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TROPICAL CLIMATE AND ITS INFLUENCE ON RICE

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TROPICAL CLIMATE AND ITS INFLUENCE ON RICE[1/]

ABSTRACT

Major climatic factors are discussed in relation to their influence on crop period, productivity, and stability.

Most places in monsoonal Asia receive about 300 cal/cm^2 per day during the ripening period of the wet season rice crop. With the right variety and proper management this level of solar radiation should allow rice crops to produce 4 to 5 t/ha.

Advantages and disadvantages of altering plant height and growth duration are described. Intermediate plant height has certain recognized benefits when water control is undependable but these benefits may not be realized unless the varieties resist lodging. Early maturing varieties will become increasingly important. For direct-seeded rice, the shortest growth duration, without much sacrifice in yield potential, is about 90 days; for transplanted rice, it is about 100 days.

[1/]by Shouichi Yoshida, plant physiologist, The International Rice Research Institute (IRRI), Los Baños, Laguna, Philippines. A paper presented at the International Rice Research Conference, IRRI, 17-21 April 1978. Revised and submitted to the IRRI Research Paper Series Committee 25 April 1978.

TROPICAL CLIMATE AND ITS INFLUENCE ON RICE

Climatic factors such as temperature, sunlight, and rainfall influence the growth and yield of rice in two ways. Directly, they affect physiological processes involved in grain production, such as vegetative growth, development of spikelets, and grain filling. Indirectly, they affect grain yield through incidence of diseases and insects.

From a crop physiologist's point of view, there are three important aspects of rice cultivation -- crop period, productivity, and yield stability. Climatic factors affect each in different ways.

In the temperate region, rice cultivation is irrigated and starts when spring temperature is between 13 and 20°C, and the crop is harvested before the temperature drops below 13°C in autumn. In the tropics where temperature is favorable for rice growth throughout the year -- and with irrigation not available in most places -- rice cultivation starts with the rainy season.

In both the tropics and the temperate region, productivity, or rice yield per hectare, is primarily determined by the level of incident solar radiation. In the tropics, with appropriate management, a dry-season crop which has more sunlight, normally yields higher than a wet-season crop (Yoshida 1977a).

Stability of crop yields is affected by several factors. In Hokkaido, Japan, which is about the northern limit of rice cultivation, low temperature frequently causes crop failure. In the past 90 years, 22 crops were affected by cool temperature in summer (Satake 1976). In addition, low sunlight associated with excessive rainfall during ripening causes low yield. In the tropics, too little or too much rainfall at any stage of rice growth causes partial or total crop failure. In Thailand, more than 15% of the cropped area was affected by either drought or flood during eight years from 1907 to 1965 (Table 1), and more than 10% of the cropped area was damaged in 24 of the 58 years. In both the tropics and the temperate region, typhoons are unavoidable hazards.

Geographers define the tropics as the region between the Tropic of Cancer and the Tropic of Capricorn. It is commonly said that the tropics is where winter never comes, implying that temperatures remain high throughout the year. At high altitudes in the tropics, however, the weather is cool,

Table 1. Damaged area, production, and cause of damage to rice in Thailand (1907-1965)[a].

Year	Damaged area (%)	Production (thousand t)	Production decrease from previous year (%)	Cause of damage
1917	21.0	2,989	21.1	Flood
1919	43.4	2,270	32.9	Drought
1928	16.3	3,882	14.1	Drought
1929	19.5	3,875	0.2	Drought
1936	31.7	3,380	28.5	Drought
1942	34.3	3,854	24.7	Flood
1945	24.3	3,572	27.5	World war
1954	18.6	5,709	30.7	Drought
1957	15.5	5,570	32.9	Drought

[a]Israankura 1966.

and the common definition no longer fits. Temperature drops by about 0.6°C per 100-m elevation increase in the lowest 1,500 m of the earth's atmosphere (Lockwood 1974). Thus, it would be more meaningful to define the tropics in terms of temperature.

Among the several temperature-based definitions of the tropics, the one shown in Table 2 is the simplest and fits the Asian climate (Kira 1945). This classification was intended to cover a wide region from the arctic circle to the tropics in Asia. Hence, heat index, which involves use of base temperature (minimum temperature for plant growth) is used as a basic measure of temperature climate. When Kira's classification is applied to the subtropics and tropics, however, the heat index can be converted to annual mean temperature because monthly average temperature in those regions is always higher than the base temperature. Thus, heat index values of 180° and 240° correspond to annual mean temperatures of 20°C and 25°C, respectively. This modification defines the tropics as the region where annual mean temperature is above 25°C. Vegetation characteristics can also be considered as a convenient basis to draw lines between the tropics, subtropics, and temperate region in Asia. In Asia, an annual mean temperature of 20°C is considered as the northern limit for vegetation to include palms (palmae) and screw-pines (pandanus), and 25°C is the northern limit of dipterocarps (Dipterocarpaceae).

Karachi, Pakistan (25°N), and New Delhi, India (28°N), by the above definition, have a tropical climate even though they are north of the Tropic of Cancer.

Table 2. Climatic regions by temperature.

Climatic regions	Heat index[a] (°)	Annual mean temperature (°C)	Vegetation characteristics
Tropics	> 240°	> 25°C	Dipterocarpaceae
Subtropics	180-240°	20-25°C	Pandanus, Palmae
Temperate	< 180°	< 20°C	

[a] $\Sigma (t_i - 5)$ $t_i \geq 5$

TEMPERATURE

Temperature is one of the dominant climatic factors that affect the growth and yield of rice. Each phase of rice growth has critical low and high temperatures, normally below 20°C and above 30°C (Table 3).

Low temperatures critical for germination and rooting determine the time rice cultivation starts. For example, in northern temperate regions where the summer is short, farmers use a plastic-protected nursery. In northern China, a protected nursery is started when air temperature is about 10°C, and seedlings are transplanted into main fields when air temperature is about 20°C. On the other hand, in the Kathmandu Valley, Nepal, which is 1,324 m above sea level, a nonprotected nursery is prepared when the temperature reaches 18-20°C. IR8 planted at the right time at Kathmandu, produced about 9 t/ha (Bhattarai 1970). The rice crop is normally harvested before temperature drops below 13°C. In the tropical climate, however, rice can be grown at any time of the year provided irrigation is available.

