DEVELOPMENT OF RICE VARIETIES SUITABLE FOR DOUBLE CROPPING

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ABSTRACT

The traditional varieties of rice grown in South and Southeast Asia were tall, susceptible to lodging and low-yielding. They were photoperiod-sensitive and matured in 170–190 days. Only one crop of rice a year could be grown with these varieties. However, high-yielding varieties which are short, resistant to lodging and responsive to nitrogen have been developed. They mature in 100–100 days, have multiple resistance to diseases and insects, and tolerance for soil problems, higher yield stability and superior grain quality. Their productivity per day is much higher than that of varieties of medium growth duration (130–140 days). These short duration varieties have been widely adopted by Asian farmers. Most rice areas which were mono-cropped with late-maturing varieties of rice are now double-cropped. Farmers either grow two crops of rice during the rainy season or an upland crop before or after the rice crop is planted. This has resulted in increased food supplies, rice self-sufficiency and increased food security throughout Asia. Adoption of double cropping has created greater opportunities for on-farm employment and many new jobs have been created in post-harvest handling and marketing activities.

Introduction

Major increases in rice production have occurred in most of the rice-growing countries of Asia during the last two decades. As an example, rice production in the Philippines increased from 4.0 million tons in 1965 to 9.1 million tons in 1985 (Table 1). From the beginning of rice cultivation in Indonesia about 2,000 years ago to 1965, rice production increased to 12.9 million

Table 1 Increases in rice production in selected Asian countries, 1965–1985

Country	Rice production (metric tons)		% Increase in 1985 over 1965
	1965	1985	
Bangladesh	15.7	22.5	143.3
Burma	8.0	14.5	181.2
China	92.0	171.3	186.1
India	45.9	91.5	199.3
Indonesia	12.9	39.0	302.3
Korea (South)	4.8	7.8	162.2
Malaysia	1.2	1.8	150.0
Pakistan	1.9	5.0	263.1
Philippines	4.0	9.1	227.5
Thailand	11.1	19.5	175.6
Vietnam	9.8	15.8	161.1
Sri Lanka	0.8	2.3	287.5

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tons. However, it increased to 39.0 million tons in 1985 - an increase of 300% during the twenty year period. This phenomenal increase in rice production is largely the result of the introduction of improved rice varieties which have permitted the adoption of improved cultural practices and higher cropping intensity.

Rice varieties for double cropping

The improved rice varieties released in the mid 1960s, such as IR5 and IR8, are photoperiod-insensitive and can be planted throughout the year in the tropics and subtropics. However, they are not suitable for double cropping because they mature in 135-140 days. Moreover, they are susceptible to attacks of major diseases and insects. They are thus not suitable for growing in a two-rice-crops-a-year system which is vulnerable to the build-up of disease and insect organisms.

In the late 1960s, we initiated a program for developing high-yielding rice varieties suitable for double cropping. It was evident that such varieties must have the following characteristics: high yield, shorter growth duration, multiple resistance to diseases and insects, good grain quality, and tolerance for several soil problems.

1 High yield

Yield is the primary consideration in a varietal development program. During the selection process, those saved were early-maturing lines which matched the yield potential of varieties with medium growth duration. The key to the success of this program was the selection of genotypes with rapid vegetative vigor in the earlier growth stages. Because of higher growth rates in the earlier stages, the early-maturing varieties such as IR36, IR50, or IR64 are able to produce approximately the same total biomass in 85-90 days as the medium duration varieties do in 115-120 days. Moreover, the harvest index of early-maturing varieties is slightly higher than that of the medium-maturing varieties. The yields of early and medium growth duration varieties are similar.

