A REVIEW OF WHEAT RESEARCH AT THE INTERNATIONAL RICE RESEARCH INSTITUTE

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ABSTRACT

Rice-wheat rotation is common above 20° N latitude, and there is growing interest in extending this rotation to areas nearer the equator in Southeast Asia, where the entire demand is met by importing wheat. To increase self-reliance, the governments of most Southeast Asian countries as well as international agencies have initiated varietal improvement programs to develop wheat varieties adapted to regional environments. Some adapted varieties have been released recently.

To determine the feasibility of cultivating wheat in the postrice season and to identify optimal cultural practices, IRRI's Multiple Cropping Department has conducted studies since 1981 in Los Baños (14° 10′ N) and Cagayan Province (17°46′ N), Philippines. This paper summarizes the results obtained to date.

The presently available varieties have a yield potential of 2 t/ha or more. Among varieties tested, UPLW-3 was the most productive. Sowings earlier than 1 Dec exposed the seedlings to waterlogging, whereas sowings beyond 1 Jan exposed the grain filling stages to higher atmospheric temperatures. A mid-December sowing was found optimal. Maximum yields were obtained with 100 kg seeds/ha sown at 20 cm row spacings; increased seeding rates or narrower row spacings did not increase yields. Wheat produced 1 t grain/ha without irrigation, but maximum yields were obtained by applying irrigation at crown root initiation, booting, and grain filling. Fertilizer experiments suggested that, depending upon the initial fertility level, wheat responds to more than 40 kg N/ha. Applying all fertilizer at sowing or at early growth was advantageous. There was no response to P. Because at lower latitudes wheat growth is relatively poor, crop duration is short, and yields are low, intercropping with crops such as maize that are longer maturing and adapted to the regional environment may be useful.

Identification of potential rice-wheat rotation areas in Southeast Asia is required. Wheat varieties with better adaptation to the agroecologies of this region are needed. Economic viability and ecological sustainability of rice-wheat sequences in areas below 20° N latitude should be determined.

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A REVIEW OF WHEAT RESEARCH AT THE INTERNATIONAL RICE RESEARCH INSTITUTE

Rice and wheat are the two main cereal crops in Asia. Rice is more adapted to higher temperatures and is adversely affected by temperatures lower than 20 °C (15). The optimal temperature for wheat growth is 10-20 °C (8). Therefore, in many parts of subtropical Asia, especially India and Pakistan, rice is grown during the hotter wet season (WS) and wheat in the cooler dry season (DS) (Fig. 1). Lately, rice - wheat sequences have become popular in many tropical locations between 20° and 23° N latitude in India, Bangladesh, and China. There is growing interest in extending these sequences to areas below 20° N (3) in Indonesia, Malaysia, the Philippines, Thailand, and Vietnam.

In these lower latitudes, rice is cultivated in WS. In DS, the fields are planted to rice or upland crops, or fallowed, depending upon the availability of irrigation water. Presently, there is no significant commercial production of wheat in Southeast Asia. The entire regional demand (more than 4 million t/yr) is met by importing wheat and wheat flour from other countries at a huge cost (Table 1). Because of increasing urbanization and changes in dietary habits, it is projected that the demand for wheat will increase several times. To reduce the large drain of already limited foreign exchange and increase self-reliance, the governments of most Southeast Asian countries as well as the Centro Internacional de Mejoramiento de Maiz y Trigo and the International Center for Agricultural Research in Dry Areas have initiated varietal improvement programs to develop wheat varieties adapted to regional environments.

Many countries of this region have become surplus producers of rice and therefore wish to diversify. Wheat, being relatively drought resistant, is a potential alternative crop where cool and dry months occur. The development of adapted wheat varieties will contribute to crop diversification.

