. 2-2. Distribution of indica varieties according to the growth duration (the days from sowing to harvesting). 395 varieties were used. (Tanaka, 1958)

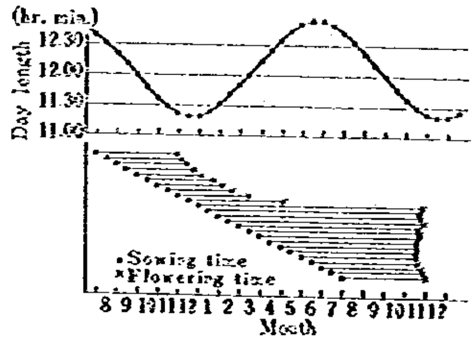


Fig. 2-3. Influence of day length on the flowering time of rice plant (Sato, 1960)
Variety : Neang Méas, at Battambang, Cambodia.

Most new varieties including IR 8, which have been developed in recent years, are non- or less-photosensitive, as can be seen in Fig. 2-4. This figure shows days from sowing to harvesting of four new varieties planted in Bangkok at one-month intervals throughout the year. IR 8, RD 1, which is recommended in Thailand, and its sister line, BKN 17-3, seem to be almost non-photosensitive. C4-63, which came from the Philippines, showed a slight photosensitivity, but the difference between maximum and minimum growth duration was only 2 weeks.

(2) Growth Duration and Yield

Although yield of rice is limited by various factors, it is possible that growth duration has an important influence upon grain production of in some varieties of *indica* rice. In the yield trial with a number of varieties conducted at IRRI, an interesting correlation was observed

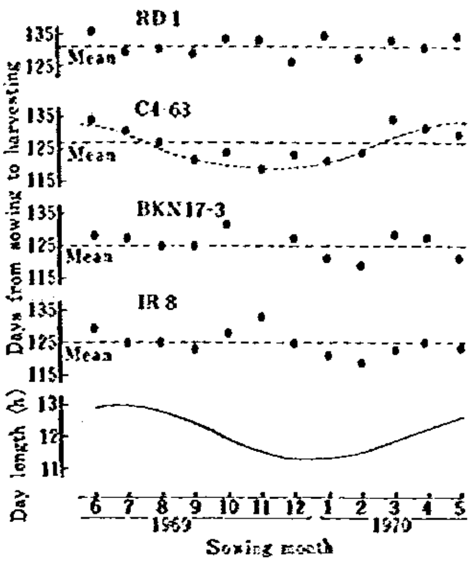


Fig. 2-4. Relation between sowing time and growth duration (Osada et al., 1973)
Each variety was sown at the beginning of every month at Bangkok.

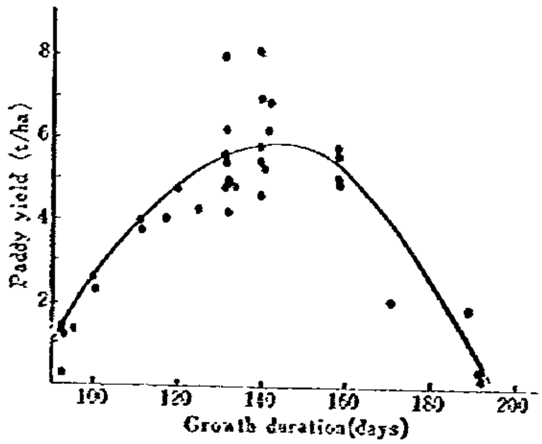


Fig. 2-5. Growth duration and paddy yield for 40 varieties. (Tanaka, 1971)

between growth duration and yield (Fig. 2-5). High yields were obtained mainly from varieties whose growth durations are about 130 to 150 days and the yields of those with longer or shorter durations than that tended to be low. The longer the growth duration, the greater the total dry matter production, but the panicle/straw ratio decreased. As a result, the curve had an optimum.

Most varieties grown widely in the tropics at present grow for 5 or 6 months or even longer. Generally, most of the carbohydrates accumulated in the grain derive from photosynthetic products produced after flowering or at the ripening stage and the rest from those accumulated in the straw before flowering. Therefore, in order to obtain a high yield it is necessary to maintain various physiological functions active as far as possible in the latter half of the growth cycle, especially after flowering. On the other hand, those functions tend to be highest at the early growing stage and decline gradually with the advance in the plant growth towards maturity. Consequently, at the heading and ripening stages physiological functions such as photosynthetic activity of leaves and root ability are lower in long-duration than in short-duration varieties.

Such a relationship was shown by changing the growth duration of photosensitive varieties in Thailand (Table 2-1). Four photosensitive varieties were sown at two different times at 40-days intervals; one was sown in July as the ordinary planting and the other in August as the late one. Because these varieties are season-bound, as mentioned before, difference in heading time between the two plantings was slight. Therefore, the time from sowing to heading of the late planting was much shorter than with the ordinary planting. On the other hand, duration from sowing

Table 2-1. Relations between the days from sowing to flowering and the rate of decrease in photosynthetic activity at flowering time. (Osada・Nara, 1970)

Variety	Ordinary planting		Late planting	
	Days from sowing to flowering	Rate of decrease* of photosynthtic activity	Days from sowing to flowering	Rate of decrease* of photosythetic activity
Muey Nawn 62 M	117	92	86	96
Khao Pakk Maw 113	124	90	86	95
Gam Pai 15	127	73	92	93
Nahng Prayah 70	153	55	126	61

* Percentage of the rate of photosythsis per unit leaf area at flowering time to the same rate at active tillering stage. Active tillering stage corresponds to 77 days after sowing in both plantings.

to active tillering did not vary remarkably with the planting time. Photosynthetic activity of leaves was measured at the active tillering (77 days after sowing in both plantings) and heading stages. In all varieties, the decreasing rates between the activity at the latter stage and that at the former were smaller in the late planting than in the ordinary one.

In general, the time from sowing to the maximum tillering stage is not much influenced by growth duration. Moreover, the period between panicle formation and heading, and length of ripening are almost constant irrespective of variety. Accordingly, the difference in growth duration is mainly due to the difference in the period between maximum tillering and panicle formation. If the growth duration in short, the interval of these two stages is also short; sometimes panicles are formed even prior to the maximum tillering stage. However, most tropical rice requires one month or more after the maximum tillering stage to form panicle primordias. This long interval is called the "vegetative lag phase" which is thought to be one of the causes of lowered productivity. Since internode elogation continues even during this phase, plants form many elogated internodes and become susceptible to lodging. Increase of non-productive tillers or acceleration of mutual shading due to the increase of leaves also seems to be unfavorable for grain production.

On the contrary, if growth duration is less than 100 days, the vegetative growth period is too short to produce enough tillers or to expand leaves luxuriantly. This results in low yield.

The above-mentioned relationship between growth duration and yield was observed among varieties with differing growth durations. However, this can be seen in the same variety also when its growth duration is changed by changing planting time. In Thailand, Takahashi et al. (1967) studied the effect of planting time on yield with a number of photosensitive varieties transplanted in every month from July (ordinary transplanting month) to November. Total growth days and plant height were lower in the order of the transplanting month. Highest yield was obtained from August or September plantings in all varieties.

2-1-3. Irregular Flowering of New Non-photosensitive Varieties

Though this subject may not be adequately covered in this chapter, it should be mentioned that some of the new non-photosensitive varieties tend to form irregular or premature panicles only a few weeks after transplanting when seedlings have remained in the nursery for too long more than about 50 days. According to an experiment made by Osada et al. (1970) at Bangkok using four new non-photosensitive varieties, when seedlings were kept for 60 days in the nursery bed, many plants produced irregular panicles soon after transplanting, but plants from 30-day old seedlings did not (Table 2-2). The rate of occurrence varied with variety; the percentage of plants which formed abnormal panicles was high in the descending order, C4-63, IR 8, LT 17-3 and RD 1. Panicles of these varieties usually exsert after plants expand 18 to 20 leaves on the main stem, whereas irregular ones are formed next to the 12th or 13th leaf, their primordias being differentiated in the nursery. They are very small and almost non-productive and form only on the main stem; panicles on tillers seem almost normal. Photosensitive varieties did not show such an abnormality.

Table 2-2. Irregular flowering of the non-photosensitive new varieties induced by the long nursery period (Osada et al, 1970)

Variety	Percent of plants with irregular panicles
RD 1	45
C 4—63	90
BKN17—3	69
IR 8	81

Rice seedlings raised for 60 days in nursery were transplanted. Emergence of irregular panicles was counted for 30 plants of each variety in the field.

In the tropics where most paddy fields are rain-fed, the nursery period has often to be prolonged because of delay in field preparation for transplanting owing to the lack of water. In addition, in conventional rice cultivation, farmers often plant many seedlings per hill: five, six or even more. Consequently, when very old seedlings are transplanted, abnormal panicles within a hill may increase with increases in the number of seedlings per hill, as these panicles are formed only on the main stem. This must have an unfavorable influence on yield. Indeed, it was found experimentally that the number of seedlings should be reduced to two or three, when old seedlings are used.

2-2. FERTILIZER RESPONSE, DRY MATTER PRODUCTION AND PHOTOSYNTHESIS

2-2-1. Fertilizer Response

Rice yields in the tropics except Taiwan are much lower than those in the temperate regions, for example, in Japan or Korea, where high grain yields are attained by applying large quantities of fertilizers and by using varieties suitable for heavy fertilizing which have been selected for many years. In the tropics, rice crops receive little or no fertilizer. Varieties widely grown there produce reasonable, although not high, yields without the addition of fertilizer, but it is difficult to obtain high yields at high fertilizer levels.

When a large amount of fertilizer is applied to rice plants, the increase in grain yield is not necessarily proportionate to the amount, the response being different from variety to variety. This is known as the "fertilizer response". High response varieties can increase yield with an increased supply of fertilizer, whereas yield does not increase and sometimes decreases in low-response ones. In general, *japonica* varieties have a higher fertilizer response than *indicas* do, although there are varietal differences in the response among each group. In Fig. 2-6, a *japonica* variety, Tainan-3, shows higher fertilizer response than an *indica* variety, Peta, in the wet season crop. However, even Peta responds to fertilizer positively in the dry season for the reason mentioned later.

Generally, varietal difference in fertilizer response seems to be determined mainly by three factors, resistance to diseases and insects, resistance to lodging, and physiological or morphological characteristics at high fertilizer levels. Low response of *indicas* seems to be especially attributable to their morphological traits.

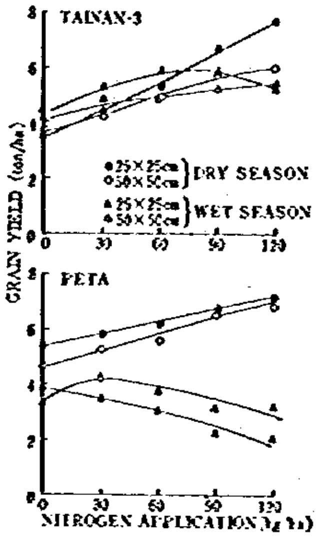


Fig. 2-6. Grain yield of Tainan-3 and Peta at two spacings and five nitrogen levels, at IRRI, in 1962 ~63 dry and 1963 wet seasons. (Tanaka et al., 1964)

2-2-2. Characteristics in Plant Type of *Indica*

First, most *indica* varieties are taller than *japonicas* and hence susceptible to lodging. For example, the statures of recommended varieties, other than floating rice in Thailand, range from 120cm to more than 180cm, the average being some 150cm, while *japonica* varieties are, in general, less than 120cm. Second, generally, the leaf blade of *indica* is long and broad and droops; vegetative growth is vigorous. These traits are thought to be unfavorable for the attainment of high grain yields, particularly when fertilizer is applied abundantly. Increase in the supply of fertilizer may accelerate susceptibility to lodging and make the efficiency of dry matter production low by deterioration of the light receiving status owing to long, drooped leaves and vigorous vegetative growth, resulting in unexpectedly low yield.

2-2-3. Plant Type and Light Receiving Status of Rice Population

At the early growth stage when the foliage is less luxurious, individual leaves of the population, including the lower ones, can receive ample light. While at a later growth stage when the foliage is more luxuriant, the amount of total population photosynthesis will not increase proportionately to leaf area owing to the fact that the self-shading of the lower leaves of the population decreases the incident light to a great extent. Therefore, in order to keep photosynthesis at high levels under relatively luxuriant conditions, it is necessary to have a plant type that distributes as much light as possible to the inner part of the population.

Light receiving conditions of a rice population differ with variety and it is generally said that when plant height is not too great and leaves are short, narrow and errect, more light can enter the inner part of a population than when the configuration is the reverse. Many *japonica* varieties belong to the former type, while most *indica* varieties are of the latter type and their light receiving conditions tend to deteriorate especially at high fertilizer levels.

Light transmission ratio in the population decreases exponetially with increases in leaf area, though there is a varietal difference in the curve (Fig. 2-7). At the same leaf area or LAI (Leaf Area Index) the ratio of Peta, which has long, broad leaves and low fertilizer response is lower than Taichung Native No.1 or CP-231, showing that the quantity of light reaching the lower part of the population is less than with the other varieties.

2-2-4. Plant Type and Dry Matter Production

Grain yields are largely determined by dry matter production particularly during the time from booting to ripening, although this is influenced by the translocation of photosynthetic products. The greater the dry matter production, the higher the grain yield (Fig. 2-8). Consequently, varietal characteristics of plant type and light receiving status has a great influence upon yield through the efficiency of dry matter production, because the foliage of the rice population is luxuriant at those growth stages.