However, since the short duration varieties produce the same amount of grain in fewer

Table 2 Yield of promising early-maturing lines and varieties (IRRI, 1984 dry and wet seasons)

Selection	Growth duration (days)	1984 DS		1984 WS	
		Total yield (t/ha)	Yield per day (kg)	Total yield (t/ha)	Yield per day (kg)
IR19743-46-2-3-3-2	98	5.6	73	4.2	54
IR29658-69-2-1-2	107	6.8	79	4.8	56
IR29658-94-2-1-3	107	7.4	86	4.9	57
IR29725-22-3-3-3	108	7.1	82	3.8	44
IR31802-48-2-2-2	106	6.7	79	3.6	42
IR31851-63-1-2-3-2	106	7.6	89	3.6	42
IR31868-64-2-3-3-3	110	7.1	80	4.2	47
IR32307-107-3-2-2	110	7.3	82	4.1	46
IR32429-47-3-2-2	105	7.6	90	5.7	68
IR58	100	6.5	82	4.6	58
IR36	110	7.2	81	4.4	49
IR64	110	7.9	88	4.8	54
IR42 (check)	135	7.8	68	4.5	39

days compared to the medium duration varieties, their productivity per day is much higher. In replicated yield trials at IRRI, IR64 produced 88 kg/day during the 1984 dry season and 54 kg/day in the wet season (Table 2). For IR42, the corresponding figures were 68 kg/day (dry season) and 39 kg/day (wet season).

2 Shorter growth duration

To reduce the growth duration of high-yielding dwarfs, we used several tall, traditional early-maturing varieties such as TKM6, Tadukan and Mudgo. These early-maturing parents have a very low yield potential and are susceptible to diseases and insects. However, we combined earliness with high yield traits such as rapid growth rates and high harvest index and developed numerous breeding lines with short growth duration and high yield. As shown in Figure 1, 70% of the entries in our replicated yield trials in 1978 matured in less than 110 days

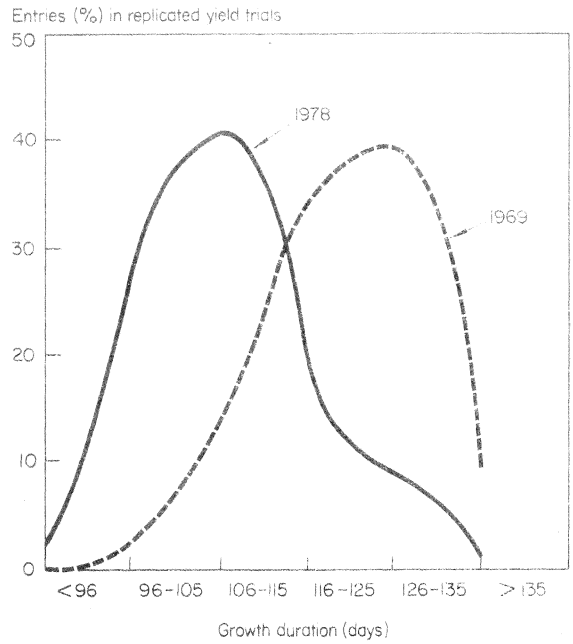

Fig. 1 Proportion of entries (% of total) with different growth duration grown in replicated yield trials in 1969 and 1978 wet seasons at IRRI.

(96–110 days), a marked change from the 1969 yield trials where only about 18% of the entries matured in less than 116 days. This proportion of early-maturing entries has been maintained ever since. All the early-maturing IR varieties mature in 100–110 days. IR58 is the earliest, maturing in 100 days.

We have evaluated breeding lines with even shorter growth duration. However, yield starts to decline as the growth duration is reduced to less than 100 days. The total yield and productivity per day of lines with a growth duration of less than 95 days are sharply reduced. We are therefore developing lines with a growth duration of 100–110 days.