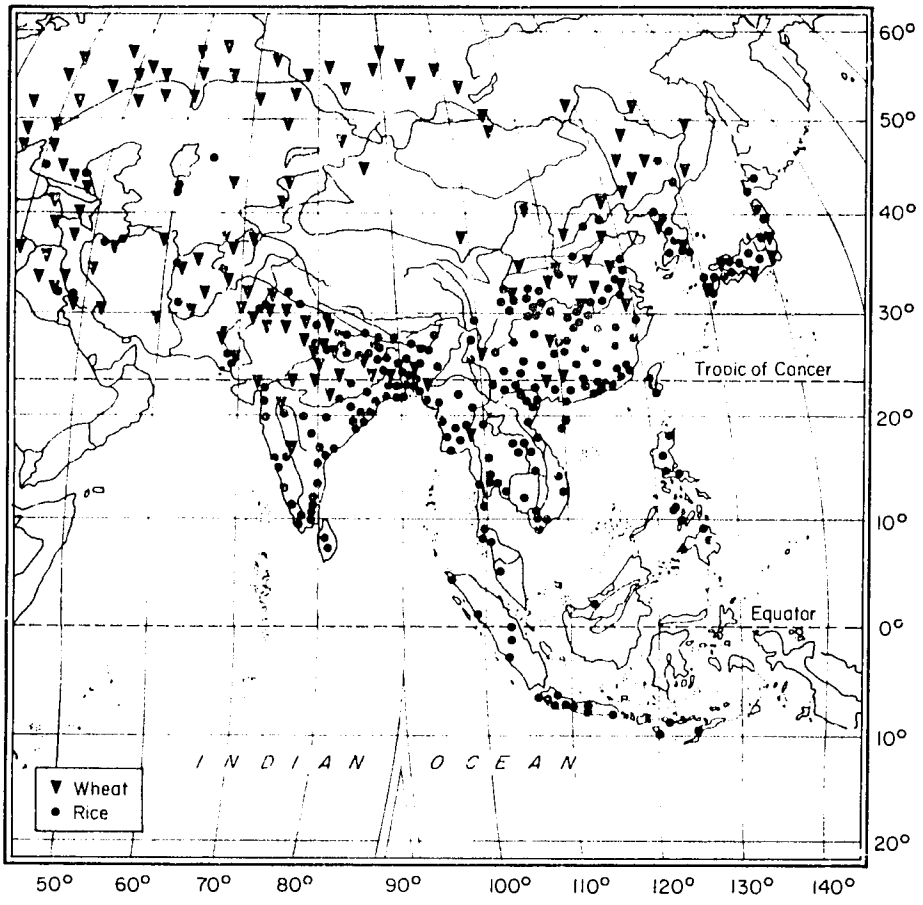
Wheat is actually not a new crop in the region. There is evidence that it was cultivated from the 17th century to the end of the 19th century in Cagayan Province and other highlands of central Luzon in the Philippines (13). It is still grown in isolated highlands in Java in Indonesia, the Chiang Mai region of Thailand, and parts of Burma (3). But the varieties grown are not very productive.

The Institute of Plant Breeding (IPB), University of the Philippines at Los Baños, recently released three wheat varieties that are somewhat adapted to hot climates — UPLW-1 (Trigo 1), UPLW-2 (Trigo 2), and UPLW-3 (Trigo 3). (In the early years covered by this review these cultivars had not yet been released by the Philippine Seed Board. They were designated Trigo 1, Trigo 2, and C169-6 [Trigo 3]. In subsequent sections, they are referred to as UPLW-1, UPLW-2, and UPLW-3, although in earlier reports their other designations were used.) Many promising lines are currently being tested. However, there has been little research on the agronomic management required to maximize wheat production in the tropics. The agronomic practices are likely to differ from those in subtropical and temperate locations, because high temperatures adversely affect wheat phenology, growth, and development (7, 11). To bridge this gap, the Multiple Cropping Department of the International Rice Research Institute (IRRI) began agronomic studies in 1981 DS. The initial studies were to determine the feasibility of cultivating wheat in the postrice season (December-March). This paper is a brief review of field studies from 1981 to 1986.