The duration of the rice crop until flowering is primarily determined by each of the three factors -- temperature, day length, and sensitivity of a variety to these two climatic factors. After flowering, temperature becomes the dominant factor affecting duration of the ripening period. Thus, temperature dominates for about 30 days from flowering to maturity in the tropics -- but for 65 days in South Wales, Australia, and Hokkaido, Japan (Tanaka and Vergara 1967). Variety slightly influences the duration of the ripening period; varieties with greater grain size take a longer time to mature (Yoshida 1977b). Day length does not affect the duration of the ripening period.

Temperature greatly influences growth rate just after germination; as temperature increases, the growth rate increases. At later stages (3-5 weeks after sowing), however, temperature only slightly affects

Table 3. Response of the rice plant to varying temperature at different growth stages[a].

Growth stage	Critical temperature (°C) Low	High	Optimum	References
Germination	16-19	45	18-40	Chang and Vergara (1971); Nishiyama (1976)
Seedling emergence and establishment	12-35	35	25-30	Nishiyama (1976)
Rooting	16	35	25-28	Nishiyama (1976)
Leaf elongation	7-12	45	31	Nishiyama (1976)
Tillering	9-16	33	25-31	Nishiyama (1976)
Initiation of panicle primordia	15	-	-	Owen (1969, 1972a, b)
Panicle differentiation	15-20	30	-	Nishiyama (1976); Satake (1969)
Anthesis	22	35-36	30-33	Poggendorft (1932); Kusanagi and Washio (1974); Sato et al (1973); Tanaka and Wada (1955); Vergara et al (1970)
Ripening	12-18	>30	20-29	Nishiyama (1976); Yoshida and Parao (1976)

[a]Yoshida 1977a.

tillering and the relative growth rate. During the reproductive stage, within a temperature range of 22°C to 31°C, the number of spikelets per plant decreases as temperature increases (Fig. 1). Thus, the optimal temperature for rice decreases as growth advances from the vegetative to the reproductive stage. For this reason, relatively high-altitude areas would be more productive than low-altitude areas in the tropics unless temperatures are low enough to damage the rice crop.

The rice plant is considered most sensitive to low temperature about 9 days before flowering, which corresponds to the young microspore stage (Satake 1976). In a low-temperature situation, both day and night temperatures appear to affect spikelet sterility, and a daily mean temperature of less than 20°C may induce sterility. Rice is most sensitive to high temperature at flowering (Satake and Yoshida 1978); a daytime temperature higher than 35°C at flowering time may increase spikelet sterility.

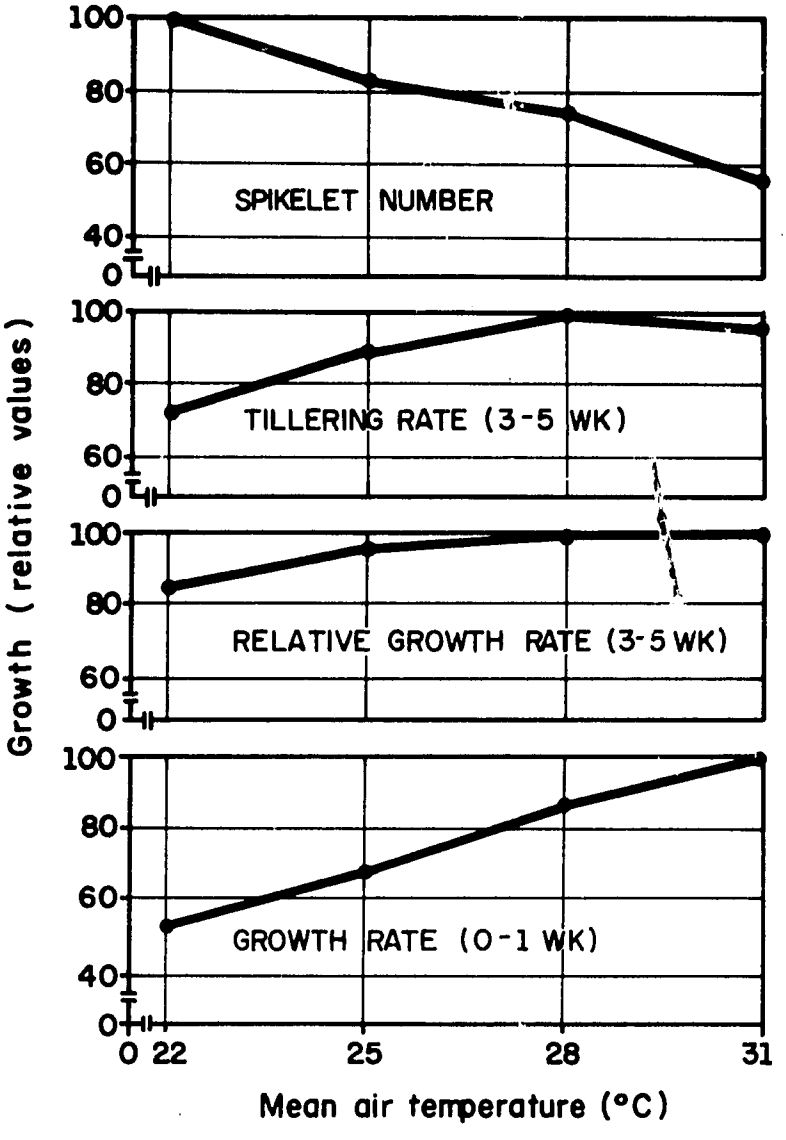

Fig. 1. Effects of temperature on growth of IR8 in a controlled environment (Yoshida 1973).

SOLAR RADIATION

The amount of solar radiation at 26 sites in 15 rice-growing countries ranges from 50 cal/cm^2 per day in December at Milan, Italy, to 700 cal/cm^2 per day or higher in June or July at Lisboa, Portugal and Davis, California, U.S.A., or from November through January at Griffith, Australia (Fig. 2). Most places, however, appear to receive 300 cal/cm^2 per day or more during the rice ripening period.

High solar radiation is considered an important factor contributing to the high national average yields of rice achieved in Australia, Spain, and Portugal. Excessively cloudy weather during the rice-growing seasons is often a concern in India. Among three locations recording climatological data there, Cuttack receives the lowest amount of solar radiation, but its minimum solar radiation is about 300 cal/cm^2 per day.