Dry matter production can be principally represented in the form of the balance between photosynthesis and respiration. In Fig. 2-9, supposing that incident light intensity in the population is at a definite level, population photosynthesis increases rectili-

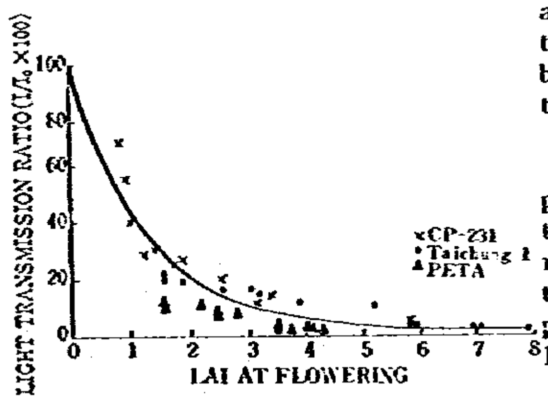


Fig. 2-7. Light transmission ratio and leaf area index (LAI) curve for three varieties, at IRRI, in 1962~63 dry season (Tanaka et al., 1963)

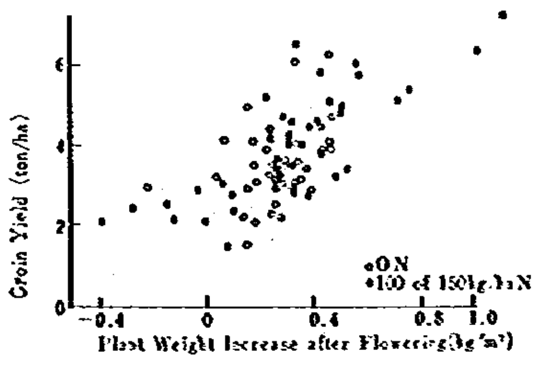


Fig. 2-8. Relation between grain yield and plant weight increase after flowering. (Tanaka et al., 1966)

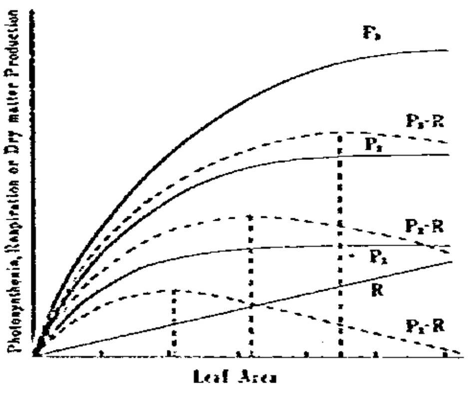


Fig. 2-9. Leaf area, photosynthesis, respiration and dry matter production of the rice population (schematic figure).

P_1, P_2 and P_3 are photosynthesis at solar radiation energy 1, 2 and 3 (1<2<3), respectively. R : respiration. Dotted curves denote dry matter production and dotted perpendicular lines denote optimum leaf area.

nearly with increase in the leaf area, when leaf area is still relatively small, but with subsequent increase in the leaf area, the slope of the curve is reduced, owing to the self-shading of leaves (curve P_1). On the other hand, respiration shows a rectilinear increase with increase in leaf area (curve R). As a result, the net amount of CO_2 fixation (equivalent to the dry matter production) can be represented by curve P_1-R which has a maximum. The leaf area at which the maximum amount of dry matter is produced is called the "optimum leaf area". If the incident light intensity becomes stronger, the photosynthesis curve will become higher as in curve P_2, P_3, but the respiration will remain unchanged. Thus, the balance P_2-R, P_3-R or the rate of dry matter production becomes higher and the optimum leaf area also becomes larger. The more the light, the higher the optimum leaf area.

Indica varieties, which are generally inferior as far as light reception goes, are mostly planted in the rainy season when sunlight is not abundant. Consequently, the optimum leaf area tends to be smaller. In other words, the nonproductive leaf area increases beyond the optimum. This results in a decrease in the efficiency of dry matter production. Furhtermore, this tendency is accelerated with an increasing supply of fertilizer, due to the active foliage growth. However, supposing that sunlight is abundant, as in the dry season, even *indica* varieties will be able to produce more dry matter by increasing the optimum leaf area. This is shown with an *indica* variety, Peta, grown in the dry season as described above (Fig. 2-6).

Most of the *indica* varieties recently released in the tropics, including IR 8, have been developed primarily to improve plant type and have high fertilizer response. Since these varieties are generally shorter and form more tillers with relatively short, narrow and erect leaves, the spatial distribution of light is more uniform, and hence the light receiving status deteriorates less under luxurious conditions, compared to the traditional varieties. This means that when the effective leaf areas are equal, the optimum leaf area of the former is larger than that of the latter.

2-2-5. Rate of Photosynthesis per Unit Leaf Area

The major part of the dry matter composing a plant body is derived directly or indirectly from the products of photosynthesis in the leaves, while the remaining dry matter consists of substances absorbed by roots, but the amount accounts for less than 20% of the total. Thus, it is evident that photosynthesis of the individual leaves is the most fundamental function in the production of materials. A number of reports concerned with the photosynthesis of rice leaves, mainly of *japonica* varieties, have so far been published. As those reports seem to be, in principal, applicable to *indica* varieties also, will not expand on the original reports except for the following.

Generally, the rate of photosynthesis per unit leaf area is determined positively by the nitrogen content of the leaves. Among varieties differing with fertilizer response, there is an interesting difference in the response of the rate of photosynthesis to the amount of nitrogen applied. Osada found with both *japonica* and *indica* varieties that the rate of increase of photosynthetic activity per unit leaf area with increasing concentration of nitrogen in the cultural solution was higher in varieties suitable for heavy fertilizing than in those having a low response. It was also reported that *japonica* varieties have a higher optimum concentration of nitrogen in the cultural solution than *indica* varieties.

As the rate of photosynthesis per unit leaf area is an indispensable factor affecting yield, as mentioned above, varietal differences in the photosynthetic activity of leaves have been paid continuous attention in studies on the photosynthesis of rice plants. However, according to experiments with *japonica* varieties, differences in the rate of photosynthesis per unit leaf area of many varieties varied only ± 10% from the average rate of the varieties tested. Recently, Ohno (1972) found larger differences among a number of *indica* varieties grown at IRRI, the highest rate being 35% higher than the lowest one. It would be particularly significant to seek varieties that have high photosynthetic activity and use them for breeding, but measuring the photosynthetic activity of many varieties is not easy, because the activity can be compared exactly only when measured at the same time. In his experiment, Ohno investigated several leaf characteristics as well and confirmed that the dry weight, nitrogen contents per unit leaf area or NAR (Net Assimilation Rate) can be indices to screen varieties for high photosynthetic rate.

It was reported that *indica* rices have a higher rate of dry matter production than *japonica* rices. This suggests an interesting question, whether or not any difference exists between *japonica* and *indica* varieties in the rate of photosynthesis of leaves.

2-3. ENVIRONMENTAL FACTORS, GROWTH AND YIELD

2-3-1. Characteristics of Environmental Factors in the Tropics

Generally speaking, the climate of tropical Asia is characterized by monsoon weather with a wet season with southeastern monsoon winds from June or July to October and an almost dry season with northeastern winds from November to April. Although there are some differences depending on the topography (for example, in Malaya or Java where dry and wet seasons are not distinct), this climatic characteristic has a strong influence on the agriculture of tropical Asia. On the other hand, due to the lack of irrigation facilities, in most of the rice growing areas, a large part of the paddy fields, some 80% of the total, is still rain-fed. Therefore, the bulk of rice is planted in the wet season under conditions of low sunlight intensity, and the abundant solar radiation in the dry season is mostly wasted.

With regard to solar radiation during the rice growing season in the tropics, compared to that in the temperate regions, the following should be mentioned. First, the intensity of solar radiation in the former is generally higher than in the latter, but the total radiation per day in the tropics is lower, because its day is shorter than that of temperate regions. Second, the total radiation per day in the tropical rainy season appears relatively high, because in many places, even on rainy days, it usually rains off and on with frequent intervals of clear weather. In temperate areas, if it is rainy, rain-fall often continues all day long without any sunshine and hence radiation energy is sharply reduced. Solar radiation energy per day at Bangkok in September, the month of the highest rainfall, is as much or more than 70% of that in the finest month, April. This value seems not to be very deficient for rice cultivation (Table 2-3). However, though the difference is relatively small, low light energy must have a negative influence on yield. Additionally, it is speculated that even if the total amount of incident light energy per day is equal, the effect of light of which the intensity changes frequently at short intervals through out the day might differ from that under steady weather.

Rice cultivation in tropical Asia is, in general, not much limited by temperature. Most of the low-altitude areas in the tropics have far higher average temperatures than 20°C and small annual changes (Table 2-4). Inland, the temperature sometimes decreases markedly in winter but only for short periods. For instance, at Chieng Mai in the northern part of Thailand, the temperature in December and January falls considerably, the daily mean and minimum temperatures being 20.0 to 21.5°C and 13.3 to 14.5°C, respectively (Table 2-4). But in the other months the temperature rises considerably. It is said that the temperature decline is about 0.5 to 0.6°C for every 100m increase in altitude, and at high elevations the temperature often falls below 20°C, but those places are rather exceptional.

Table 2-3. Monthly mean of solar radiation energy at Bangkok. (cal/day/cm²)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
416	421	467	490	419	419	397	390	375	391	419	417

Figures are the mean of 8 years, 1961~1971 although data of some months are not available. Observed by the Meteorological Department, Thailand.

Table 2-4. Monthly mean value of daily mean, maximum and minimum temperature at Bangkok and Chiang Mai, Thailand. (°C)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Bangkok Mean	25.9	27.6	29.0	30.2	29.6	28.8	28.4	28.2	27.8	27.7	26.9	25.7	28.0
Max.	31.8	32.7	33.8	35.0	34.1	32.8	32.2	32.0	31.5	31.2	30.9	31.0	32.4
Min.	20.0	22.4	24.2	25.5	25.2	24.9	24.5	24.3	24.1	24.2	22.9	20.4	23.6
Chiang Mai Mean	21.0	23.1	26.0	28.8	28.9	27.8	27.4	27.0	26.9	26.1	24.3	21.5	25.7
Max.	29.0	32.0	34.9	35.5	34.7	32.1	31.5	30.8	30.8	30.6	30.0	28.5	31.8
Min.	13.3	14.9	16.9	21.0	23.3	23.5	23.3	23.2	22.9	21.6	18.6	14.5	19.7

Bangkok : 13°47'N. 2.3m above sea level.
Chiang Mai : 18°47'N. 311m above sea level.
Mean of 15 years, 1951~1965. Observed by the Meteorological Department, Thailand.

As the temperature seems to be sufficient for rice cultivation, its effect on the growth of rice has so far been given little attention. From a recent experiment, however, it was found that temperature has an intimate relation to the seasonal changes in the growth and yield of rice plants.

2-3-2. Solar Radiation, Growth and Yield

There is much evidence to indicate that light plays an unusually important role in the production of rice grains. As stated above, a part of the carbohydrates in the grains consists of photosynthetic products formed during a certain period before heading, but a great part is produced by photosynthesis during the ripening stage. Therefore, in order to attain a high yield, an ample amount of solar radiation is indispensable, especially during the ripening period. Dry season crops have higher yields than rainy season crops.

In the "date of planting experiment," carried out at IRRI for several years, planting rice every month throughout the year, and as a result of a high positive correlation was found between yield and the amount of solar radiation for 30 or 45 days before harvesting.

Of course, the effect of light on the healthy vegetative growth in the former part of growth cycle should not be neglected. Deficiency of light during this period brings about growth of plants with excessive weak and spindling leaves, and results in inferior light reception or lowered resistance to disease and pests. It was recognized that when rice plants were grown under low light intensity, the dry matter per unit leaf area or leaf thickness was reduced, accompanied with decreases in the photosynthetic and respiratory activities of leaves.

2-3-3. Temperature, Growth and Yield

The monthly means of daily mean temperature at Bangkok, located in the low land of the tropics, range from approximately 25 to 30°C during the year, the annual difference being only about 5°C. When non-photosensitive varieties were planted there every month during the year, growth patterns and yields varied considerably depending on the planting time. These variations seemed to be based particularly on changes in solar radiation and temperature. In this section details of these experiments are presented.