3 Multiple disease and insect resistance

Multiple disease and insect resistance is important in intensive cropping systems. Improved management practices such as application of high levels of fertilizers as well as planting of successive crops of rice one after the other, are ideal for the build-up of insect populations and diseases. Susceptible varieties are vulnerable to the attack of diseases and insects and thus have a low yield stability. This necessitated the development of early-maturing varieties with multiple disease and insect resistance from the very beginning. Table 3 shows

Table 3 Disease and insect ratings of early-maturing varieties[a]

Variety/ Selection	Growth duration (days)	Reaction[b] to								
		BL[c]	BLB	RTV	GSV	BPH bio.			GLH	SB
						1	2	3		
IR579-48-1-2	107	R	R	S	S	S	S	S	S	MR
IR747B2-6-2	100	R	R	S	S	R	S	R	S	MR
IR1561-228-3-3	110	R	R	S	S	R	S	R	S	MR
IR28	105	R	R	S	R	R	S	R	R	MS
IR30	107	MS	R	MR	R	R	S	R	R	MS
IR36	107	R	R	MR	R	R	R	S	R	MR
IR50	105	R	R	R	R	R	R	S	R	MS
IR56	105	R	R	R	R	R	R	R	R	MS
IR58	100	R	R	R	R	R	R	S	R	MR
IR60	106	R	R	R	R	R	R	R	R	MR
IR62	112	MR	R	MR	R	R	R	R	R	MR
IR64	112	MR	R	R	R	R	MR	R	R	MR

a Based on tests conducted in the Philippines.
b R = resistant; MR = moderately resistant; S = susceptible.
c BL = blast; RTV = tungro; GSV = grassy stunt; SB = stemborer; BLB = bacterial leaf blight; BPH = brown planthopper; GLH = green leafhopper.

that most of our early-maturing varieties are resistant to as many as four diseases and 3 insect species. These varieties with multiple resistance have a much higher yield stability compared to susceptible varieties (Fig. 2).

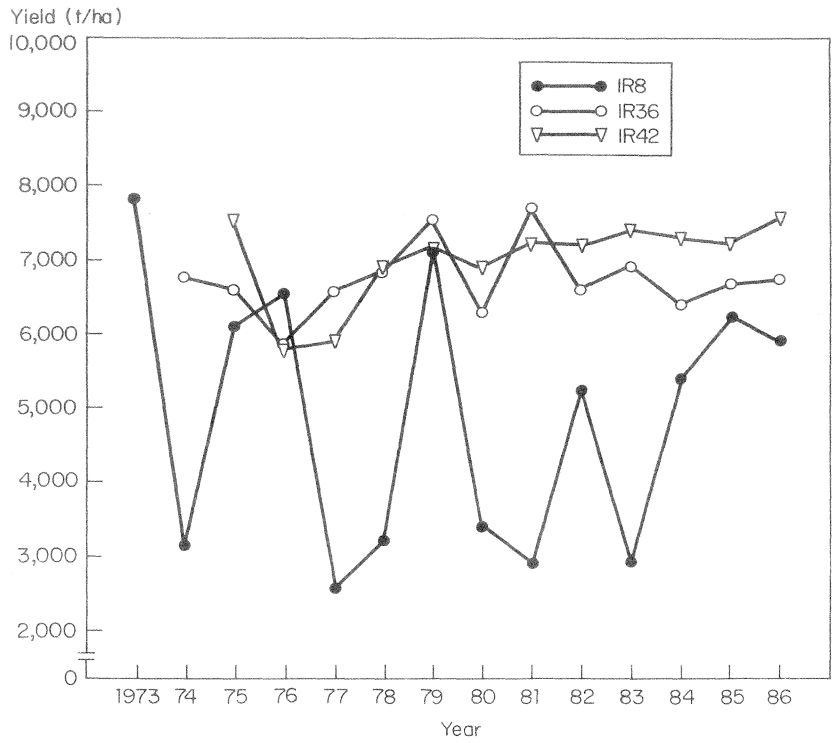

Fig. 2 Yields of IR8, IR36 and IR42 in dry season replicated yield trials at IRRI. Yields of IR36 and IR42 with multiple resistance show little year-to-year variation but the yield of susceptible IR8 fluctuates widely.