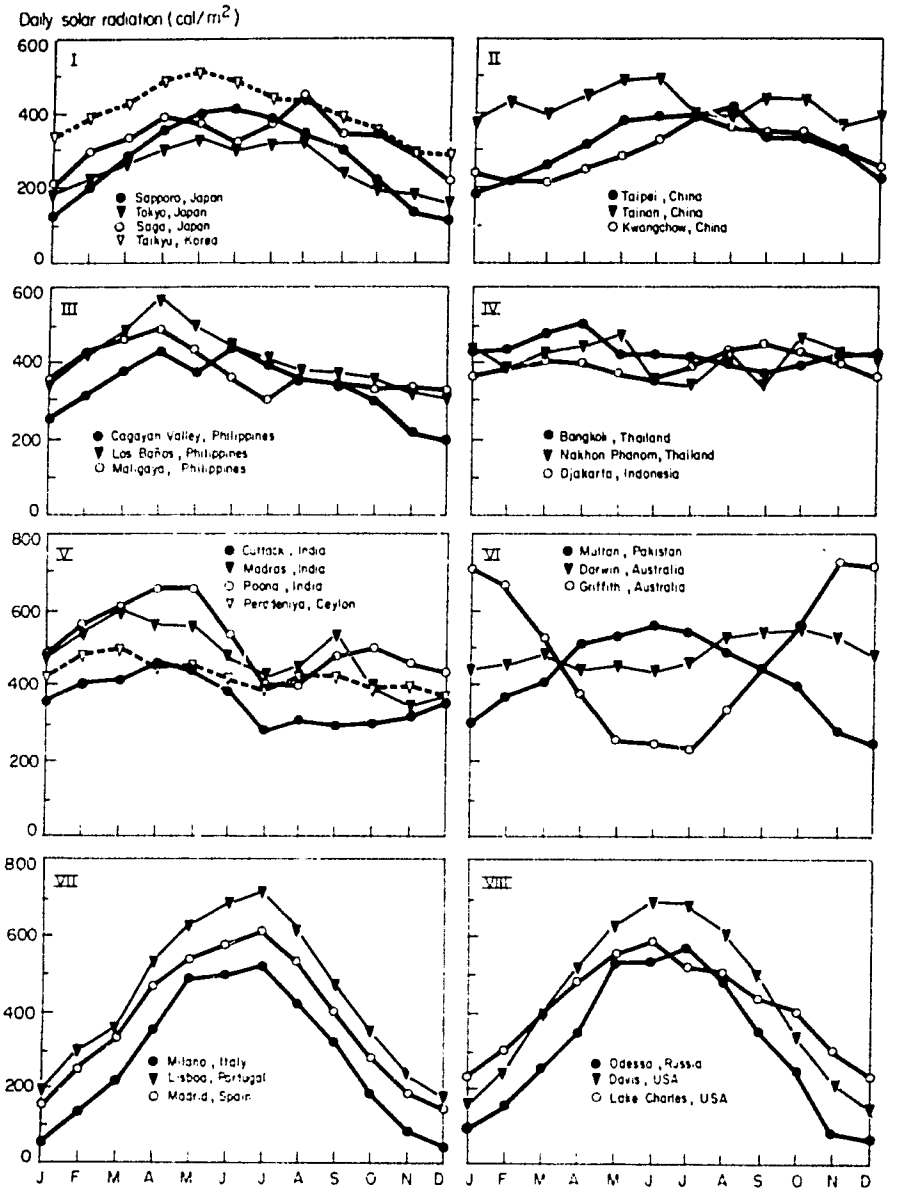

Fig. 2. Solar radiation in some of the world's major rice-growing areas (I - VIII).

The solar-radiation requirements of a rice crop differ from one growth stage to another (Table 4). Shading during the vegetative stage only slightly affects yield and yield components. During the reproductive stage, however, it has a pronounced effect on spikelet number and, hence, on yield. Shading during the ripening period also reduces grain yield considerably, because of a decrease in the percentage of filled grains.

Grain yield is most affected by solar radiation at the reproductive stage. Solar radiation at the ripening stage has the next highest effect on yield (Fig. 3). Solar radiation during the vegetative stage has an extremely small overall effect on grain yield.

Table 4. Effect of shading at different growth stages on yield and yield components of IR747B2-6[a].

Sunlight (%)	Grain yield (t/ha)	Harvest index	Spikelets (no./m^2)	Filled grains (%)	1000-grain wt (g)
		Vegetative stage			
100	7.11	0.49	41.6	88.9	20.0
75	6.94	0.48	40.6	89.9	19.9
50	6.36	0.51	38.3	89.5	19.9
25	6.33	0.51	38.1	84.3	19.8
		Reproductive stage			
100	7.11	0.49	41.6	88.9	20.0
75	5.71	0.47	30.3	87.8	20.3
50	4.45	0.40	24.4	89.4	19.5
25	3.21	0.36	16.5	89.4	19.1
		Ripening stage			
100	7.11	0.49	41.6	88.9	20.0
75	6.53	0.49	41.1	81.1	20.0
50	5.16	0.44	40.6	64.5	19.5
25	3.93	0.38	41.7	54.9	19.1

[a]Yoshida and Parao 1976.

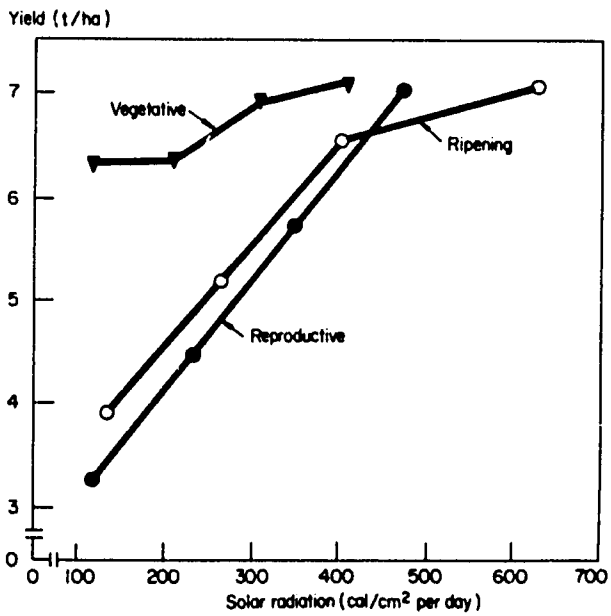

Fig. 3. Effect of solar radiation at different growth stages on grain yield of IR747B2-6 (Yoshida and Parao 1976).