Among 12 plantings, the height of 20-day old seedling sown in the cool season, from November to January, decreased markedly (Fig. 2-10). In particular, the height of seedlings of December-plantings in which the mean temperature during the nursery period was 24.6°C did not exceed 20cm, while that of the plantings in the hotter season was between 24 and 27cm, approximately. As in the case of seedlings, when adult plants in the fields were exposed to low temperatures, elongation was inhibited. Increased in plant weight and leaf area of those plants also decreased. In addition, among the 12 plantings there was a close, positive correlation between plant height at 80 days after sowing, which may be regarded roughly as the "full or mature length" of the variety, and the mean of daily mean temperatures during one month prior to that time (Fig. 2-11). Height of seedlings in the nursery and of plants less than 80 days old in

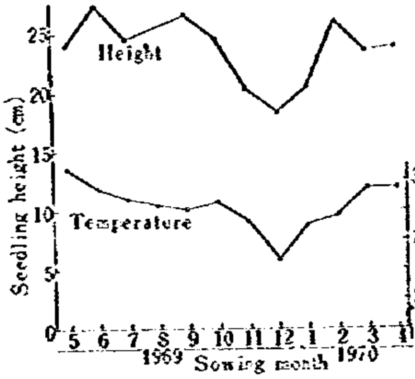


Fig. 2-10. Temperature during nursery period and height of 20-day old seedlings. (Osada et al., 1972)

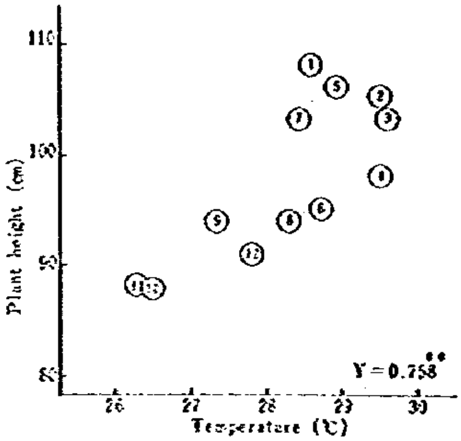


Fig. 2-11. Correlation between plant height at 80 days after sowing and mean temperature during one month prior to that time. (Osada et al., 1973)

Numerals in the figure denote sowing month.

** : Significant at 1% level.

the field did not show such a correlation. It may be thought that the influence of temperature observed in 80-day old plants was obscured in the younger plants, as the height of younger plants is usually more variable than that of the older ones not because of both temperature and various other factors such as irrigation conditions, rooting after transplanting etc. If this is true, it can be said that even in the tropical low land, temperature always influences the growth of rice plants.

A close correlation between temperature and grain production was obtained also by analyzing interrelations between solar radiation and temperature during the ripening period, and ripening of grains or yield (Fig. 2-12). Solar radiation must affect grain production positively, but correlation between radiation and yield was not very intimate. However, among plantings which ripened in the months of low temperature, October to February a close correlation can be seen (Fig. A in Fig. 2-12). On the contrary, among different plantings except those whose ripening occurred in the high radiation months, March to June, a negative correlation can be seen between temperature and

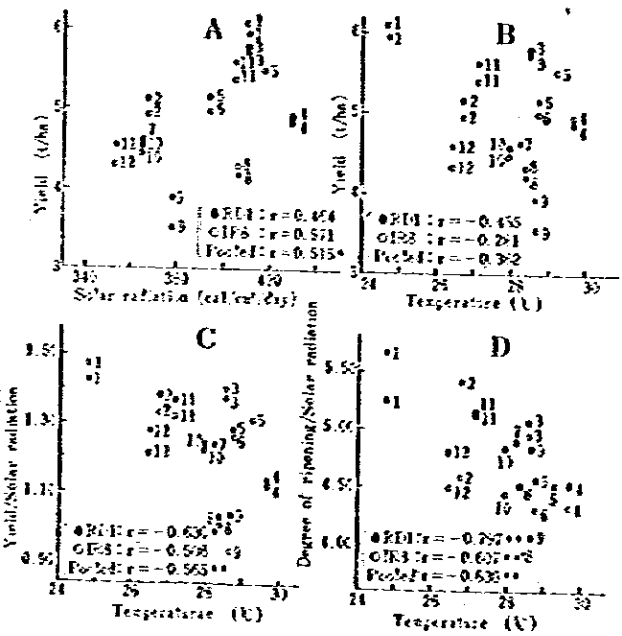


Fig. 2-12. Relationship among solar radiation energy and temperature during ripening perid, ripening and yield (Osada et al., 1973)

Numerals in the figures denote the month for ripening

* : Significant at 5% level

** : Significant at 1% level

yield, although the correlation of the combined over-all plantings is not close (Fig. B). This result suggests that the positive effect of radiation was obscured to some extent by high temperature, while the negative influence of temperature became indistinct with high radiation.

According to Murata (1964), when it is assumed that the solar radiation always exerts a positive, proportional influence on rice yield, the ratio of yield to the solar radiation intensity, can be considered to be free from the influence of radiation. Accordingly, if the above assumption is correct, the correlation of the temperature with yield/solar radiation intensity will become closer than with yield alone.

In this experiment, this influence of temperature was clearly seen by analysis based on this assumption. That is, correlation of temperature with yield/solar radiation became closer than with yield itself (Fig. C). Furthermore, as in this experiment changes in yield throughout the year were determined mainly by percent of ripened grains and 1000-grain weight, regarding the products of the two yield components as an index to express "degree of ripening", relationship between temperature and the ratio of the degree to solar radiation was examined. As a result, a closer, negative correlation was noted (Fig. D).

Consequently, it can be concluded that solar radiation exerted a positive effect on ripening and yield of rice, whereas temperature had a negative influence; the lower the temperature during the ripening period, the better the ripening. The practical significance of this result is that crops should be planted so that ripening periods correspond to a time of high solar radiation and low temperature, as in December or January.

It is thought that high temperature brings about a deterioration in the balance of photosynthesis and respiration, due to its accelerating effect on respiration, and results in lowering yield. Tanaka (1967) pointed out that grain yield tends to be higher in areas where temperature during ripening is low. He ascribed this tendency not only to a favorable balance between photosynthesis and respiration but also to prolonging the ripening period which in turn increases the total amount of solar radiation received during ripening.

At IRRI in the Philippines also, the amount of solar radiation during ripening showed a close correlation with grain yield throughout the year, but no negative influence of temperature was noted. It is said that high solar radiation is usually associated with high temperature in the Philippines, but sometimes the effect of high radiation may be relatively strong compared to the influence of high temperature. Although the difference is small, temperature, especially in the hot part of the dry season, April or May, tends to be higher at Bangkok than at IRRI, while the solar radiation intensity at the former place in this season seems to be lower than at the latter, because of the number of days with haze. This may account for the disaccord in the influence of temperature on yield, although other factors including soil conditions might be involved also. At any rate, it should be noticed that in the tropics there are places where temperature can have either a favorable or an unfavorable effect on ripening or yield of rice.

2-4. SOME PROBLEMS CONCERNING RIPENING

2-4-1. Determination of Percent of Ripened Grains

The percent of ripened grains to the total number of grains and is one of four yield components. When one measures the percent, precise identification of fully ripened grains is difficult unless some proper standard is available, because among a mass of grains, there are grains of all sorts from completely empty to fully ripened. In the case of *japonica* varieties, Matsushima and others revealed that the specific gravity of grains has a close relation to the size and quality of kernels and a grain of which the specific gravity is 1.06 or more is regarded as a ripened grain. Practically, the percentage is determined by separating ripened grains in NaCl solution, specific gravity 1.06, and by counting the number of sunken and floating grains. However, in the case of *indica* types, ripened grains have been so far defined mainly by the naked eye, a subjective method which must cause a large error according to who does the measuring and when. In order to investigate the ripening of grains, it is necessary to establish an appropriate standard.

Osada et al. (1973) investigated the specific gravity characteristics of grains to measure the percentage of ripened grains of *indica* varieties and found the following difference between *indica* and *japonica*. Table 2-5 shows the percent of grains which sank at each specific gravity of NaCl solution to the total number of grains. In this test, grains with a specific gravity of less than 1.00 were thought to be imperfectly ripened and were discarded by separating in water. The peak values of specific gravity which had the most number of grains were higher in indica than in *japonica* varieties. Results of the other trials showed a similar tendency, but several traditional *indica* varieties which have long grains had a much higher percentage at specific gravity 1.20 or more, than RD 1 and IR 8. This result indicates that the standard specific gravity value obtained for *japonica* types can not be applied to *indica*

Table 2-5. Varietal difference in the variation of specific gravity of grains (Osada et al., 1973)

Specific gravity	Indica		Japonica		
	RD 1	IR 8	Norin No. 1	Fujiminori	Hoonenwase
	%	%	%	%	%
≧ 1.20	63.5	21.0	4.5	0	3.7
1.19	7.3	12.3	23.3	0	14.5
1.18	6.4	12.4	17.7	1.1	23.1
1.17	5.7	13.7	17.5	9.0	21.5
1.16	5.0	9.2	6.6	19.5	14.3
1.15	2.5	7.1	4.7	16.7	5.8
1.14	1.5	5.6	4.3	15.2	3.5
1.12	1.8	6.6	5.6	15.9	3.9
1.10	0.7	3.8	5.9	11.2	2.0
1.08	0.3	2.6	4.5	6.1	2.2
1.06	0.2	1.3	2.3	3.7	1.7
1.04	0.1	1.2	2.7	1.6	0.5
1.02	0.1	2.0	0.4	0	0.3
1.00	0	0.1	0	0	0
Total	100.0	100.0	100.0	100.0	100.0

directly for the determination of percent of ripened grains. Moreover, the specific gravity of grains may vary with cultivating conditions also. Therefore, further studies will be necessary with reference to the quality of kernels in order to find the reasonable standard specific gravity value. However, considering these results and the case of *japonica*, a specific gravity of 1.10 to 1.12 may be regarded as a tentative standard value for *indica* varieties. Even if the value is not appropriate, the degree of ripening could be compared by using such a standard, instead of subjectively.

2-4-2. Non-ripened Grain

When the ripening of rice grains is considered, grains which did not ripen fully, from completely empty to unfully ripened, are generally called non-ripened or unfully ripened grains or sometimes empty grains, the distinction of these words being rather obscure.

As stated by Matsushima (1966), grains can be divided into "ripened grains" and "non-ripened grains". Non-ripened grains consist of two kinds which differ qualitatively: "imperfectly ripened grains" which have materials to varying degrees, from a trace to a considerable amount, and "non-fertilized grains" which have no materials whatever. The former are due to the stopping of kernel-development after fertilization caused by a disorder in the process of ripening, and the latter are due to obstacles to fertilization. Discrimination between the two kinds of grains by eye may be difficult. However, in the study of the ripening of grains - in particular, in the case of poor ripening - it is important to distinguish between them and to know the causes of non-ripening.

In the experimental planting of RD 1 and IR 8 every month throughout the year, the percentage of non-fertilized grains identified by the I-KI solution method devised by Matsushima et al. (1960), and the percentage of ripened grains measured on the basis of specific gravity 1.10 are shown in Table 2-6. The percentage of ripened grains varied considerably depending on the ripening months, but the percentage of non-fertilized grains was almost constant throughout the year, the values seeming to be similar to those of many *japonica* varieties. As far as this experiment is concerned, this result indicates that changes in the rate

Table 2-6. Percent of non-fertilized and ripened grains at monthly plantings. (Osada et al., 1973)

Var.	Ripening month											
	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
	Percent of non-fertilized grains											
RD 1	8.1	9.7	7.0	9.7	8.2	7.2	6.4	7.5	9.0	10.7	8.9	7.9
IR 8	6.2	6.6	7.1	8.1	6.3	8.0	8.2	7.8	6.7	8.5	8.1	6.5
	Percent of ripened grains											
RD 1	67.1	65.9	63.7	73.2	59.9	81.0	71.2	72.8	67.9	—	61.1	64.6
IR 8	57.5	55.9	57.8	71.9	51.9	71.3	61.4	70.0	66.1	67.3	60.3	—

of non-ripened grains was determined not by fertilization but mainly by the ripening conditions after fertilization.

2-4-3. Occurrence of Non-fertilized Grains under High Temperature

When flowering takes place in the hot part of the dry season, April or May, in Thailand, some non-photosensitive varieties produce a number of empty grains. From the experiment conducted during two years, the following was revealed:

(1) Empty grains in some varieties increased considerably when the daily maximum temperature exceeded 35 or 36°C during the flowering period. Sometimes more than 50% of the grains were empty. Relative humidity appeared not to be too low for normal flowering.

(2) These empty grains were non-fertilized ones which did not show iodine reaction in the I-KI solution mentioned above. Thus, it was thought that the abnormal increase of empty grains was due to failure to fertilize at high temperature.

(3) The rate of occurrence of empty grains differed by variety. C_4-63 and some of its sister lines showed serious sterility; RD 2 and 3 recommended in Thailand and the local variety, Luang Tawng, moderate; whereas RD 1, IR 8 and Taichung Native NO.1 did not show an abnormal increase in empty grains, the percentage of empty grains being similar to that in the rainy season crop.

Sato (1960) investigated seasonal changes in the percentage of non-fertilized grains, planting a photosensitive variety, Neang Meas, some of which received short-day treatment, at half month intervals throughout the year. A marked increase in sterility percentage was observed when flowering took place in the hot part of the dry season, particularly in April when the percentage was 100. Sato attributed the cause to obstacles to fertilization such as imperfect splitting of another or wilting of stigma caused by high temperature and low humidity.

Except for only a few, varieties which can be planted in the dry season are new non-photosensitive hybrids that have been developed recently and hence their performances are not well known. On the other hand, in order to increase rice production, the necessity for a dry season crop is increasing rapidly. Therefore, such an abnormality in the new varieties should not be ignored as a problem occurring merely in the dry season when planting of rice is still rare at present.