4 Grain quality

Grain quality in rice is dependent on the milling recovery, grain size, shape and appearance and cooking characteristics. Higher milling recovery is a universal requirement and to some extent determined by the size, shape and amount of chalkiness in the grain. Most consumers in the tropics and subtropics prefer long or medium long and slender translucent grains. The grain chalkiness of dwarfs (as in IR8) causes low milling recovery and poor consumer acceptance. We therefore selected only those early-maturing lines with long, slender and translucent grains.

The cooking quality is determined largely by the amylose content and gelatinization temperature. In the tropics and subtropics, varieties with intermediate amylose content and intermediate gelatinization temperature are preferred. We incorporated intermediate gelatinization temperature in IR36, IR50, IR60, IR62, and IR64. However, most donor parents for earliness and disease and insect resistance have high amylose content. Consequently most of our early-maturing varieties inherited the high amylose content.

The early-maturing IR64 released last year is the first improved variety with intermediate amylose content and intermediate gelatinization temperature. Its consumer acceptance is highest of all the improved varieties and it is being adopted rapidly in the Philippines. It is now being evaluated in many other countries.

Short duration varieties have consistently a higher protein content compared to medium duration varieties. For example, the protein content of early-maturing IR36 and IR58 is 1%

higher than that of IR8 and IR42 at the same yield level (Table 4).

Table 4 Grain yield and protein content of four rice varieties with varying growth duration (IRRI, 1978–82 dry seasons)

Variety or line	Growth duration (days)	1978	1979	1980	1982	Mean
			Brown rice protein (%)			
IR42	131	8.2	8.3	8.8	7.8	8.3
IR8	124	7.1	7.3	7.7	7.7	7.4
IR36	110	8.6	8.5	10.2	8.8	9.0
IR58	104	8.8	8.6	10.2	9.2	9.2
			Grain yield (t/g)			
IR42	131	6.5	6.6	6.4	6.7	6.5
IR8	124	3.4	7.2	3.4	5.4	4.9
IR36	110	6.0	6.9	5.5	6.3	6.2
IR58	104	5.8	6.9	5.7	6.3	6.2

5 Tolerance for soil problems

Many rice soils in Asia suffer from nutritional deficiencies and toxicities. For example, Zn deficiency in rice soils is becoming a common concern in many countries. A vast majority of rice

Table 5 Reaction[a] of some early-maturing varieties to adverse soil conditions

Variety	Toxicity					Deficiency	
	Salt	Alkalinity	Peat	Iron	Boron	Phosphorus	Zinc
IR28	7	5	6	4	4	3	5
IR30	5	6	3	3	3	3	3
IR36	3	3	3	3	3	7	2
IR50	4	4	3	5	3	3	3
IR56	3	4	3	5	3	3	4
IR58	3	4	4	4	4	4	3
IR60	3	4	4	6	3	5	5
IR62	4	5	4	3	4	4	6
IR64	3	3	4	5	4	4	4

a On a 0-9 Scale: 0 = no information; 1 = almost normal plant; 9 = almost dead or dead plant.

soils have varying levels of salinity. Varieties tolerant of these deficiencies and toxicities have a more stable performance. We have therefore incorporated tolerance for several soil problems in short duration varieties. IR36, for example is tolerant of salinity, alkalinity, iron toxicity and zinc and iron deficiencies (Table 5).

Breeding history

Breeding for short growth duration at IRRI started with the development of IR747B2-6 from the cross of TKM6[2]/TN1 in 1967. This breeding line matures in 100 days, has good resistance to the brown planthopper (BPH) and bacterial blight (BLB) but is susceptible to tungro (RTV), the green leafhopper (GLH) and blast (B1). This line was crossed with another early-maturing line IR579-48-1-2 from the cross IR8/Tadukan. This cross, designated as IR1561, resulted in several promising selections with higher yield potential. One of the lines of this cross, IR1561-228-3-3 was grown on 0.5 million ha in the Philippines during 1973–74. It was released in Vietnam under the name TN73-2 and was planted to over a million ha during 1973–76. This selection was also released as a variety in China, Mauritania, Egypt and Kenya. In the International Rice Testing Program Yield Nursery (IRYN-E), this selection was the top-yielding entry for two years. Another line of this cross, IR1561-216-6 was named "Prasad" in India.