Solar radiation of 200 cal/cm^2 per day during the reproductive stage makes a yield of 4 t/ha possible. Less solar radiation during the ripening period is required to achieve the same level of yield. Thus, the effect of solar radiation is apparent only when grain yield is higher than 4 or 5 t/ha. Below that yield level sunlight per se may not have any direct significance. That means that with the right variety and good management yields of 4 to 5 t/ha are possible in the wet season.

RAINFALL AND WATER REQUIREMENT

The water requirement of a rice crop is affected by both climate and soil. Solar radiation, temperature, wind speed, and air humidity are primary determinants of evapotranspiration. Soil factors such as texture, depth of water table, and topography determine seepage, percolation, and runoff.

The water requirements of irrigated rice crops at 43 sites in China, Japan, Korea, Philippines, Vietnam, Thailand, and Bangladesh are summarized below (Kung 1971).

		Water requirement
Water loss		
Transpiration		1.5-9.8 mm/day
Evaporation		1.0-6.2 mm/day
Percolation		0.2-15.6 mm/day
	Total	5.6-20.4 mm/day
Field operation		
Seed nursery		40 mm
Land preparation		200 mm
Field irrigation		1000 mm
	Total	1240 mm/crop

For most places the daily water consumption ranges from 6 to 10 mm, and the total water requirement is about 1,240 mm/rice crop.

To estimate whether rainfall is sufficient to meet the water requirement of a rainfed rice crop, both gains and losses of water must be considered.

Water gains

In monsoonal Asia, three basic patterns of rainfall distribution are recognized (Nieuwold 1977).

In *equatorial monsoon climates*, both monsoons (northeast and southwest) bring rainfall. As a consequence, monthly rainfall is evenly distributed throughout the year, and no regular dry season occurs.

In *dry* and *wet monsoon climates*, only one monsoon brings most of the rainfall, and a wet season is clearly separated from a dry season.

In these two types of climates amount of annual rainfall ranges from about 1,000 to 3,000 mm and rainfed rice cultivation is possible.

In the *dry tropics* the annual rainfall is small and rice is grown only when irrigation is provided.

These basic rainfall patterns could be further classified into subgroups according to the criteria set for particular objectives. Kawaguchi and Kyuma (1977) proposed 9 climatic groups for tropical Asia while Oldeman and Suardi (1978) considered 17 climatic zones related to cropping patterns in Asia.

Water losses

Water is lost through evapotranspiration, seepage and percolation, and surface drainage. A simple way of estimating evapotranspiration of a paddy field is to use energy balance. The evapotranspiration of a paddy field is related to incident solar radiation by:

$$E = 0.0105 \times S \text{ (mm/day)}$$

where E is potential evapotranspiration and S, incident solar radiation (cal/cm^2 per day). In other words, evapotranspiration is proportional to the amount of incident solar radiation and is about 1 mm/day per 100 cal/cm^2 per day solar radiation. Because solar radiation during the rice-growing season ranges from 300 to 700 cal/cm^2 per day, the corresponding evapotranspiration is about 3 to 7 mm/day.

Evaporation is the major part of evapotranspiration at early stages of rice growth and it decreases sharply as plant growth progresses (Fig. 4).

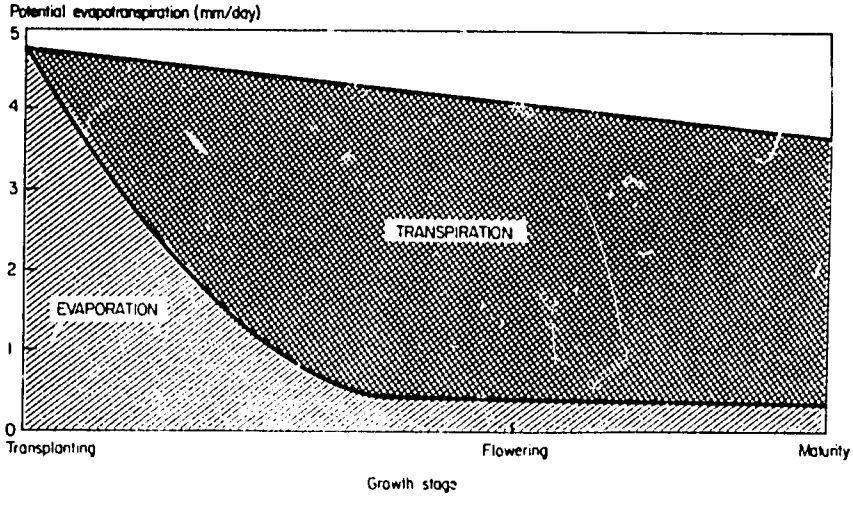

Fig. 4. Evapotranspiration model of an irrigated rice crop under a constant level of solar radiation (400 cal/cm^2 per day).

The model of evapotranspiration illustrates two important points:

- Evapotranspiration from a paddy field is highest at the early stage of plant growth and decreases slightly toward maturity. Water loss by evapotranspiration of the crop is smaller than that by evaporation from free water surface.

- The water requirement of a rice crop at flowering is not greater than at the other growth stages.

The rice plant, however, is most sensitive to water stress at around flowering stage (Table 5). Hence, lack of water from the panicle initiation to flowering stage often results in crop failure. The first stage at which the rice plant is sensitive to water stress is from 11 to 8 days before flowering; it coincides with the stage of sensitivity to low temperature. The second water-stress sensitive stage is from 3 to 0 days before flowering, which coincides with the stage of sensitivity to high temperature.

Water balance

Water balance, the balance between rainfall and evapotranspiration, gives a rough estimate of water shortage or excess (Fig. 5). Wet season, is the time when rainfall exceeds evapotranspiration. At Los Baños, January to April is the dry season and June to December is the wet season. May is a transition period. Water deficit or drought occurs at unpredictable times. From 1967 to 1971, monthly water deficit occurred three times during the wet season -- July 1967, October 1969, and August 1971.