2-5. PHYSIOLOGICAL DISORDERS

Various sorts of physiological disorders of rice plants in tropical Asia have been recognized. Recently, Tanaka and Yoshida (1970) reviewed the disorders in all parts of the world. Based on this review and others, several important physiological disorders are briefly described as follows:

2-5-1. Bronzing

The typical symptom is the discoloration of older leaves into brown or reddish brown, like bronze, which starts as many small brown spots on the tips of leaves and spreads downward, leaving the midrib region green. As the disease progresses, younger leaves are also attacked and eventually the affected leaves die. The disease occurs in the ill-drained, sandy soils adjacent to lateritic high lands. As to the cause of bronzing, there are two different opinions; one is that it is caused by the toxicity of excess iron and the other by the combined effect of high aluminum and low calcium in the soil. Bronzing was first observed in Ceylon where it is at present well controlled by use of resistant varieties including H4, application of lime and improved fertilizer applicaiton. Similar symptoms appear in the northeastern part of Thailand and India.

2-5-2. Penyakit Merah (Red Sickness)

This disease occurs in Malaysia and shows two types of symptoms. In one type, many small brown spots appear first on the tip of der leaves and spread downward. Later, affected leaves turn dark brown and die. In the other type, discoloration to yellow or orange appears first on the tips of older leaves and spreads downward, leaving the midrib green. Eventually, leaves turn entirely orange and die. There are different opinions about the cause of Penyakit Merah, but it is probable that the first type is caused by excess iron in the soil under submerged conditions and the second type by a virus.

2-5-3. Mentek

This disease occurs in Indonesia, Main symptoms of Mentek are or reddish brown leaves, stunted growth and the abnormality of panicles. The disease was considered to be a physiological disorder caused by a deficiency of available phosphate and potassium in the soil under reductive conditions. However, recent studies indicate that Mentek seems to be caused by a virus.

2-5-4. Amiyito-po

The disease occurs in Burma and is probably due to potassium deficiency. About a month after transplanting leaves turn dark green, growth is retarded and lower leaves are prone to die. Although tillering of affected plants seems normal, the rate of sterility is high and yield is very low.

2-5-5. Myit-po

Myit-po occurs also in Burma and is probably due to phosphate deficiency. The symptom appears soon after transplanting. In serious cases, plants do not form tillers and die. This disorder can be prevented by application of phosphates.

2-5-6. Yellow Leaf

About one month after transplanting, plants turn yellow and are stunted. Yellow Leaf is thought to be caused by a deficiency of sulfate, as affected plants are revived by application of sulfate at the base of the plants. This disease occurs also in Burma.

2-5-7. Suffocating Disease

Suffocating Disease has been known for a long time in Taiwan. The symptoms of this disease are poor growth, yellowing of leaves, root rot and appearance of brown spots similar to Helminthosporium leaf spot. According to recent studies, there are two kinds of this disease; one is a virus disease which is called transitory yellowing and the other is a disorder due to the reductive conditions in the soil. However, the occurrence of the latter disease has been reduced remarkably by the improvement of soil drainage of potassium.

2-5-8. Khaira Disease

Khaira Disease occurs in the northern part of India. About two weeks after transplanting brown spots appear on the lower leaves and growth is retarded. About six weeks later, affected plants recover to some extent, but yield is very low. The disease seems due to a deficiency of zinc, and application of zinc is very effective in combatting it.

2-5-9. Hadda

This disease has been known in western Pakistan and became prominent after introduction of new hybrids from IRRI. The symptoms are poor growth and appearance of brown spots on the lower leaves about 3 weeks after transplanting. About 5 or 6 weeks after transplanting, diseased plants begin to recover, but in serious cases die. Zinc deficiency seems to be the cause.

2-6. REFERENCES CITED

CHAPTER THREE
PADDY SOILS IN THE TROPICS

Satoru Motomura*
Fumio Yazawa**

3-1. INTRODUCTION

As rice plants, in general, are cultivated under condition of flooding, most rice fields are developed on low land areas. Even in comparatively high land, paddy fields always lie on lower-lying areas than the surroundings. The important rice producing areas in the world are mainly found in the basin of deltas and the flood plains of rivers.

Flooding of the soil during the rice growing period and drying of the soil after harvesting alternate every year in the cultivation of rice. Especially in Southeast Asia, where there is a clear division between dry season and wet season, some rice fields are under water as deep as 4 or 5 meters in the rainy season, and paddy soils dry up to a considerable depth because of large cracks induced by shrinkage of soil in proportion to decrease in soil moisture in the dry season.

In this way, the soils under rice cultivation have been subjected to repeated flooding and drying for a long time and are strongly influenced by artificial action like plowing and puddling. Such natural and artificial effects sharply reflect on the development of soil profile, physical and chemical properties, and biological characteristics, which contrast remarkably with upland soils, which are always in the oxidizing state.

3-2. Paddy Soil Types

The great soil groups' names (according to the 1949 USDA classification) of soils used for rice cultivation in Southeast Asia, that is paddy soils, are given in Tables 3-1 according to Dudal and Moorman (1964). The right-hand column of this table shows the approximate equivalents according to the 7th Approximation of the new soil classification system proposed by USDA in 1960.

Of these great soil groups, alluvial soils are extensively utilized for paddy cultivation. They are subdivided into three subgroups, namely marine alluvial soils, brackish water alluvial soils, most of which are regarded as acid sulfate soils, and fresh water alluvial soils based on the sedimented materials. Drainage rather than water supply is an important problem in the cultivation of rice in this great soil group. Where

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* Sections 3-1 to 3-17, ** Sections 3-18 to 3-30.

Table 3-1 Soils Used for Paddy Cultivation in South-East Asia
(Dudal and Moorman, 1961)

Great soil groups	7th Approximation (Orders)
Alluvial soils	Entisols, Inceptisols
Andosols	Inceptisols
Regosols	Inceptisols
Grumsols	Vertisols
Low humic gley soils	Alfisols
Gray hydromorphic soils	Ultisols
Non calcic brown soils	Ultisols
Red yellow podzolic soils	Ultisols
Dark red latosols	Oxisols
Reddish brown latosols	Oxisols
Organic soils	Histosols

sufficient water is available and the relief is flat or gently soping, grumsols (vertisols), low humic gley soils, gray hydromorphic soils and non-clacic brown soils, which have usually developed on low terraces or high plateaus, are often used for paddy growing. Among them both low humic gley soils and gray hydromorphic soils are much more important as paddy soils. Dark red latosols or reddish brown latosols, which occur mainly in hilly or mountainous areas, also are sometimes used for the growing of wet rice on terraced fields after land preparation. Organic soils such as peat soils and much soils, although covering a fairly large area in some Southeast Asian countries, are used only locally for rice cultivation.

3-3. MORPHOLOGICAL CHARACTERISTICS IN PADDY SOIL PROFILE

Soils which have long been cultivated for lowland rice demonstrate prominent hydromorphic characteristics to acquire specific morphological features as a result of flooding and artificial action like cultivation practices under waterlogged condition. Indeed, the paddy soil profile exhibits some diagnostic horizons such as alluvial horizon accumulating oxidizing sediments of iron and manganese, formation of plough pan right below the surface plow layer, presence of gley horizon and so on, which usually cannot be observed in upland soils.

In general, paddy soils developed on areas where the ground water level is relatively low, are characterized by horizon differentiation of Apg-Bg-C* through the reductive-eluviation and oxidative-illuviation pro-

* During the soil forming process, the soil column is differentiated into A, B and C horizons. To make the characteristics of the horizons more clear, it is convenient to use suffixes. The suffix "p" is used for A horizon indicating plowing or other disturbance. The suffix "g" is used to designate the horizon being changing to a more neutral soil color by the influence of water and with in many cases, some mottles of iron and/ or manganese oxidative sediments. "G" is used to designate the horizon showing reductive characteristics throughout the year, and, as a suffix, used to indicate the horizon being strongly influenced by reductive condition throughout almost the whole year. For example, Apg implies a plow layer still kept in the reduced state even in the draining period.

cesses promoted by the alternation of flooding and drying of the soil. The soil of the surface plow layer is converted to the reduced state during the growing period of rice as described later in detail, and iron and manganese in the reduced plow layer become more mobile and with downward movement of irrigation water go down to a sub-surface layer or subsoils where the oxidative environment continues even during the flooded period. The iron and manganese leached from the surface plow layer are precipitated there to form so-called illuvial B horizon. Thus, the B horizon of exidizing-illuviation serves as a necessary and sufficient key for detecting the specific morphology which is acquired during the rice cultivation. Therefore, the presence of illuvial B horizon including the aspect of accumulated iron and manganese, is one of the most important criteria for distinguishing the characteristics of soil productivity and classifying paddy soils.

The paddy soil formation mentioned above proceeds under relatively well-drained high terrace conditions irrespective of the climate, so far as downward movement of irrigation water takes place.

On the other hand, paddy soils where there is a high water table throughout the year genetically have a bluish gray or bluish green colored gley horizon and are differentiated into the horizon sequence Apg-G or AoG-G.

In Southeast Asia, the major rice producing areas lie on vast, flat, deltaic plains, mostly consisting of very fine textured sediments with high clay content, so that irrigation water can hardly move down through the solum during the flooded period. In the dry season, some large cracks appear on the surface as soil moisture decreases with the lowering of the ground water table. However, these large cracks are rapidly closed by the high swelling pressure when the osils swell with the re-wetting of the soils at the begining of the rainy season. This is evidenced by the presence of slickensides in the subsoils of many paddy fields in the great deltaic plains. Thus, downward movement of irrigation water or rain water may be almost completely hindered in deltaic soils throughout the rice growing season. In such a case, a fundamental differentiation of horizon sequence is Apg-Cg type.

3-4. MECHANISM OF SOIL REDUCTION IN PADDY FIELD

Soils cultivated for rice have a relatively large amount of decomposable organic matter in the form of roots, stubble and straw. When such a soil is waterlogged, the raw organic debris is rapidly decomposed, accompanying microbial consumption of dissolved molecular oxygen in the soil. During this process, the soil is anaerobic. After molecular oxygen is alomost completely consumed, nitrates in the soil are utilized by soil microbes for their respiration. However, a major portion of the nitrates usually disappear in 24 to 72 hours, followed by the reduction of manganese compounds and the formation of ferrous iron.

edox potential (Eh) rapidly drops and soil pH rises during this process. As shown in Fig. 3-1 as an example (Motomura, 1963), changes in Redox potential are closely related to the amount of ferrous iron produced, indicating that a ferric-ferrous system may largely control redox potential in flooded soil. Soil pH comes up to 7.0 with the progress of soil reduction. When soil rich in easily decomposable organic matter is waterlogged, its pH sometimes decreases in the first few days due to the temporary accumulation of various organic acids, but thereafter increases asymptotically to a fairly stable value of 7.0 a few weeks later because organic acids accumulated in the early stage of the flooding are easily decomposed. Such changes are more remarkable in soil with a higher content of decomposable organic matter.

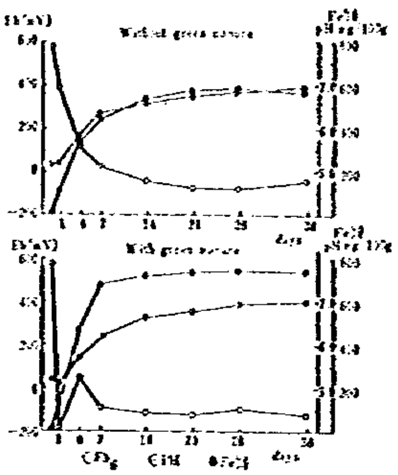

Fig. 3-1 Periodical changes in redox potential, soil pH & Fe (II). (Motomura, S. 1969)

In the course of ferrous iron formation after the disappearance of oxygen and nitrates, ammonia and carbon dioxide formation is conspicuous. At this stage organic acids which are the intermediates of anaerobic decomposition of organic soil matter have not yet developed so distinctly. When redox potential declines still more with the advance in ferrous iron formation, culfide and methane are produced. Hydrogen gas emerges within 24 hours of the early waterlogged period when easily decomposable organic matter, particularly soluble sugar, exist in a large quantity in the soil, but this quickly disappears within 48 hours. A little hydrogen is found again at the time of methane production.

Organic acids accumulate in large quantities when redox potential falls somewhat. Major organic acids detected in waterlogged paddy soils are the lower fatty acids such as acetic, formic and butyric acid, and among them by far the most common is acetic acid. However, along with the vigorous formation of methane these organic acids rapidly decrease and finally disappear.