Selections of IR1651 were early-maturing, had high yield potential and were resistant to several diseases and insects including BPH. They were susceptible to RTV and GLH, however. Several of these selections were therefore employed in the hybridization program. IRRI named the first early-maturing variety IR28 in 1974. This variety originated from the cross IR2061 (IR833-6-2//IR1561-149/IR1737) which had one of the IR1561 lines as a source of earliness. Another early-maturing variety, IR30, released by IRRI in 1974 originated from the cross IR2153 (IR15641-102-6-3/IR20[1]/*O. nivara*). These varieties had multiple resistance and were widely grown in the Philippines and were released in several other countries such as Indonesia, Iran, Vietnam, China, Burma, Bangladesh, India, Egypt, and Nigeria (Table 6).

A new biotype of brown planthopper capable of attacking these varieties originated in the Philippines in 1976, in Indonesia in 1977, and in Vietnam in 1978. The Philippine government released an early-maturing IRRI line, IR2071-625-1-252 from the cross IR1561-228-1-2/IR1737//CR94-13 which was named IR36 in 1976. This variety also had one of the IR1561 lines as a source of earliness. IR36 rapidly replaced IR26, IR28 and IR30 in the Philippines and is still the most widely planted variety in the country.

IR36 which was released in Indonesia in 1977 and in Vietnam in 1978 became the most widely grown variety in these two countries. Approximately 60% of the rice area in Indonesia is now planted to IR36. IR36 has also been released in India, Laos, Kampuchea, Malaysia, Zambia, Malawi, and Mozambique. IR36 is now the most widely grown variety of rice in the world. More than 10 million ha of rice land were planted to IR36 annually between 1980–1984. No other variety of rice or any crop has been planted in such a wide area before.

The main reasons for the popularity of IR36 are its multiple disease and insect resistance (Table 3), early maturity, good grain quality, tolerance to many problem soils, and high and stable yield potential. In the IRYN-E (which is composed of elite breeding lines from many countries and is evaluated at more than 40 locations worldwide each year), IR36 was consistently the highest- or second highest-yielding entry between 1975 and 1980. Because of its wide spectrum of tolerance to adverse conditions, it has become popular in many rainfed environments and is even grown under rainfed upland conditions. It is the most widely adopted variety under the "gogo rancah" type of rice culture in Indonesia.

Another early-maturing IRRI line, IR9224-117-2-3-3 was named IR50 by the Philippine government in 1980. This variety has a higher level of tungro resistance compared to other early-maturing varieties and has been released in Indonesia and India. Another early-maturing IRRI selection, IR13429-109-2-2-1, was recommended by the Philippine Seedboard as IR56. This

Table 6 Early-maturing varieties developed from IRRI-bred materials

Selection	Name	Where named
IR579-48-2-1	Palman 57 Giza 180	India Egypt
IR747B2-6-2	GPL 1	Solomon Islands
IR1561-228-3-3	TN73-2 32 Xuan 5	Vietnam, Kenya, Mauritania, China
IR1561-216-6	Prasad	India
IR2053-87-3-1	BR7	Bangladesh
IR2061-214-3-8-2	IR28	Philippines, Indonesia, China, Burma, Bangladesh, India, Cameroon, Iran
IR2061-628-1-6-4-3	Laxmi	Nepal
IR2153-159-1-4	IR30	Philippines, Indonesia, Vietnam, India, Nigeria
IR2071-625-1-252	IR36	Philippines, Indonesia, Malaysia, Vietnam, Laos, Kampuchea, India, Malawi, Mozambique, Zambia
IR307-247-2-2-3	Semeru NN6A	Indonesia Vietnam
IR9129-192-2-3-5	NN7A	Vietnam
IR9224-117-2-3-3-2	IR50	Philippines, Indonesia, India
IR9752-71-3-2	IR58	Philippines
IR13429-109-2-2-1	IR56	Philippines, Indonesia
IR13429-299-2-1-3	IR60	Philippines
IR13525-43-2-3-1-3-2	IR62	Philippines
IR18348-36-3-3	IR64	Philippines

variety is resistant to three BPH biotypes and has also been recommended in Indonesia.