Table 5. Effects of drought on yield and yield components of rice[a/].

Drought treatment (days from heading)	Yield (g/hill)	Panicles (no./hill)	Sterility (%)	Filled grains (%)	1000-grain wt (g)
-55	18.0	11	11	70	21.8
-51	16.8	11	9	66	22.0
-43	19.5	11	14	65	21.5
-35	20.0	12	11	60	20.5
-27	17.0	11	12	54	20.2
-19	15.7	11	34	52	20.8
-11	6.5	10	62	29	21.6
- 3	8.3	10	59	38	20.9
+ 5	16.5	11	10	59	21.9
+13	20.5	10	7	66	22.5
No stress	22.7	10	15	65	21.9

a/Matsushima 1962.

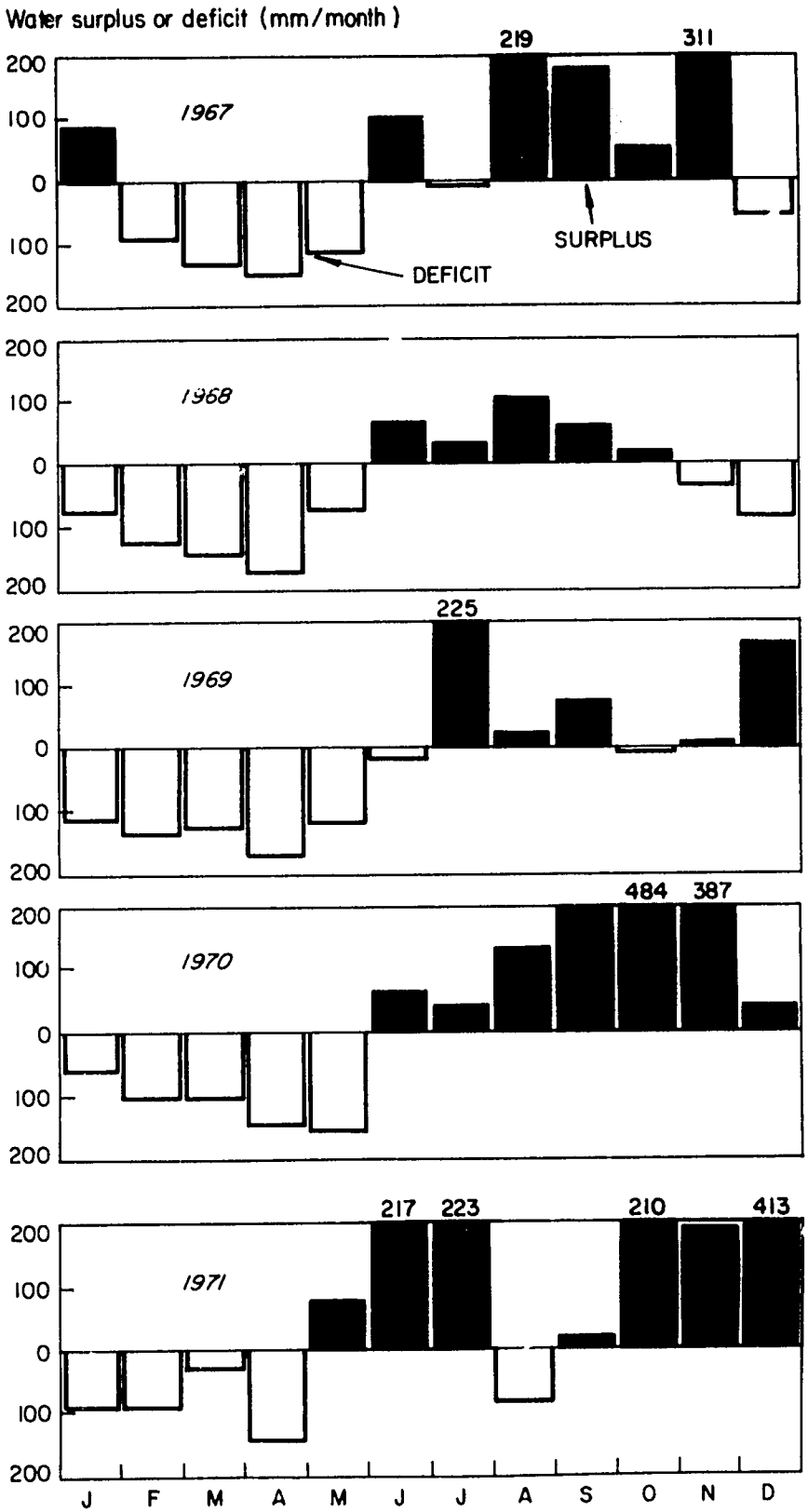

Fig. 5. Monthly balance of precipitation minus evapotranspiration at Los Baños, 1967-1971.

The average seepage and percolation rates for Philippine paddy soils are estimated at 2 mm/day for the wet season and at 4 mm/day for the dry season (Wickham and Singh 1978). Thus, the total monthly water requirement of the Philippine rice crop averages about 180 mm for the wet season and about 270 mm for the dry season (Table 6). These estimates agree with the general statement that the monthly water requirement for rice is about 200 mm and a minimum total water requirement for 1 rice crop is about 1,000 mm, assuming that the crop duration is 4 months and that land preparation requires 200 mm of water. If land preparation takes more than 30 days, as much as 500 to 600 mm of water is required (Wickham and Sen 1978).

The unpredictable variation in amount and distribution of rainfall for a given location and from year to year is most disturbing. The best thing we can do is to estimate the probability of drought occurrence on the basis of long-term records.

The best way to cope with unpredictable rainfall is to have irrigation and drainage facilities, particularly supplemental irrigation, in the wet season. The second best way is to plant and harvest a rice crop at times that have the statistically highest probability of rainfall or to use photoperiod-sensitive varieties. A third way is to improve varietal resistance to drought and to partial or total submergence.

Table 6. Average water requirement of a paddy field in the Philippines.

	Wet season	Dry season
Solar radiation ($cal/cm^2/day$)[a]	367	463
Evapotranspiration (mm/day)	4	5
Seepage and percolation (mm/day)	2	4
Daily total (mm)	6	9
Monthly total (mm)	180	270

[a] Average values for wet season (July-November) and dry season (January-May).