Two metabolic pathways in waterlogged paddy soil leading from fatty acids to methane are recognized by the isotopic technique using ^{14}C tracer (Takai, 1969). One is the reduction of carbon dioxide, and the other is transmethylation of acetic acid. The reaction formulas are shown in the following equations:

$$^{14}CO_2 + 4H_2A \longrightarrow {}^{14}CH_4 + 2H_2O + 4A$$

$$^{14}CH_3COOH \longrightarrow {}^{14}CH_4 + CO_2$$

With respect to this, Takai (1969) clearly explained the step-by-step soil metabolism which takes place during the developing process of soil reduction in comparison with changes in the microbial action concerned. He has indicated that there are two stages in this course: namely, the stage where aerobic and facultative anaerobic bacteria aerobically decompose the organic matter by using oxygen, nitrates, and manganese and iron oxides as hydrogen acceptors, and the stage where obligate anaerobic bacteria such as sulfate reducer and methane bacteria in place of aerobes or facultative anaerobes work vigorously after development of a strongly reduced condition as shown by fairly low redox potential. Successive

Table 3-2 Successive Reduction Process in Submerged Paddy Soils (Takai, Y. 1969)

Period of incubation	Stage of reduction	Chemical transformation	Initial Eh in soil V	Expected pattern of energy metabolism	Formation of NH_4-N	Formation of CO_2	Formation of organic acids	Hypothetical pattern of organic matter decomposition
Earlier	The 1st stage	Disappearance of molecular oxygen	+0.6 ~+0.5	Oxygen respiration	Rapid progress	Rapid progress	No accumulated or a few amount accumulated	Aerobic and semi-anaerobic decomposition process
		Disappearance of nitrate	+0.6 ~+0.5	Nitrate reduction				
		Formation of Mn^{2+}	+0.6 ~+0.4	(Manganese reduction)				
		Formation of Fe^{2+}	+0.6 ~+0.3	(Ferric reduction)				
Later	The 2nd stage	Formation of sulfide	0 ~ -0.19	Sulfate reduction	Slow progress	Slow progress	Early stage: rapid accumulation Advanced stage: rapid decrease	Anaerobic decomposition process
		Formation of hydrogen	-0.15~ -0.22	Fermentation				
		Formation of methane	-0.15~ -0.19	Methane fermentation				

reduction in a flooded soil is summarized by Takai in Table 3-2. Which stage in this reduction series surpasses another stage during flooding, depends largely on the relative ratio between the active iron oxide content, that is oxidizing power, and the easily decomposable organic matter content, that is reducing power. The first stage of the reduction process lasts for a long period when the former dominates the later, whereas the second stage is liable to occur from an early period of flooding and advances considerably when the latter is superior to the former. An example of this is illustrated in Fig. 3-2. As seen from this figure, in the A soil, poor in organic matter, the first stage prevails for a long period, while in the B soil rich in organic matter, the second stage is more violently promoted.

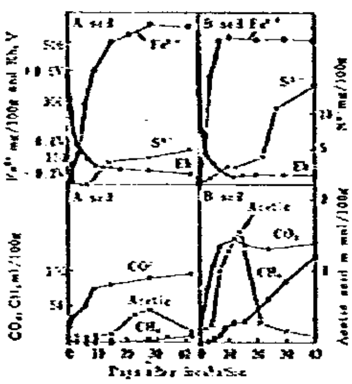

Fig. 3-2 Reduction Process under Submerged Condition in A Soil with a Low Content of Organic Matter and in B Soil with the Higher Content.

(Takai, Y. 1969)

Organic acids like acetic acid also are oxidatively decomposed to produce carbon dioxide coupled with ferric iron reduction through the following pathway:

$$CH_3COOH + 8Fe(OH)_3 \longrightarrow 2CO_2 + 8Fe(OH)_2 + 6CO_2$$

Therefore, the addition of hydrous iron oxide may retard methane formation in flooded paddy soils significantly.

3-5. DISTRIBUTION OF MICROORGANISMS IN PADDY SOIL

It is rather natural that soil microbes living in paddy soil differ distinctly from those in upland soil which is always kept in the aerobic condition. According to the experimental results obtained by Ishizawa and Toyoda (1964) many more bacteria, but many fewer actinomycetes and fungi are found in paddy soil than in upland soil, as shown in Table 3-3. Among bacteria, paddy soil has a higher soil has a higher count of sulfate reducer and denitrifier which are thought to be obligate anaerobes and facultative anaerobes, respectively, whereas upland soil has a considerable amount of nitrifier which is obligate aerobe. It should be noted that a considerable amount of sulfate reducer and denitrifier are found even in the lower part of paddy soil.

Table 3-3 Abundance of Microorganisms of Paddy and Upland Soils in Japan (Numbers of microorganisms per g of dry soil)

(Ishizawa, S. and Toyoda, H. 1961)

Kinds of Microorganisms	Paddy Soil*			Upland Soil**		
	1st. Horizon	2nd. Horizon	3rd. Horizon	1st. Horizon	2nd. Horizon	3rd. Horizon
Aerobic and Facultative Anaerobic Bacteria	30,000,000	13,100,000	8,370,000	21,850,000	6,280,000	1,610,000
Actinomycetes	2,200,000	880,000	380,000	4,770,000	1,720,000	350,000
Fungi	85,000	16,000	6,000	231,000	43,000	11,000
Anaerobic Bacteria	2,320,000	1,120,000	220,000	1,470,000	570,000	160,000
Sulfate Reducer	79,000	16,000	4,000	550	610	3
Denitrifier	297,000	164,000	122,000	42,000	27,000	—
Nitrifier	11,300	—	—	70,470	53,020	520

* Average of 18 samples.
** Average of 26 samples.

On the other hand, Ishizawa and Toyoda (1964) studied the effect of soil moisture on the distribution of various types of microorganisms, and found that actinomycetes and fungi were predominant in low moisture and dry condition of soil, and that the higher the moisture content of soil was, the more bacteria were found. Takai (1952) reported that bacteria were the prevailing soil microbes in flooded soils.

3-6. CHANGES IN PHYSICAL PROPERTIES OF PADDY SOIL

Rice cultivation practices such as plowing, puddling, flooding, draining and so on may cause drastic changes in soil structure of the surface plow layer in paddy fields. Plowing and puddling break down the soil peds and aggregates. Flooding considerably reduces soil cohesion, which is closely related to capillary power, resulting in fluid flow of soil particles. Following this, cementing materials such as colloidal organic matter and active oxides are decomposed and dissolved with the progress of soil reduction so as to weaken binding power among soil particles. And then, the so-called jelly-like structure common in reduced soils is formed in co-operation with ferrous iron formation. Under flooded and reduced condition, water permeability of the soil becomes very low on account of the formation of hydrophilic organic and inorganic colloids and the swelling of soil particles. In the course of drying and oxidizing after drainage, soil particles dispersed under flooded conditions become oriented with a decrease in the apparent specific volume and the cementing materials mobilized under reduced conditions bind soil particles to each other due to their irreversible dehydration. With more progress in the drying, soil particles shrink so tightly as to get compact and large cracks appear in soils with a high content of clay dominated by swelling types of clay minerals.

As shown in Fig. 3-3, Kida (1960) has schematically delineated the changing pattern of soil structure of the surface plow layer in paddy fields.

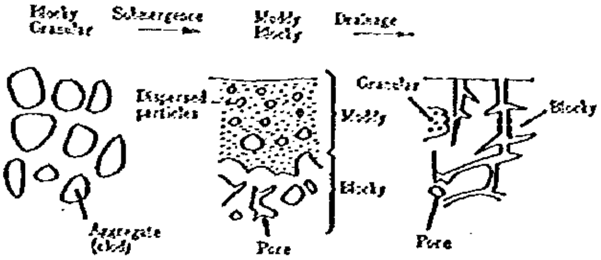

Fig. 3-3 Changes in Soil Structure of Plow Layer in Paddy Soils. (Kida, T. 1960)

3-7. CLAY MINERALS IN PADDY SOIL

Physical and chemical properties of soils are governed to a great extent by the quantity and quality of clay minerals contained. The kinds of clay minerals commonly found in soils are listed as follows*:

Type of crystal lattice	Swelling capacity	Corresponding minerals	Generalized name	Activity (CEC etc.)
	low	kaolinite	7Å minerals	low
1 : 1 type	low	hydrated halloysite		low
	medium	halloysite		low
	low	illite		medium
2 : 1 type	high	montmorillonite		high
	medium	vermiculite	14Å minerals	medium
2 : 2 type	low	chlorite		medium
Amorphous		allophan		medium, but dependent on pH. High in P fixation

* Silicate clay minerals are built up of silica terahedral sheet and aluminumoctahedral sheet. The minerals with the fundamental crystal unit being made up of one silica layer alternating with one aluminum layer are 1:1 type, and are generalized as kaolinitic minerals. Though halloysite has the same crystal structure and chemical composition as kaolinite, the latter shows hexagonal plate in shape and the former seems to be cubic, flakelike or rod shaped. It is hydrated halloysite (continued)

In alluvial areas where paddy soils are widely distributed, the clay mineral composition depends to a large extent on geology or parent materials from the catchment. Generally speaking, clay minerals in paddy soils lack regularity in crystalline lattice, and it is supposed that though the soil forming action specific to paddy soils may not change the fundamental properties of clay minerals, it may change some of their attributes, like their ion-absorbing capacity.

In Japan, soils dominating montmorillonitic clays are known to have a higher yield potential and a higher response to nitrogen fertilization in rice cultivation than those having kaolinitic minerals and/or allophan as the major clay mineral component. This is probably due to the fact that montmorillonitic clay minerals have a higher cation-holding capacity and higher potential for ammonium nitrogen supply than the others. The difference in ammonia supplying power among the clay minerals is considered to be principally based on the variation in absorption pattern of easily decomposable organic matter and/or ammonium nitrogen and in enzyme activity on the decomposition of organic matters.

In order to clarify the general features of the clay mineralogy in Malayan soils, Kawaguchi and Kyuma (1969A) set up four groups according to kaolinitic minerals content. Each of those groups is further subdivided into A and B subgroups according to their illite content. The results are given in Table 3-4, which shows the number of soils belonging to each of these eight groups. As seen from the table, clay mineral composition of paddy soils in Southeast Asian countries is commonly dominated by kaolinitic and illite minerals, followed by a small amount of montmorillonitic, vermiculite and mixed-layer minerals. Illite contents are lower in Malayan soils than in soils from the Central and Northern valleys of Thailand, which are, in turn, less illitic than Bangladesh soils. This is evidence of the intensive weathering which the parent materials of Malayan soils underwent in the past. The paddy soils from Northeastern Thailand are characterized by a high content of kaonitic minerals and a low content of illite (Kawaguchi and Kyuma, 1969B). Marine alluvial soils have a large quantity of kaolinitic and montmorillonitic minerals, followed by illite Grumsols developed on marly sediments are typically montmorillonitic. It is reported that the paddy soils in Southeast Asian countries generally do not contain chlorite, except for a few soils from the Nortern valleys in

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that holds one molecular layer of water between two crystal units of 1:1 type minerals. On the other hand, clay minerals with the fundamental crystal unit characterized by an aluminum octahedral sheet sandwiched between two silica tetrahedral sheets are 2:1 type. Of these clay minerals, illite is 10 Å long between two unit crystal sheets, and is neither swollen nor shrunk by water. Vermiculite is 14 Å and 10 Å in the air-drying and absolutely dry states, as is vermiculite, which swells to a large extent in the wet state. Chlorite is composed of laternate 2:1 crystal units and magnesium octahedral sheets, namely, the crystal unit contains two tetrahedral sheets and octahedral sheets, giving rise to the term 2:2 type minerals. Allophan is the amorphous form combining hydroxides of silica, aluminum and iron with each other, and its chemical composition is variable, the molecular ratio of SiO_2 to Al_2O_3 usually being 1 to 2. Allophan is commonly found in the soils derived from volcanic ash as parent materials.

Thailand (Kawaguchi and Kyuma, 1969A).

3-8. NITROGEN METABOLISM IN PADDY SOIL

Table 3-4 Clay Mineral Composition of Plow Layer Soils
(Kawaguchi K. and Kyuma, K. 1969)

Group	Kaolin %	subgroup	Illite %	
I	≤35	A	≤10	Subdivisions based
		B	≥15	on the relative
II	40—55	A	≤10	abundanse of either
		B	≥15	montmorillonitic
III	60—75	A	≤ 5	or vermiculitic
		B	≥10	clay in 2:1 and/or
IV	≥80	A	≤ 5	2:2 type clay
		B	≥10	minerals

Group		I		II		III		IV	
Subgroup		A	B	A	B	A	B	A	B
Malaya	West Coast riverine	1	0	6	1	3	2	3	0
	West Coast marine	7	1	4	0	0	1	0	0
	East Coast	0	0	0	0	1	2	1	3
	Sum	8	1	10	1	4	5	4	8
Thailand	Central Valley	1	5	0	14	0	4	0	0
	Northern Valley	0	3	1	20	0	9	0	0
	Khorat	0	0	4	0	5	0	3	0
Ceylon	Dry Zone	3	2	5	3	1	3	1	0
	Int. & Wet Zone	0	0	1	1	0	1	12	0
Cambodia		2	1	3	1	3	1	4	1
Philippines (around Manila)		6	0	0	0	0	0	0	0
East Pakistan	Brahmaputra	0	7	0	13	0	0	0	0
	Ganges	0	15	0	0	0	0	0	0
	Others	0	6	0	11	0	1	0	0

The transformation of nitrogen in a soil after flooding takes place in conjunction with oxidation-reduction occurring in the flooded soil. While nitrate nitrogen is stable under the oxidative condition, ammonium nitrogen is stable under the reductive condition. Most nitrogen is present in organic form in the soil, and rice plants under flooded condition absorb most of the nitrogen in the form of ammonium. Koyama (1971) reported that more than half of the nitrogen absorbed by plants originated from soil nitrogen even in the case of nitrogen fertilization, and that this rate was much higher in tropical regions than in temperate zones. Accordingly, the patterns of mineralization from soil nitrogen and of loss from the soil have a strong influence on the plant growth and yield of rice.