In the mid-1970s, several short duration rice varieties were introduced from China and used in the hybridization program at IRRI. An early-maturing selection IR9752-71-3-2 was selected from the cross IR28/Kwang Chang Ai/IR36 and evaluated in Philippine Seedboard trials. It was recommended as IR58. This variety matures in 100 days and has the shortest duration of all IR varieties. It inherited its short duration character form the Chinese variety Kwang Chang Ai.

Recently, two early-maturing varieties with resistance to three BPH biotypes have been released by the Philippine Seedboard (Table 6). IR60 originated from the same cross as IR56. IR62 is derived from the cross Ptb33/IR30//IR36. The latest of the early-maturing varieties to be recommended by the Philippine Seedboard is IR64 (Table 5) which was selected from the cross IR5657-33-2-1/IR2061-465-1. Its yield potential is higher than that of the other early-maturing varieties. IR64 combines most of the following desirable traits: high total yield, higher productivity per day, sturdy stems for lodging resistance, short growth duration, multiple resistance to diseases and insects, superior grain and cooking characteristics and tolerance for adverse soil problems. Twenty land races or traditional rice varieties from 8 countries (Fig. 3)

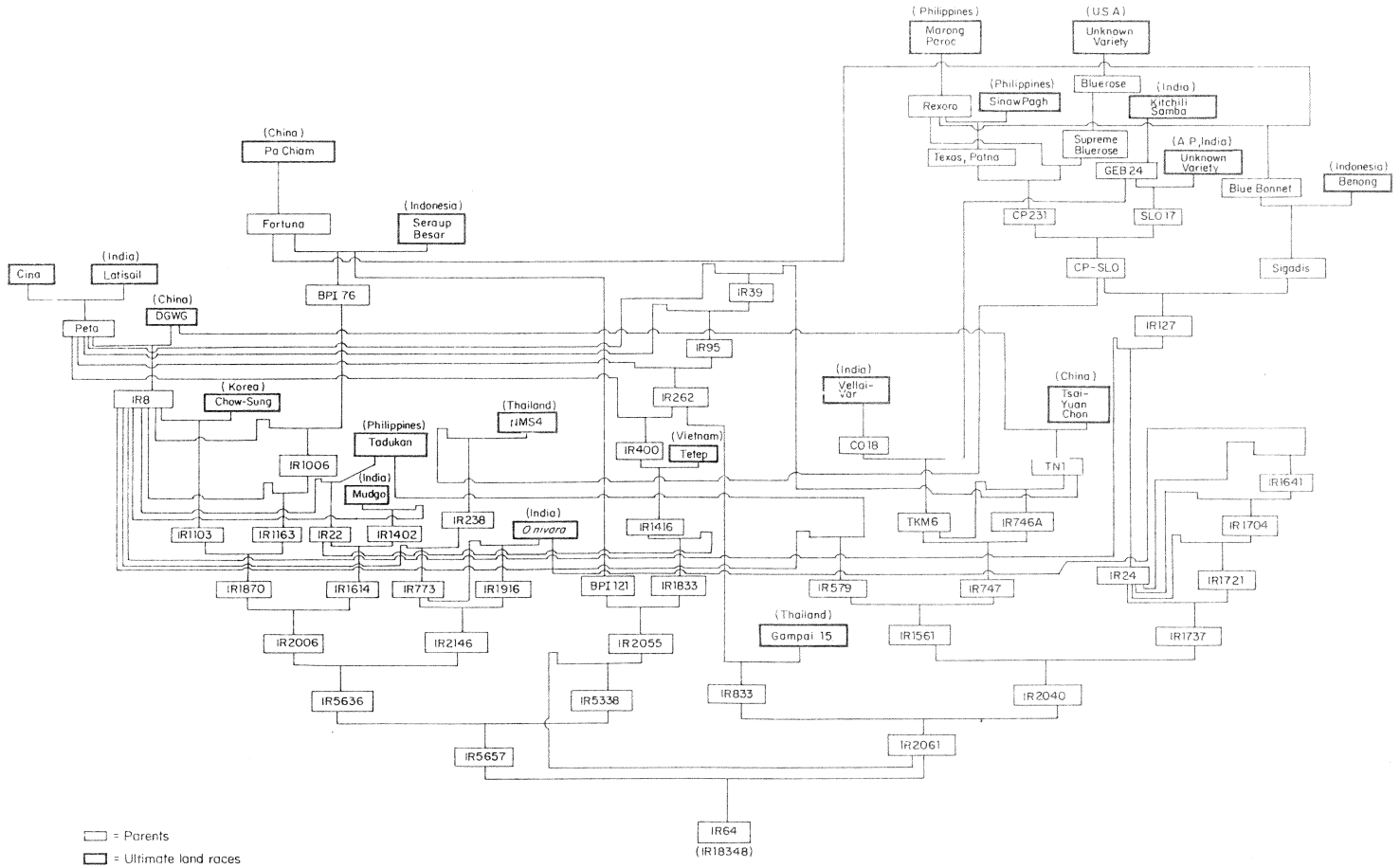

Fig. 3 Twenty land races, or traditional rice varieties, from 8 nations are in the genetic ancestry of IR64, released in May 1985. Female parents are always on the left; males on the right.

were utilized to develop this variety.

Impact of early-maturing varieties

Major changes have occurred in the cropping patterns in Asia after the introduction of short duration varieties. In the Philippines, many farmers now grow an upland crop either before or after rice under rainfed conditions. In some parts two crops or rice are regularly grown during the rainy season (Fig. 4). In the province of Iloilo, for example, 70% of the rainfed

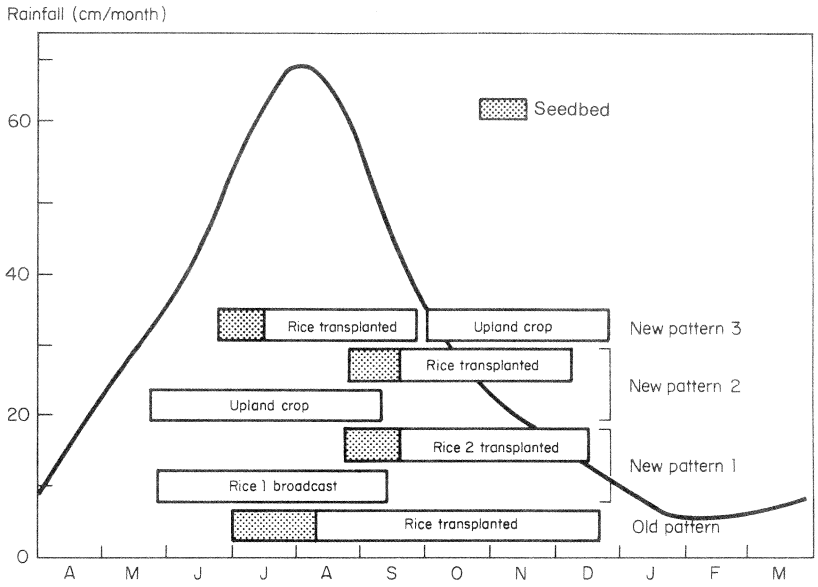

Fig. 4 Schedule of old and new cropping patterns in the Philippines superimposed on rainfall pattern.

area is double-cropped with rice. Farmers grow three crops a year in the irrigated areas.