TAILORING RICE VARIETIES ADAPTED TO CLIMATIC CONDITIONS

As previously pointed out, climate affects crop period, productivity, and stability. To a limited extent, rice environment can be modified, as in the case of the plastic-covered nurserybed in the temperate region. The construction of irrigation and drainage facilities is man's most important effort to modify the rice environment and maximize and stabilize rice yields. With the current situation in the tropics,

however, it is unlikely that the provision of irrigation and drainage facilities for rice cultivation will expand greatly within a foreseeable period of time. More importantly, temperature in the field and solar radiation cannot be changed. At best plant breeders can modify rice varieties and better adapt them to existing environments. Or cultural practices can be adjusted to avoid some hazards.

A sustained effort in rice-growing countries and at IRRI has been the tailoring of rice varieties better adapted to climatic conditions. The desirable characteristics aimed at include sensitivity to day length, resistance to drought, tolerance for deep water and flood, and tolerance for low and high temperatures. These topics have been discussed elsewhere (Parthasarathy and Rajan 1972).

In the following sections I discuss two problems of varietal alterations:

- Plant height. A defect of high yielding dwarf varieties is short stature, which makes them not adapted for areas without dependable water control.

- Early maturity. Use of early maturing varieties is one way to make maximum use of tropical climate. In the tropics, where temperature remains favorable for plant growth throughout the year, the ultimate concern is with total yield per year, whereas in the temperate region the concern is mostly with yield per crop.

IRRI varieties

An examination of IRRI varieties that is focused on growth duration and plant height gives some ideas on the limitations of IRRI varieties in different environments and what can be done to improve such varieties.

There are 15 IRRI varieties known in the Philippines. They range from IR5 to IR42. Below are some of their characteristics (Fig. 6):

- They are either photoperiod insensitive or weakly sensitive.

- Most varieties have a growth duration from 105 to less than 130 days; only 4 (IR5, IR26, IR32, and IR42) have a growth duration longer than 130 days; 3 (IR28, IR30, and IR36) are early maturing.

- Only two (IR5 and IR34) are taller than 120 cm; the rest are mostly 100 to 110 cm tall. IR36 is extremely short.

Plant height

It is believed that the traditional, tall, droopy-leaved rice cultivars in the tropics are popular because they efficiently suppress weeds (Jennings 1966). There is evidence to support this notion (Table 7). Furthermore, tall varieties are more adapted to areas with less dependable water control.

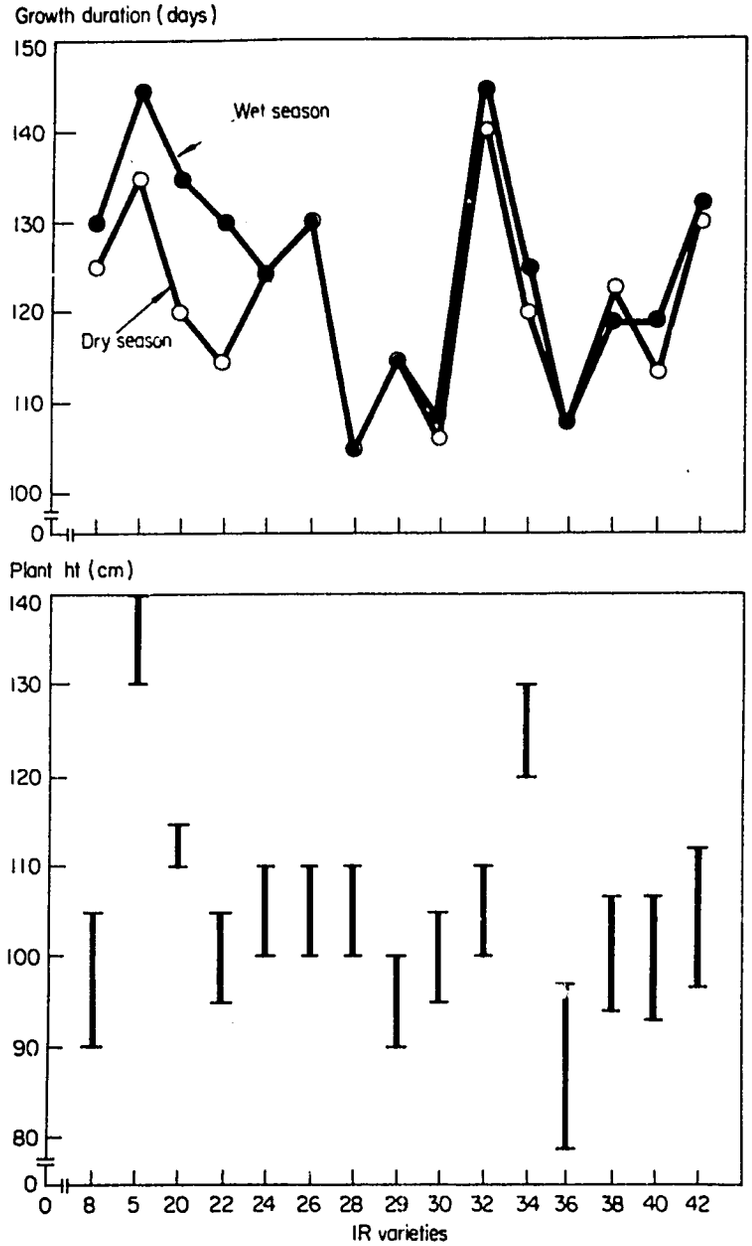

Fig. 6. Growth duration and plant height of IRRI varieties IR8 through IR 42.

Because the traditional varieties are generally tall, and the modern varieties are generally short, a compromise between them would be varieties of intermediate plant height. The grain yield of a rice crop decreases as water depth increases (Table 8). The yield-decreasing effect of partial submergence could be attributed to impaired tillering and decreased photosynthetic leaf surface. The increase in plant height should counteract the effect of partial submergence. In one experiment with IR8 (Peta) and Bahagia (a sister line of IR5), Bahagia, of intermediate plant height, suffered much less from moderate water depth

Table 7. Yield reduction due to weeds and plant heights 10 weeks after transplanting of various rice cultivars grown under different weeding regimes[a].