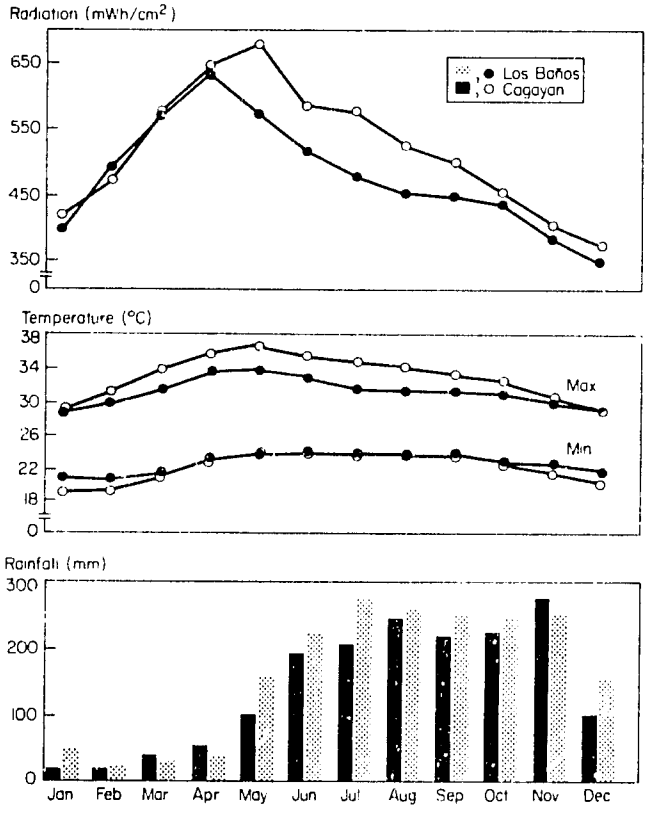
EXPERIMENTAL SITES

Wheat management research was conducted in Los Baños, Laguna (14°10′ N), and Alcala, Cagayan (17°46′ N), Philippines. In Los Baños, experiments were conducted on lowland and upland fields of the IRRI Experimental Farm (clayey, pH = 5.4-6.0, approximately 0.8% organic C). The crop season is characterized by high day and night temperatures with small diurnal variation (Fig. 2). Average annual rainfall in Los Baños is 1,988 mm, of which 262 mm is from 1 Dec to 31 Mar. The solar radiation becomes increasingly higher as the crop season progresses.

In Cagayan, the experimental fields were on a recent river terrace (clay loam, pH = 6.2) adjacent to the Cagayan River (10). Relative to Los Baños, the Cagayan site has higher maximum and slightly lower minimum temperatures, thus exhibiting a larger diurnal variation (Fig. 2). The mean annual rainfall is 1,720 mm, of which 181 mm is from 1 Dec to 31 Mar. During the wheat growth season, the two sites receive similar solar radiation.



1. Rice- and wheat-growing areas of Asia.



2. Mean monthly weather data (1951-70) for Los Baños and Cagayan, Philippines.

Table 1. Size and value of wheat imports by Southeast Asian countries, 1983 (4).

Country	Wheat imports (thousand t)	Value[a] (thousand US$)
Burma	7	1,260
Hong Kong	189	34,020
Indonesia	1,757	316,260
Malaysia	538	96,840
Philippines	811	145,980
Singapore	149	26,820
Sri Lanka	598	107,640
Thailand	203	35,540
Vietnam	228	41,040
Total	4,480	806,400

[a]At US$180/t.

MANAGEMENT STUDIES

Unless otherwise mentioned, all experiments were sown with 100-120 kg seeds/ha in 25- or 30-cm rows. The fields were fertilized at sowing time with 80-100 kg N/ha. The crops were irrigated and maintained free of weeds. Attempts were made to keep the fields free from diseases and insect pests. The major diseases were *Helminthosporium* leaf spot and foot rot caused by *Sclerotium* spp. The main insect pests were pink stem borer (*Sesamia inferens*) and corn earworm (*Helicoverpa armigera*). For convenience, the year of an

experiment is designated by the DS in which it was harvested, although the crop may have been planted in December of the preceding year.

Sowing date

To determine sowing date effects on wheat grain and dry matter yields and days to flowering and maturity, a trial was conducted in 1982-83 in Los Baños with one promising line (C220-5), two Seedboard-released varieties (UPLW-1 and UPLW-3), and two introduced varieties (INIA 66 and ANZA). Seeds were drilled in a well-prepared upland field on 3 Dec, 15 Dec, 29 Dec, 12 Jan, and 26 Jan. The trial was repeated in a well-tilled lowland field in Cagayan Province in 1983-84 and 1984-85. Sowing dates in the first year were 23 Dec, 7 Jan, and 20 Jan and in the second year 17 Dec, 29 Dec, and 15 Jan. All varieties used in Los Baños except ANZA were tested in Cagayan Province.

Days to flowering and maturity were reduced in all varieties and at both locations, as sowing was delayed (Table 2, 3). Maximum dry matter and grain yields were obtained when seeds were sown about the middle of December. UPLW-3 was the highest yielder. Despite the cooler temperatures in Cagayan, grain yields were lower than in Los Baños because Cagayan fields could not be maintained free from water stress. Earlier sowings experienced temporary waterlogging during initial growth stages, whereas later sowings were exposed to progressively increasing temperatures, particularly after anthesis. The higher temperatures after anthesis resulted in decreased 1,000-grain weight (Fig. 3). Such reduction in grain weight and consequently in grain yield with increased temperature is well documented (1, 5, 7, 14). Circled points in Figure 3 are from the 15 Jan 1985 planting in Cagayan, which experienced severe drought stress after flowering, resulting in very low grain yield and 1,000-grain weight. These data were therefore omitted from the analysis.

Grain yields higher than 2.0 t/ha can thus be obtained at lower latitudes provided that a variety such as UPLW-3 is sown in mid-December to ensure that reproductive stages occur at relatively cool atmospheric temperatures.

Tillage and planting methods

In 1982 DS, combinations of three tillage levels (zero, two rototillings, and conventional tillage [plowed twice, followed by a rototilling]) and three planting methods (dib-

Table 2. Response of wheat to date of sowing in Los Baños, Philippines, 1983 DS.