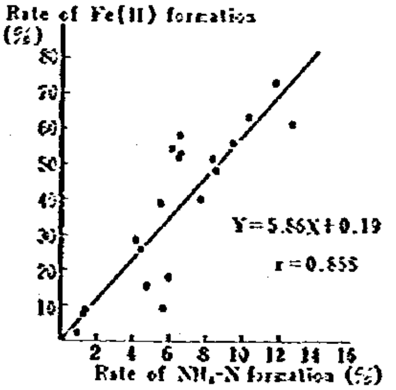

Fig. 3-4 Relationship between Ammonium Formation & Fe (II) Formation.
(Motomura, S. 1969)

3-8-1. Production of Ammonia

As described before, soil nitrogen is mineralized to produced ammonia through the action of soil microbes at the stage of ferrous iron formation after the disappearance of molecular oxygen and nitrates in the soil in the course of development of soil reduction after flooding. As seen from Fig. 3-4, a high correlation has been found between the rate of ferrous iron formation (the ratio of ferrous iron produced relative to free iron oxide) and that of ammonia formation (the ratio of ammonia produced relative to total soil nitrogen)(Motomura, 1963).

The main factors influencing mineralization of organic nitrogen in the flooded soils are as follows: (a) soil temperature, (b) quality and quantity of organic matter in soils, and (c) pre-treatment of the soil prior to flooding.

Soil temperature elevation should affect the microbial action and hence the mineralization of soil nitrogen. Shioiri (1943) reported a virtual doubling of ammonia production when the temperature of anaerobic incubation was raised from 26° to 40°C. Yamane and Sato (1961) also obtained nearly the same result, which showed that ammonia production increased with incubation temperature up to 60°C.

Shioiri et al. (1941) found the interesting result that the amount of ammonia produced doubled when the soil was air-dried prior to flooding. This corresponds to about 20 kg per hectare assuming that the average dry soil weight of one hectare's plow layer is on average 1,000,000 kg.

A remarkable increase in the amount of ammonia is produced when soil pH is raised temporarily to above approximately 8.5 by liming. An example of this effect obtained from some Thai paddy soils under field condition is is given in Table 3-5 (Motomura, 1973).

Table 3-5 Effect of Liming on Mineralization of Soil Nitrogen

(Motomura, S. 1973) NH_4-N ppm

	Liming Rate kg/ha				pH	T.N.
	0	400	600	800	(H_2O)	%
Bang Khen	40.0	53.6	—	62.4	5.2	0.126
Klong Luang	17.2	23.2	—	21.2	4.2	0.125
Sakon Nakhon	6.5	—	14.3	—	4.5	0.035

The favorable effect of pre-treatment on ammonia production is considered to be mainly due to the fact that easily soluble humus is depeptized from soil mineral-organic complexes to make it susceptible to microbial action (Harada, 1959).

The most important factor affecting ammonia production in the flooded soil is the quality and quantity of organic matter contained. In soils rich in decomposable organic matter, ammonia is rapidly produced and reaches 300 ppm within 30 days after flooding, while in soils poor in organic matter, mineralization of soil nitrogen goes on very slowly and the amount of its end product is quite low, as shown in Fig. 3-5 as an example (Ponnanperuma, 1964). On the other hand, inorganic nitrogen is released faster and in larger amounts from organic matter with a low carbon-nitrogen ratio than from that with a high ratio. When organic materials with a high carbon-nitrogen ratio like rice straw are incorporated in the soil, special attention should be paid to the time and quantity of organic materials added, because such materials may cause nitrogen

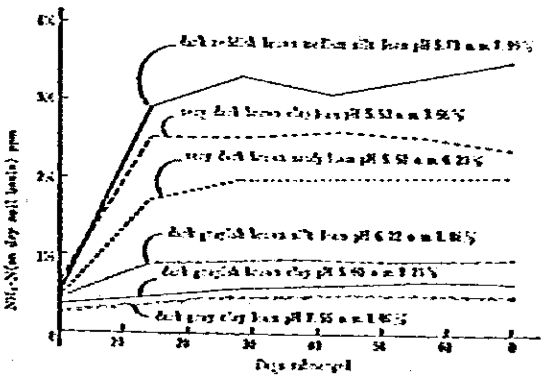

Fig. 3-5 Kinetics of Total NH_4-release in Six Submerged Soils.

(Ponanperuma, F.N. 1961)

starvation to rice plants owing to assimilation of soil nitrogen by soil microbes during the decomposition of the organic materials added.

Table 3-6 shows the amount of ammonia produced after two weeks' anaerobic incubation at 40°C using various types of paddy soils from Southeast Asian countries (Kawaguchi and Kyuma, 1969A). The results indicate that ammonia production is generally high for Malayan paddy soils as compared to the soils from Thailand, Cambodia and Bangladesh, and that the ammonification rate is apt to be lower in inland areas of Southeast Asia than island areas. This is probably due to the difference in quality of soil humus, of which the latter areas are humified more progressively.

Although a part of the ammonia produced in flooded soil or fertilizer nitrogen is adsorbed on soil colloid through base exchange reaction, most of them are present in soil solution and readily assimilated by plants. However, in coarse-texture soils, ammonia in soil solution easily leaches out of the soil with downward movement of irrigation water.

Table 3-6 Amount of Ammoniacal Produced in Anaerobic Incubation
(Kwaguchi, K. and Kyuma, K. 1969)

	NH_4-N mg/100g	% of T.N.
Malaya	12.67	6.47
Thailand	5.13	5.26
Ceylon	8.69	7.01
Cambodia	4.02	5.13
Philippines	6.33	5.32
East Pakistan	6.73	4.54
Japan	11.73	6.37

3-8-2. Denitrification in Paddy Soil

Oxygen gas in the atmosphere is dissolved in the surface water of paddy soil. Furthermore, such aquatic plants as algae and duckweed grow and release oxygen into the surface water through their photosynthetic action. In this way, with permeation of the surface water, the surface soil in paddy field is supplied with some oxygen gas.

Soil microbes consume far more oxygen in their respiration than can be supplied on account of the vigorous decomposition of organic matter for a time after flooding, so that oxygen supplied disappears very rapidly in the soil. Thus, a reduced condition is set up in the flooded soil, which shows a bluish or greenish gray color on account of the ferrous iron compound produced during the developing process of soil reduction. With the progress of soil reduction after rapid decomposition of organic matter, the supply of oxygen from irrigation water comes to surpass the consumption by soil-microbes. At this stage, oxygen supplied from irrigation products to oxidizing ones, but its influence is limited to a depth of from a few millimeters to one or two centimeters. The soil color of this layer shows yellowish brown as a result of the conversion of ferrous iron to the ferric state. This layer corresponds to an oxidized layer where soil microbes live aerobically. Below this layer is the so-called reduced layer where microbes live anaerobically. In this way, the surface or plow layer of paddy soils is eventually differentiated into two layers, that is, an oxidized layer and a reduced layer, during flooding.

In the reduced layer of paddy soils, obligate aerobic bacteria like nitrifiers may not thrive because of the anaerobic condition there, and ammonia stays very stable because it is not subjected to biochemical change. In the oxidized layer, on the other hand, nitrifier may be so active that ammonia may be oxidized to nitric acid through nitrificalton. Nitric acid produced in this manner may diffuse itself or be transported by percolation water into the reduced layer. In the reduced layer or local reduced spots present in the oxidized layer, nitric acid may be converted to nitrogen gas and/or oxides of nitrogen by a dentrifier to volatilize into the atmosphere. This is the main mechanism of denitrification taking place in paddy soils, by which much nitrogen is lost from the soil into the atmosphere. Shioiri et al. (1941) clearly explained this process, giving a schematic diagram of the differentiation of the surface plow layer under the flooding and biochemical changes involved, as shown in Fig. 3-6.

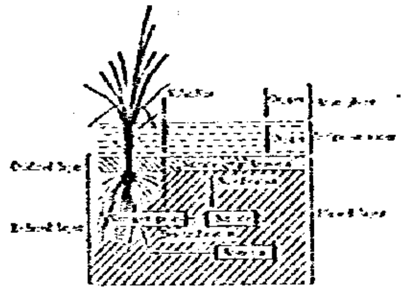

Fig. 3-6 Denitrification in Paddy Soil
(Shioiri, M. 1943)

When nitrogen fertilizers are applied to soil for rice production after flooding, most of the nitrogen applied remains in the uppermost layer, which may become the oxidized layer after the soil differentiation of the plow layer. This may mean that a considerable amount of nitrogen applied as basic fertilizer will be lost under flooded condition, principally through denitrificaiton subsequent to the nitrification process as described above. In order to minimize possible loss of nitrogen from the soil, therefore, nitrogen fertilizer should be applied to the soil as deeply as possible. This application method proposed by Shioiri is commonly practiced in Japan as the deep placement method of fertilizer application.

Recently, to prevent nitrification in the soil, a certain type of nitrificaiton inhibitor is being developed. Thio-urea, N-serve, dicyan diamin, PCP etc. are found to be conducive to improvement of rice yield as a result of advances in the efficiency of nitrogen fertilizer.

3-8-3. Fixation of Atmospheric Nitrogen in Paddy Soil

It is assumed that nitrogen fixation takes place in paddy soils through the action of living-free nitrogen fixers such as azotobacter, beijerinckia, clostridium, photosynthetic bacteria and blue green algae. This nitrogen fixation from atmosphere must contributes significantly to maintenance and improvement of soil fertility in paddy fields.

The population of free living nitrogen fixers in habiting Thai paddy soils investigated by Matsuguchi (1971) is given in Table 3-7. Gray podzolic soils, humic gley soils, non-calcic brown soils, grumsols, fresh water alluvial soils, and marine alluvial soils were relatively abundant in each free-nitrogen fixer examined except for beijerinckia, whereas regosols and brackish water alluvial soils were poor in all nitrogen fixing microbes. In low humic gley soils containing comparatively low organic matter, heterotropic bacteria such as azotobacter, clostridium,

Table 3-7 Distribution of Free-living Nitrogen Fixers during Main Season in Paddy Field of Thailand (Matsuguchi, T. 1971)

Great soil groups	NOS. of Samples	Azotobacter	Beijerinckia	Clostridium	Athiorhodaceae	Bluegreen algre
Gray podzolic soils	1	10^4	--	10^4	10^4	10^4
Low humic gley soils						
North region	5	10^2	10^1	10^5	10^5	10^5
Northeast region	6	10^2	--	10^3	10^4	10^3
Central plain	5	10^3	10^2	10^5	10^4	10^4
Humic gley soils	1	10^4	--	10^4	10^4	10^4
Non-calcic brown soils	1	10^3	--	10^5	10^3	10^4
Regosols	1	10^2	--	10^4	10^3	10^2
Grumsols	1	10^3	--	10^4	10^2	10^4
Fresh water alluvial soils						
North region	3	10^3	10^2	10^4	10^4	10^4
Northeast region	2	10^4	10^3	10^3	10^4	10^4
Central plain	1	10^4	10^2	10^5	10^4	10^5
Brackish water alluvial soils	3	10^3	--	10^4	10^3	10^2
Marine alluvial soils	6	10^4	--	10^5	10^4	10^5

Numbers of Microorganisms Perg of dry Soil

Table 3-8 Estimated Amounts of Microbial Nitrogen Fixation per Year in Paddy Field of Thailand (Matsuguchi, T. unpublished data)

Soil Groups	Fixed nitrogen kg/ha/year		
	Paddy soil	Paddy water	Sum
Marine alluvial soils	6.5	4.8	11.3
Brackish water alluvial soils	2.5	0.8	3.3
Fresh water alluvial soils			
Low pH's soils	3.8	1.3	5.1
High pH's soils	29.6	0.2	29.8
Low humic gley soils	3.0	0.5	3.5

beijerinckia etc. were scarce while auto-autotrophic micro-organisms like blue green algae and photosynthetic bacteria were relatively abundant. Beijerinckia which had been thought to be widely distributed in tropical soils was detected in only a few of the soils examined and was at a rather low level (less than 10^{-1} per one gram of dry soil). The population of these microorganisms is recognized to have a high correlation with soil pH and content of available phosphorus in the same great soil groups.

Matsuguchi and Tangchom (n.d.) have estimated the amount of annual nitrogen fixation in Thai paddy soil from the acetylene reducing activities of soil and surface water of the paddy fields as shown in Table 3-8. Marine alluvial soils and fresh water alluvial soils fixed much more nitrogen than brackish water alluvial soils and low humic gley soils, the amount being estimated at between 11.3 and 29.3 kg per hectare in the former and 3.3 to 3.5 kg in the latter. The average in the whole country amounted to 6.9 kg of nitrogen per hectare. Analysis of atmospheric nitrogen fixation in soil, water and rice roots of the field by the acethylene reduction method and the isotopic ^{15}N method carried out by Yoshida and Ancajas (1972) showed that the nitrogen fixing bacteria in the rhythosphere of rice can fix about 3 to 63 kg of atmospheric nitrogen per hectare in association with the rice plants in the field. They also clarified thatthe nitrogen fixing activities in flooded soils increased after the panicle initiation stage of the rice plant and it was higher in the planted soil than in unplanted soils.

So far, much attention has been directed to ward nitrogen fixation by blue-green algae. After incubation of paddy soils collected from each region of India for three months, P.K. De (1936) observed that 4 to 35% of the total nitrogen in soil increased through the action of blue-green algae reproduced vigorously by the application of lime and phosphorus, resulting in an increment of total nitrogen in the soil, which corresponded to about 20 kg as nitrogen per hectare.

In this way, nitrogen in paddy soil is steadily enriched more or less through nitrogen fixation from the atmosphere by soil microbes and blue-green algae.