Cultivar	Yield (t/ha)		Yield reduction due to weeds (t/ha)	Av. plant ht. (cm)
	Weed free	Unweeded		
IR1561-228-3-3	5.7	2.8	2.9	79.7
IR26	5.4	2.6	2.8	77.2
IR28	5.2	2.5	2.7	83.5
IR34	6.1	3.7	2.4	95.1
IR36	4.7	2.4	2.3	79.9
BG 90-2	6.2	4.1	2.1	84.3
IR4816-70-1	6.3	3.5	1.8	91.8
IR1632-93-2-2	5.0	3.7	1.3	92.4
Binato	4.7	3.5	1.2	143.1
Peta	2.9	1.8	1.1	113.9

[a]Moody 1977.

Table 8. Yield of variety 'Jaya' under three levels of submergence (25, 50, 75% of crop height) at each of the 3 growth phases during aman (July-Nov.) and boro (Jan.-April), 1973-74[a].

Plant growth stage	Ht. of plant submerged	Relative grain yield (%) 1973 (Aman)	1974 (Boro)
Control (continuous submergence 5 ± 2 cm)		100	100
Seedling establishment to maximum tillering	25%	82	75
	50%	75	62
	75%	68	58
Maximum tillering to flowering	25%	81	74
	50%	71	64
	75%	72	56
Flowering to maturity	25%	79	71
	50%	76	66
	75%	70	50

[a]Adapted from Pande 1976.

than Ria (Sugimoto 1971). A similar experiment also appeared to confirm that increased plant height is beneficial under partial submergence (Table 9). In this example, however, one semidwarf selection (T(N)1 x T.65) performed well under partial submergence. The reason is not clear but the data for panicle number may suggest that vigorous tillering under partial submergence could be important.

Increase in plant height, however, makes the crop more susceptible to lodging and decreases nitrogen response (Fig. 7). Mahsuri produced reasonably good yields at 0 and 50 kg N/ha but it lodged at 100 kg N/ha. IR34, an improved intermediate-height variety, performed better than Mahsuri at 100 kg N/ha but its grain yield did not increase when nitrogen was increased from 50 to 100 kg/ha.

Plant height may cause spacing problems, too. Varieties of intermediate or tall plant stature tend to lodge at close spacings; short and lodging-resistant varieties give the highest yield at close spacings (Fig. 8; Tanaka et al 1964; Yoshida and Parao 1972). At close spacings and in partial submergence, culms of the rice plant tend to elongate more, and the crop may suffer more frequent lodging.

Table 9. Effect of partial submergence on yield and yield components of 5 varieties[a].

Variety		Plant ht (cm)	Panicles (no./pot)	Grains (no./ panicle)	Relative yield (%)
Padura	Control	87	62	101	100
	Submergence[b]	91	59	89	84
T(N)1 x T.65	Control	92	57	82	100
	Submergence	99	61	85	107
IR8	Control	92	43	138	100
	Submergence	103	38	119	87
Jaya	Control	92	47	109	100
	Submergence	105	41	114	95
MTU 15	Control	154	46	93	100
	Submergence	156	45	102	100

[a]Adapted from Vijaya Rai and Murty 1976.

[b]Water depth was kept at 30 cm throughout the whole growth stage.

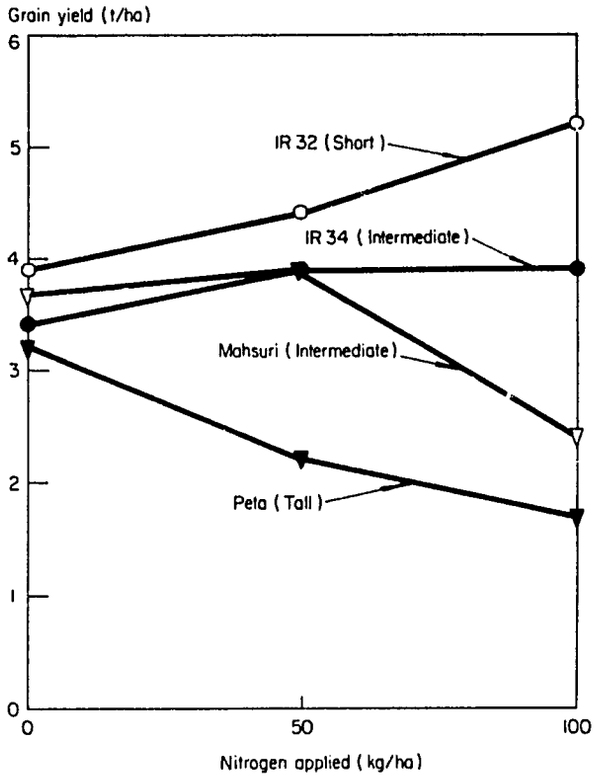

Fig. 7. Response of four varieties to nitrogen application, wet season 1976, IRRI.

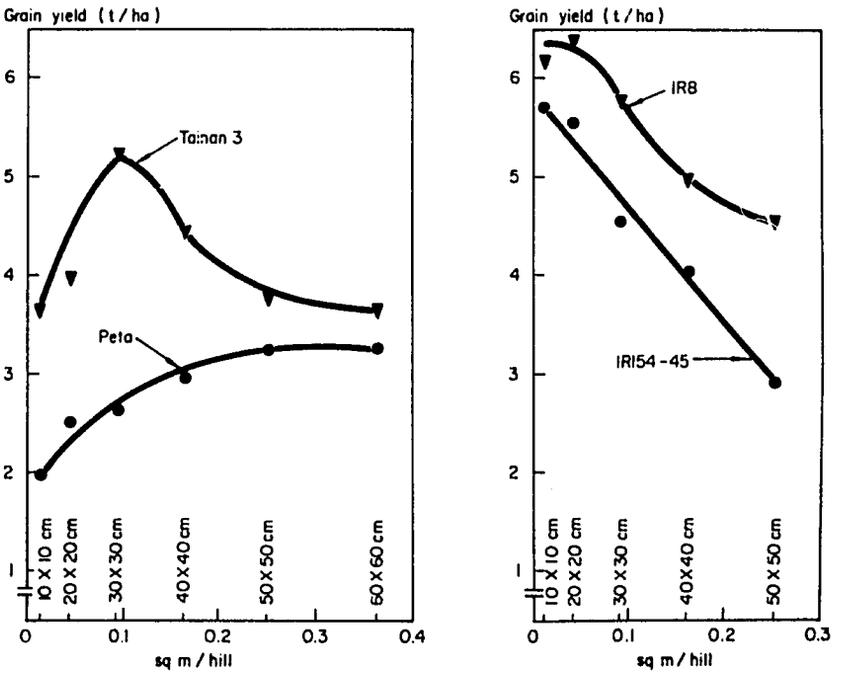

Fig. 8. Yield of Tainan-3 and Peta at 6 spacings (left), 1962 wet season (Tanaka et al 1964), and yield of IR8 and IR154-45 at 5 spacings (right), 1967 wet season (Yoshida and Parao 1972).