In Indonesia where IR36 and other early-maturing varieties have been widely adopted, the area under rice double cropping has increased rapidly, resulting in an annual growth rate of 6.4% for rice. The country used to import 2 million tons of rice annually in the 1970s but became self-sufficient in 1983 and had a surplus for export in 1985. In rainfed areas of Burma where only one crop of rice has been grown since time immemorial, the introduction of photoperiod-insensitive varieties has made it possible to grow an upland crop after a main crop of rice (Fig. 5). These changing cropping patterns have resulted in increased food supplies, higher food security and more opportunities for on-farm employment for Asian farmers.

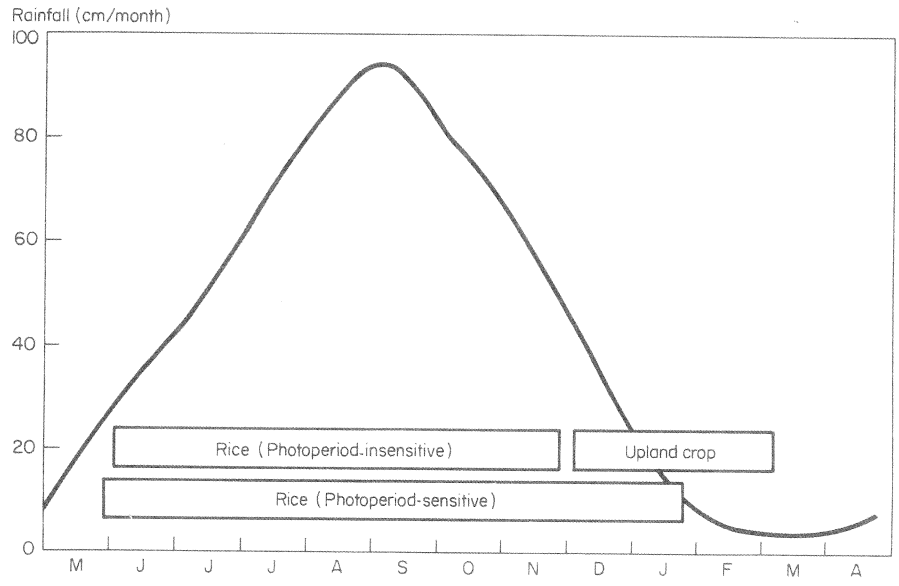

Fig. 5 Rainfall and cropping patterns in Irrawady delta of Burma.

Modern varieties for input economy

Asian farmers have saved millions of dollars in input use by adopting early-maturing varieties with multiple resistance to diseases and insects. Early-maturing varieties show rapid growth rates during the vegetative period and thus are more competitive with weeds. Weed control costs are reduced. Similarly, pesticide requirements are minimized due to multiple resistance. It has been estimated that planting the insect-resistant IR36 saves nearly $500 million in insecticide costs annually. Because the field duration of early-maturing varieties is 25–30 days shorter, they utilize less irrigation water thus lowering the costs of production further.

Discussion

Soetjipto Partohardjono (Indonesia): Do you incorporate some degree of resistance into rice varieties for cultivation in rainfed areas as they are likely to experience water stress? Does IR64 have some degree of drought tolerance as compared with other varieties such as IR36?

Answer: Yes. The incorporation of at least moderate levels of drought tolerance into short duration improved varieties is one of the objectives of the rice improvement program. IR36 for example has a moderate level of drought tolerance. The drought tolerance level of IR64 is similar to that of IR36.

Dat Van Tran (FAO): It appears from the report presented by the Chinese delegate that high yields can be achieved by the combination of suitable varieties in double cropping schemes. Is it not necessary to use different varieties for the first and second cropping as rice plants are grown under different environments, different land preparation (tillage or no tillage) and planting methods?

Answer: In the tropics where the temperature fluctuations are negligible the same variety can be grown for the first as well as the second cropping. However in the temperate areas the varieties should be different. The varieties for the first cropping should have a low temperature tolerance at the seedling stage but a low temperature tolerance at the flowering is required for the varieties for the second cropping. The same varieties can be used regardless of the methods of tillage. The ability to penetrate into the soil may vary with the method of land preparation.