3-9. PHOSPHOROUS IN PADDY SOIL

Phosphorus exists in soil in several forms, namely organic phosphorus, calcium phosphate, aluminum phosphate and iron phosphate, a part of which is occluded by iron oxides.

Analytical data of total phosphorus content and 0.2 N HCl soluble phosphorus measured by Kawaguchi and Kyuma (1969A) are given in Table 3-9. Generaly speaking, the total phosphorus content in the plow layer from different regions in Southeast Asia is quite low, especially in Thailand and Cambodia. The level of 0.2 N HCl soluble phosphorus varies with the region, but is fairly high in Bandladesh. Soils around Manila, in the Philippines,contain relatively high amounts of total phosphorus, but very little 0.2 N HCl soluble phosphorus. The high contents of both forms of phosphorus in Japanese soils are certainly due to fertilizer application over a long time.

Cholitkul and Tyner (1971) who conducted the fraction studies of soil phosphorus in Thai paddy fields reported that iron phosphate and occluded phosphate were the most abundant among various inorganic forms and followed aluminum phosphate and calcium phosphate.

With the progress in soil reduction after flooding, soil phosphorus becomes so soluble that rice plants may readily assimilate it. The reason for this can be understood as follows: (a) mineralization of organic phosphorus by its microbial decomposition, (b) release of PO_4^{3-} anion from ferric phosphate in the course of conversion of ferric phosphate to the ferrous form ($3\ FePO_4 \rightarrow Fe_3(PO_4)_2 + PO_4^{3-}$) and increment in solubility due to the formation of ferrous phosphate, (c) release of PO_4^{3-} from iron phosphate when the hydrogen sulfide produced reacts with iron phosphate to precipitate iron sulfide, and (d) reversable liberation from inorganic phosphate when anions of organic acids produced combine with iron, aluminum and calcium in inorganic phosphorus forms.

Table 3-9 Total Phosphorus and 0.2 N HCl Soluble Phosphorus
(Kawaguchi, K. and Kyuma, K. 1969)

	$T\text{-}P_2O_5$ mg/100g	0.2N HCl Soluble P_2O_5 mg/100g
Malaya	35.0	5.39
Thailand	22.3	3.01
Ceylon	31.6	5.68
Cambodia	19.3	1.27
Philippines	39.8	1.31
East Pakistan	36.7	15.39
Japan	82.8	31.57

However, if soil reduction proceeds actively, it is pointed out, soil phosphorus is finally reduced to phosphin as a metabolic end-product to volatilize from the soil into the atmosphere through the following pathway:

$H_3PO_4 \dashrightarrow H_3PO_3 \longrightarrow H_3PO_2 \ \ldots\ldots \ PH_3$.

3-10. REDUCTION OF SULFATES AND THE AKIOCHI PHENOMENON

The conversion of sulfates to sulfides takes place in a soil after it has undergone appreciable reduction. This transformation occurs as a result of the activity of soil microbes, which use SO_4^{2-} as the terminal electron acceptor in their respiration. When redox potential further progressively declines accompanying a large accumulation of sulfides, it is well known that mercaptan is produced in such a strongly reduced soil.

In normal paddy soils rich in active iron, the hydrogen sulfide emitted readily reacts with iron to precipitate black iron sulfide, which is not toxic to rice plants. If the active iron content in plow layer soils is not sufficient to combine with the hydrogen sulfide, the concentration of free hydrogen sulfide in soil solution is so high that rice roots are easily damaged, resulting in retardation of the assimilation of water and nutrients and the occurrence of root decay. In this way, though rice plants growing in a paddy soil low in active iron appear to be in normal growth at the early stage, the growth and appearance of the rice plants become extraordinarly poor at the later stage in mid-summer, and grain yield is unexpectedly low. This is the so-called Akiochi phenomenon. Moreover, the attack of Helminthosporium leaf spots is one of the general characteristics of the affected plants. These soils originate from acidic igneous rock such as granite, quartzporphyry and liparite and usually are very-coarse-texture soils sometimes with a sand and/or gravel layer inthe lower part. Therefore, nutrient-holding capacity usually is very low. This kind of soil is called degraded paddy soil. Field observations have shown that degraded soils have the following general features: (a) the soil of the plow layer is colored gray and shows little evidence of active iron compounds, (b) the lower part of the plow layer is usually bleached, (c) directly below the plough pan layer or slightly lower is a layer where ferric and occasionally manganic oxides accumulate, and (d) the roots of rice plants are usually whitish and without any visible coating of ferric oxides.

Due not only to the prevention of nutrient assimilation after root damage in these degraded soils, but also to the general deficiency of plant foods such as potassium, calcium, magnesium, silica, manganese etc., the growth of rice plants is strikingly retarded in the growing period.

In order to improve such degraded soils, it is indispensable to prevent the generation of free hydrogen sulfide. Some soil amelioration techniques such as soil dressing, admixture of bleached plow layer soils with iron-bearing sub-soils, application of iron-containing materials like brown hematite and bauxite are well known to be very effective for this purpose. Utilization of non-sulfate chemical fertilizers is also effective. In addition, it is necessary to apply large amounts of silica-, magnesium-, calcium- and manganese-containing materials and at the same time to heighten nutrient-holding capacity by incorporation of soil-improving materials. It is also effective to apply more nitrogen as top dressing than as basal dressing to prevent a shortage in nitrogen nutrition later in the growing period.

3-11. SILICA IN PADDY SOIL

When the amount of available silica in the soil as determined by the pH 4 acetate buffer extraction method is lower than 10.5 mg as SiO_2 per 100 g on an air dry basis, a response to silica application is expected in Japanese soils. However, it is not yet known what the criterion would be for tropical paddy soils. In this connection, Kawaguchi (1966) proposed 7 mg of SiO_2 per 100 g of air dry soil as a tentative criterion for silica deficiency in tropical soils.

Table 3-10 shows the available silica content of paddy soils in Southeast Asia measured by Kawaguchi and Kyuma (1969A). As seen from the table, although the available silica content is not so low, some well-weathered sandy soils have a rather low content of available silica. For example, the content is below 4.0 mg per 100 g of air dry soil in the Northeast region of Thailand, and is expecially low in the hydromorphic regosols which are widely distributed there, showing about 1.1 mg of SiO_2. These soils are regarded as typical silica-deficient soils.

Table 3-10 Available Silica Content
(Kawaguchi, K. and Kyuma, K. 1969)

	SiO_2 mg/100g
Malaya	10.5
Thailand	10.7
Ceylon	21.3
Cambodia	11.3
Philippines	42.0
East Pakistan	10.9

As shown in Fig. 3-7, Ponnanperuma (1964) suggested that solubility of SiO_2 increased as the flooding period progressed and its effect was higher in soils with higher content of organic matter. Silica dissolved in water, is present in the form of a monomer $Si(OH)_4$ of which the solubility is independent of pH in the range 1.0 to 7.7. According to McKeague and Cline (1963), monomeric silica is absorbed by freshly precipitated ferric and aluminum hydroxide and can also form complexes with $Fe(OH)^{2+}$. If these complexes are present in soils, reduction of the ferrisilicate complexes should liberate silica.

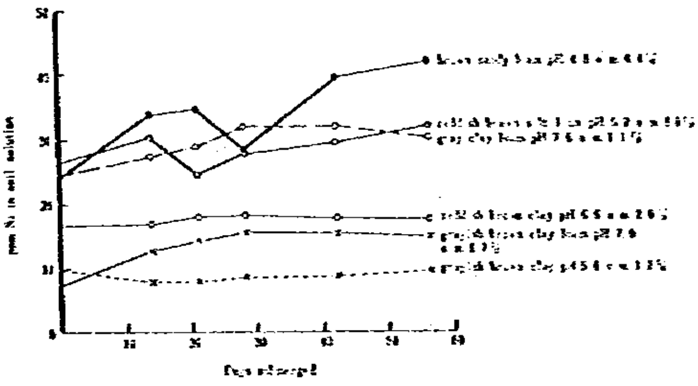

Fig. 3-7 Changes in Concentration of Silicon in Soil Solution of Six Submerged Soils.
(Ponnanperuma, F.N. 1964)

In recent years, the role of silica in the nutrition and well being of rice plants has received increasing attention. Among the benefits claimed for silica are increased yield and resistance to lodging, pests and diseases.

3-12. POTASSIUM AND OTHER BASES

From the plant nutritional standpoint, soils thought to be deficient in potassium for rice plants are rare in tropical paddy soils in Southeast Asia. Kawaguchi and Kyuma (1969A) grouped them into six classes according to the content of K_2O dissolved by 0.2 N HCl. The results for Southeast Asian paddy soils are given in Table 3-11. Potassium contents are relatively high due to ample natural supply from irrigation water and minerals during the weathering process except for soils which have been extremely weathered and leached like those from the Northeast regions of Thailand and Cambodia. These are well drained and coarse textured soils poor in clay fraction.

Table 3-11 The Number of Malayan Soils Belonging to Each Class (Set up with Respect to Levels of Available K_2O in the Surface Plow Layer) in Comparison with Soils from Some Other Countries.

(Kawaguchi, K. and Kyuma, K. 1969)

	Class	A	B	C	D	E	F	Total number of soils examined
	K_2O mg/100g Soil	>25	24.9–15.0	14.9–10.0	9.9–5.0	4.9–2.5	<2.4	
Malaya	West Coast	1	2	6	5	2	1	17
	East Coast	0	0	1	7	2	0	10
	Boggy	4	6	3	1	0	0	14
Thailand	Central Valley	8	13	11	8	2	0	42
	Northern Valley	0	11	12	18	1	0	42
	Khorat	1	1	4*	5*	4	17	32
Ceylon	Dry Zone	2	3	5	7	1	0	18
	Inter & Wet Zones	0	0	1	5	3	2	11
	Boggy Soils	0	0	0	0	2	2	4
Cambodia	Whole Country	1	2	0	5	4	4	16
Philippines	(around Manila)	2	1	3	0	0	0	6
E. Pakistan	Brahmaputra	5	4	4	6	1	0	20
	Ganges	6	7	0	0	0	0	13
	Plateau & Marginal	0	0	3	11	3	0	17
	Boggy	3	0	0	0	0	0	3
Japan		17	9	17	23	6	0	72**

* Including 2 surface crusts each.

** 22 samples from data on soils from Experimental Stations, cited from; *Collected data (mimeographed) by The Third Section, Chemistry Dept., National Institute of Agricultural Sciences, on paddy soils of the experimental station, 1967.* Fifty samples from data obtained in the author's laboratry.

Similarly, other bases like calcium and magnesium are usually sufficient to grow rice plants normally except for soils with extremely low soil pH or soils built from acidic sandstone.

The concentration of these cations in soil solution is raised after flooding. This is clearly evidenced by an increase in specific conductance of flooded soils. The increase in specific conductance when a soil is kept flooded is caused by mobilization of Ca^{2+} and Mg^{2+} in neutral and alkaline soils and in acid soils by the increase in concentration of Fe^{2+} and Mn^{2+} and the displacement of chiefly Ca^{2+}, Mg^{2+} and K^{+} by cation-exchange reaction.

3-13. CHANGES IN SOME PHYSICAL AND CHEMICAL PROPERTIES UNDER WATER MANAGEMENT AND ITS EFFECT ON RICE YIELD

The development of soil reduction in paddy fields after flooding brings about many advantages for plant growth like heightening availability of various nutrients, as mentioned above, whereas flooding causes unfavorable soil environments such as accumulation of harmful substances and shortage of oxygen in the soils. Accordingly, in order to advance rice yield under such conditions, much attention should be paid to how to exclude the disadvantages induced by flooding, and how to increase the advantages as much as possible. For this purpose, water management technique during the rice growing period is considered to be indispensable to high production of rice. It is being practiced.

One of the reasons why rice yield has stagnated in the Central Plain in Thailand is the poor activity of rice roots which is probably caused by strong soil reduction due to a very poor drainage system. Water management in such soil environments is expected to play a profound role in refreshing the root zone. However, in deltaic areas like the Central Plain in Thailand, where the topography is completely flat, the ground water table rises to near the surface plow layer during the growing period, and the soil is very fine in texture, such an effect from water management based on downward movement of irrigation water can not be expected. Accordingly, one of the best methods to improve such soil environments is to drain surface water off intermittently from the surface, so-called intermittent drainage.