Intermediate plant height has recognized advantages where there is undependable water control but those benefits may not be realized unless the varieties are made resistant to lodging.

Early maturity

There is increasing interest in early maturing varieties presumably because they allow increased cropping intensity. But at conventional spacings varieties with short growth duration usually give lower yields (Table 10) because insufficient vegetative growth prevents them from achieving maximum yields.

Close spacing is essential for early maturing varieties to achieve high yields. The grain yield of IR747B2-6 at 5- x 5-cm spacing was as high as that of IR8 in the wet season. In the dry season, IR747B2-6 produced about 8 t/ha at 10- x 10-cm spacing, whereas IR8 gave 8.6 t/ha at 20- x 20-cm spacing. At close spacings, therefore, the yield potential of IR747B-6 can be nearly as high as that of IR8.

One clear benefit of early maturing varieties is high grain production per day. In both the wet and dry seasons, IR747B2-6 is about 30% more efficient than IR8 in daily grain production.

Another advantage of an early maturing variety is high water-use efficiency. As illustrated earlier, evapotranspiration of a paddy field is proportional to incident solar radiation and to number of days the crop is in the field. Hence, a higher daily production gives a higher water-use efficiency.

As mentioned earlier, a disadvantage of an early maturing variety is that it requires close spacings to achieve high yield. In addition, it requires a high level of management because each day in the field contributes to maximum yield.

One question about early maturing varieties is how far growth duration can be shortened without sacrificing yield potential. For rice, the duration of panicle development before heading is fairly fixed at about 30 days. The duration of ripening is about 30 days in the tropics. Thus, about 60 days is necessary for reproductive growth and ripening. How many days are necessary for vegetative growth? Allocating 30 days for vegetative growth, the total growth duration of early maturing varieties is about 90 days. Using a 90-day variety and allowing 20 days in the seedbed leaves only 10 days for vegetative growth after transplanting. Obviously that is not sufficient.

Direct seeding appears essential for a 90-day variety to have sufficient vegetative growth before panicle initiation. For a transplanted rice, about 100 days would be the shortest duration for achieving reasonably high yields. In the comparison above, number of field days is shorter for a 100-day variety in transplanted rice than for a 90-day variety in direct-seeded rice. Among the materials available, IR747B2-6 is one of the best early maturing lines; it matures in 95-98 days (Table 10). IR28 matures in 105 days. Thus, attempts to shorten growth duration are

Table 10. Effect of spacing on grain yield and daily production of 3 varieties, IRRI, 1970[a].

Selection	Spacing (cm)	Growth duration (day)	Grain yield (t/ha)	Daily grain production in main field (kg/ha)
		Wet season		
IR747B2-6	5 x 5	9		
	5 x 5	95	5.62	75
	10 x 10	95	4.70	63
	20 x 20	95	4.15	55
IR22	5 x 5	114	4.92	52
	10 x 10	114	5.01	53
	20 x 20	114	4.57	41
IR8	5 x 5	124	5.32	51
	10 x 10	124	5.31	51
	20 x 20	124	5.14	49
		Dry season		
IR747B2-6	10 x 10	98	7.92	102
	20 x 20	98	7.23	93
IR154-18-2-1	10 x 10	110	7.23	80
	20 x 20	110	6.98	78
IR8	20 x 20	132	8.61	77

[a] IRRI 1970.

approaching the limit for the shortest growth duration possible with high yielding potential.

Benefits and disadvantages of contrasting plant characteristics

Good environment and good management are assumed for the good plant type or the ideotype. Under those conditions, IR8 and similar semidwarf varieties are ideal. On the other hand, when considering diverse environments and different levels of management under which rice is grown, the problem becomes specific to a given location and management level.

Table 11. Benefits and disadvantages of contrasting plant characteristics.

Plant characteristic	Benefits and disadvantages
Plant height	
Short	Increases resistance to lodging.
Tall	Suppresses weeds. Adapted to areas of less dependable water control.
Leaf inclination	
Erect	Uses solar energy efficiently when leaf area index is large.
Droopy	Uses solar energy efficiently when leaf area index is small. Suppresses weeds.
Tillering	
High	Adapted to a wide range of spacing; capable of compensating for missing hills; permits faster leaf area development (transplanted rice).
Low	Adapted to direct seeding.
Root	
Shallow, and low root-to-shoot ratio	Uses high proportion of assimilates for shoot.
Deep, and high root-to-shoot ratio	Increases resistance to drought. Uses soil nitrogen and recovers applied nitrogen efficiently.
Grain size	
Small	Related to fast grain filling, adapted to areas having drought at later stages of ripening.
Large	Has potential for high yields; requires longer ripening period.
Growth duration	
Early maturing	Increases grain production per day. Increases water-use efficiency. Requires close spacings to achieve yield potential.
Late maturing	Adapted to low fertility.
Photoperiod sensitivity	
Sensitive	Adapted to areas of a long monsoon season.
Insensitive	Can be grown any time of the year, fitted to multiple cropping systems.
Early growth	
Fast	Suppresses weeds. Essential for early maturing varieties.
Slow	Prevents excessive growth at later stages under good management.

There is no single variety that can meet all the requirements set by the different environments and management levels. In such a situation, it is important for plant breeders to recognize the benefits and disadvantages of contrasting plant characteristics (Table 11).

Apparently, gains in one aspect are accompanied by losses in another. Therefore, the choice of individual characteristics or their combination is bound to vary with location, conditions of culture, and level of use of inputs.

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