Thre results obtained from the field experiment carried out at Bangkhen Rice Experiment Station in the Central Plain of Thailand are described as an example (Motomura, 1973). The changes in soil pH and redox potential during the whole growing period are shown in Figs. 3-8 and 3-9. Soil pH gradually increased after flooding, nearing about 7.0 as flooding proceeded. Intermittent drainage of irrigation water lowered the

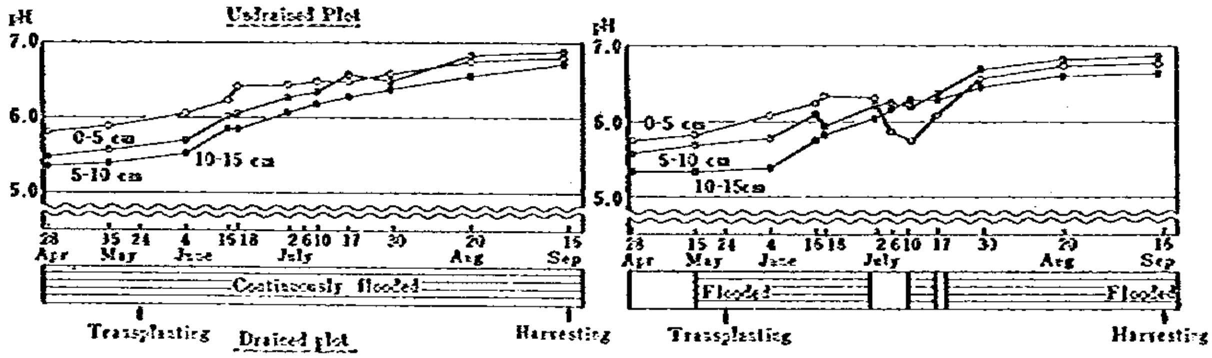

Fig. 3-8 Changes in Soil pH at Bang Khen Field in Wet Season, 1970
(Motomura, S. 1973)

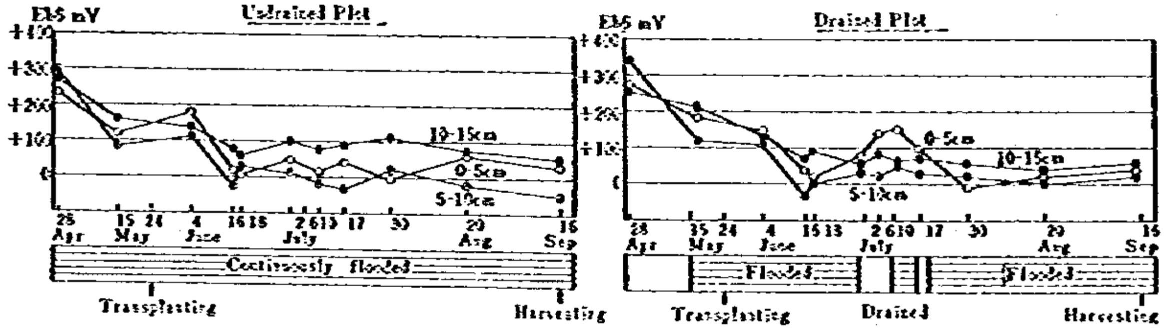

Fig. 3-9 Changes in Redox Potential at Bang Khen Field in Wet Season, 1970
(Motomura, S. 1973)

soil pH of the uppermost layer slightly, but soil pH increased again after flooding again. Such changes were not recognized in the layer more than 5 cm deep. On the other hand, redox potential decreased rather rapidly from the early stage of flooding, and increased rapidly during the draining period to attain +150 mV at the end of the treatment, but dropped again to reach an equilibrium of 0 mV after re-wetting. Such changes were limited to within only 5 cm from the surface as well as by soil pH. During the intermittent drainage treatment, some cracks began to appear on the surface as soil moisture decreased. Fig. 3-10 shows the changes in three phases of distribution during this period, comparing those from Surin soil in Northeastern Thailand. In very-fine-texture Bangkhen soil, the solid phase gradually increased in proportion to the decrease in liquid phase, and air phase increased steadily after the value of solid phase became nearly constant, accompanied by the formation of cracks. In striking contrast, in sandy Surin soil, the solid phase increased only slightly by the treatment, but the air phase was almost unchanged during the whole period of the treatment. In fact, no cracks were observed at all during this treatment.

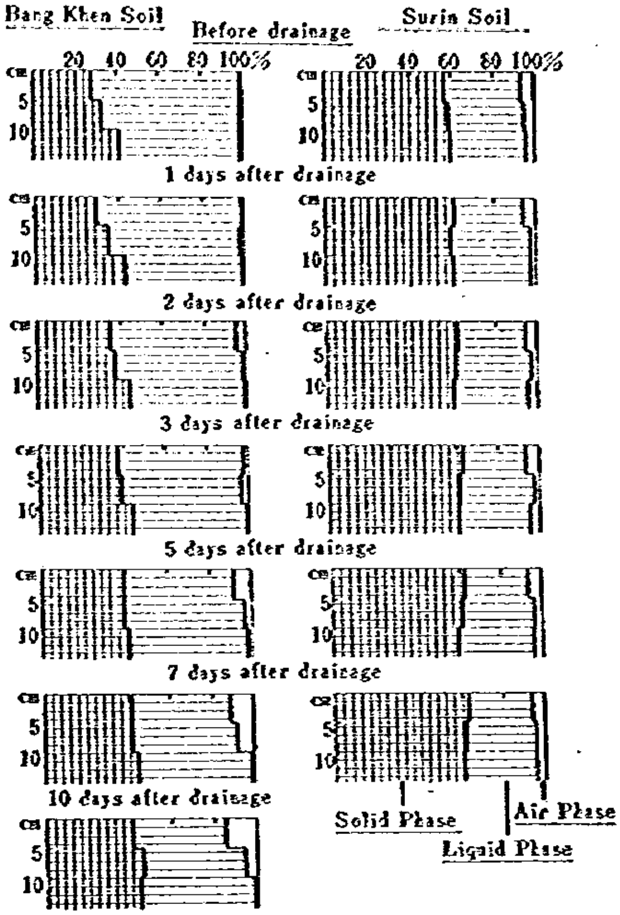

Fig. 3-10 Changes in Three Phases Distribution during Water Management
(Motomura, S. 1973)

As shown in Fig. 3-11, the content of ferrous iron which was one of the reduction products in soil declined linearly with decrement in soil moisture. Such changes were observed most clearly in the uppermost layer and were not seen at a depth of 15 to 20 cm from the surface.

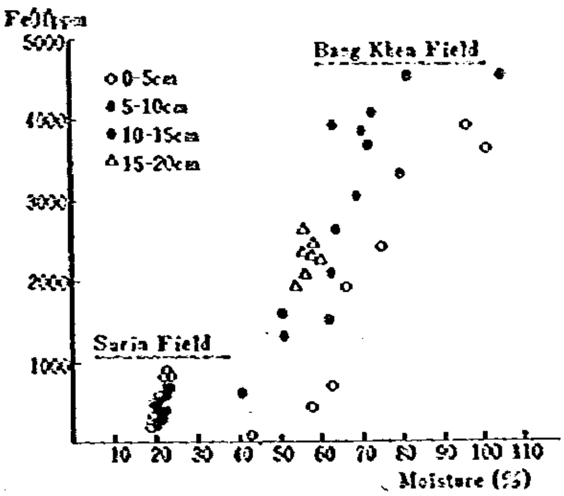

Fig. 3-11 Relationship between Moisture and Ferrous Iron Content
(Motomura, S. 1973)

Such changes in physical and chemical properties after intermittent drainage as described above, imply an improvement in the soil environment surrounding the root zone, and high rice yield. Experimental results of intermittent drainage treatment generally had a favorable effect on grain yield at Bangkhen in the 1969 wet season and at the Surin field in the 1971 wet season, while grain yield obtained from the Bangkhen field in the 1972 dry season was lower in the drained plot than in the control plot (Table 3-12). Osada (1972) also reported the negative effect of drainage treatment on grain yield obtained at a farmer's field in the 1970 wet season, where the soil was considered to be very similar to Bangkhen soil.

In this way, the drainage practice has not had a consistent effect on rice production so far, and at present there is no information to explain this discrepancy. It is, therefore, necessary to clarify the effect of drainage treatment on rice yield by further experiments in plant-water-soil relationship.

Table 3-12 Effect of Intermittent Drainage on Paddy Yield

(Motomura, S. 1973)

Locations		Paddy yield kg/ha	
		Drained	Undrained
Bang Khen, wet season,	1969	6,136	6,078
Surin, wet season,	1971	3,532	3,317
Bang Khen, dry season,	1972	4,558	5,100

Varieties: RD-1
Spacing: 15×30cm in straight row.
Fertilizers: 75—75—75 kg/ha

3-14. EFFECT ON RICE YIELD OF LIMING ACID SULFATE SOILS

Acid sulfate soils derived from brackish water alluvial sediments are characterized by extremely low soil reaction, the value of soil pH being usually 3.0 to 4.5, but occasionally less than 2.0. This low pH value is brought about by the formation of sulfuric acid as a result of bio-chemical oxidation of sulfide compounds in the soil when drained. In spite of the relatively high content of organic matter in the soil, the mineralization of soil nitrogen is known to be quite low compared with other soiltypes, because microbial activities are depressed strikingly due to the strongly acidic reaction. And also, acid sulfate soils are known to be typical phosphorus deficient soils which can fix a large amount of phosphorus. Because of decidedly low soil pH, iron, aluminum and manganese are activated so vigorously that these cations might be toxic to the normal growth of rice plants. In acid sulfate soils, it is, therefore, essentially necessary to correct soil reaction to desirable soil pH in order to increase rice production.

A field experiment concerning the effect of liming on rice production was carried out at Klong Luang Rice Experiment Station in Thailand. The results are given in Fig. 3-12 as an example. Soil pH of this field was 3.5 to 4.5 throughout the profile. So-called cat clay was present at 30 to 50 cm deep from the surface. This soil is regarded as one of the typical acid sulfate soils in Thailand. Grain production was conspicuously low without phosphorus fertilizer regardless of liming and application of other elements, the yield being less than 1.0 metric ton per hectare. This must indicate that grain production may be critically limited by a severe deficiency of phosphorus in this soil. Liming had a very favorable effect on grain yield, but this effect diminished as the nitrogen fertilizer level was increased. The contribution of liming to higher yield must be due to the fact that the liming promotes the mineralization of soil nitrogen as described above.

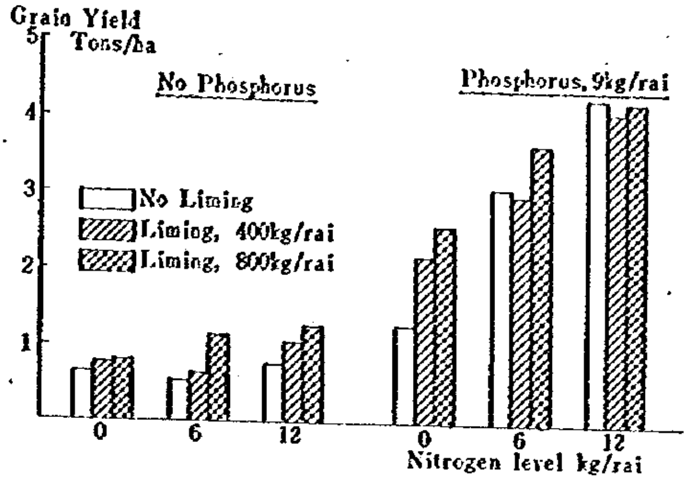

Fig. 3-12 Grain Production
(Klong Luang Experimental Station, Wet Season in 1971)
(Motomura, S. 1973)

3-15. APPLICATION EFFECT OF ORGANIC MATTER ON RICE

Rice production is largely dependent upon soil fertility as is well known. To maintain and improve soil fertility, organic materials such as farm manure, compost, green manure etc. have been applied to the paddy field for a long time in Japan.

The effect of application of such organic materials on rice plants is understood as follows: (a) supplying a source of various nutrients including trace element, (b) increasing availability of various nutrients in soil as a result of the stimulating activity of soil microbes, and (c) improvement of physical and chemical properties of soils.

Suwanwong and Suthdhani (1968) conducted a field experiment on the effect of city compost and farm manure on rice production at various places in Thailand for four years from 1961 to 1964. The results are summarized in Table 3-13. Application of organic matter brought about increasing rice yield. When 6 tons of city compost or farm manure per hectare were applied, the grain production was as high as that in the case of chemical fertilizer application. In their experiment, the highest yield was gained by a combination of city compost with chemical fertilizer.

Table 3-13 Comparison of Effect of City Compost, Farm Manure, and Chemical Fertilizer on Rice Yield
(Suwanawong, S. and Suthdhani, S. 1968)

Treatment	Yield kg/ha
Check	1,941
City compost, 2t/ha	2,181
City compost, 6t/ha	2,396
Farm manure, 2t/ha	2,195
Farm manure, 6t/ha	2,349
City compost (2t/ha) + Fertilizer*	2,350
City compost (6t/ha) + Fertilizer*	2,501
Farm manure (2t/ha) + Fertilizer*	2,271
Farm manure (6t/ha) + Fertilizer*	2,388
Chemical fertilizer (37.5—25—0 kg/ha)	2,274

* 12.5—25—0 kg/ha

However, application of a large

amount of organic matter occasionally may result in soil reduction and lead to some serious disadvantages to rice plants such as nitrogen starvation, accumulation of harmful substances and so on. It is, therefore, of special importance to select the quantity of applied organic materials and their application time in order to maximize the favorable effect of organic matter added.

3-16. CLOSING REMARKS

Soil conditions for high rice yield are manifold depending on climate conditions, cultivation practices and the inherent nature of the paddy soils themselves. In addition, since rice cultivation is usually practiced under flooding conditions, the physical, chemical and biological properties change very complicatedly as aforementioned. Accordingly, in order to gain higher grain yield, a comprehensive understanding is necessary not only of the inherent soil characteristics, but also the characteristics it has acquired through rice cultivation. Fertilizer application and soil management most suitable to the soil properties concerned must also be practiced. If a soil has any critical failures in plant growth, it is needless to say that soil improvement, first of all, should be conducted to remove such failures. Further, careful attention should be paid how to maintain and increase soil fertility by conducting reasonable soil management.

3-17. LITERATURE CITED