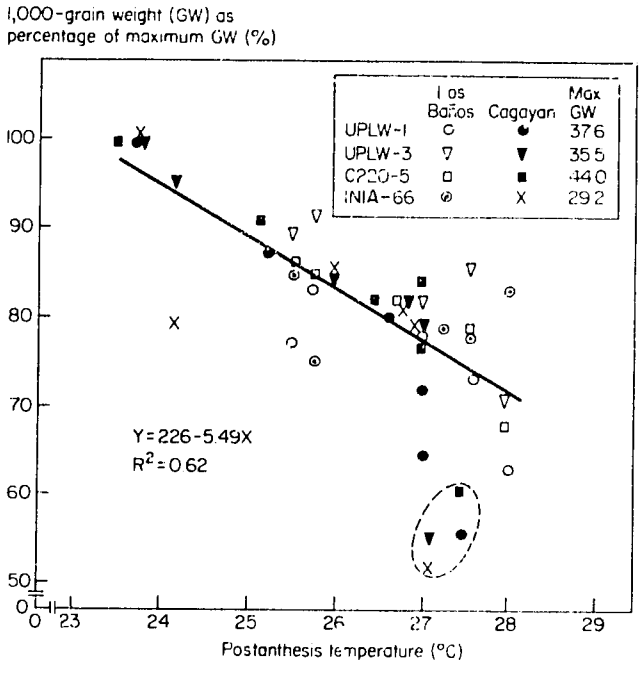
Variety	Date of sowing	Days to Flowering	Days to Maturity[a]	Grain yield (t/ha)	Dry matter (t/ha)	1,000-grain wt (g)
UPLW-1	3 Dec 82	61	95	2.7	10.2	28.8
	15 Dec 82	53	86	3.1	10.6	31.2
	29 Dec 82	54	86	2.5	9.9	29.5
	12 Jan 83	51	82	2.0	7.4	27.5
	26 Jan 83	54	83	1.2	5.9	23.7
INIA 66	3 Dec 82	61	95	0.5	4.7	24.7
	15 Dec 82	53	86	1.4	5.4	21.8
	29 Dec 82	54	86	1.1	5.3	23.2
	12 Jan 83	51	82	1.1	4.2	22.9
	26 Jan 83	54	83	0.5	2.7	24.3
C220-5	3 Dec 82	61	95	2.5	8.5	37.7
	15 Dec 82	53	86	3.2	12.4	37.0
	29 Dec 82	51	83	2.8	9.2	36.1
	12 Jan 83	47	78	2.4	7.5	34.5
	26 Jan 83	47	76	1.4	5.2	29.1
ANZA	3 Dec 82	61	95	1.2	9.7	29.7
	15 Dec 82	53	86	2.1	5.9	27.1
	29 Dec 82	54	86	1.8	6.9	25.6
	12 Jan 83	50	81	1.9	5.8	26.9
	26 Jan 83	47	76	1.1	4.9	21.5
UPLW-3	3 Dec 82	61	95	1.4	5.6	31.9
	15 Dec 82	53	86	2.8	6.8	32.5
	29 Dec 82	52	84	2.8	8.6	29.2
	12 Jan 83	47	78	2.9	9.9	30.5
	26 Jan 83	47	76	1.8	6.7	25.3
SE		0.6	0.6	0.2	0.2	1.2
Mean	3 Dec 82	61	95	1.7	7.7	30.0
	15 Dec 82	53	86	2.5	8.2	29.9
	29 Dec 82	53	85	2.2	8.0	28.7
	12 Jan 83	49	80	2.1	7.0	28.5
	26 Jan 83	50	79	1.2	5.1	24.8

[a]Complete drying for harvest; physiological maturity will be earlier.

Table 3. Response of wheat to date of sowing in Cagayan Province, Philippines, 1984 DS and 1985 DS.

Variety	Date of sowing	Days to Flowering	Days to Maturity[a]	Grain yield (t/ha)	Dry matter[b] (t/ha)	1,000-grain wt (g)
			1984			
UPLW-1	23 Dec 83	56	96	1.7	NR	37.6
	7 Jan 84	53	94	1.6	NR	32.8
	20 Jan 84	50	87	0.9	NR	29.9
C220-5	23 Dec 83	52	96	1.6	NR	44.0
	7 Jan 84	51	94	1.6	NR	40.2
	20 Jan 84	48	87	1.0	NR	36.2
UPLW-3	23 Dec 83	44	86	2.1	NR	35.5
	7 Jan 84	44	82	2.4	NR	34.0
	20 Jan 84	44	81	1.4	NR	29.9
INIA 66	23 Dec 83	46	91	1.3	NR	29.2
	7 Jan 84	45	82	1.4	NR	23.1
	20 Jan 84	44	81	1.0	NR	24.8
SE		1.1	--	0.1	–	0.8
Mean	23 Dec 83	50	91	1.7	NR	36.6
	7 Jan 84	48	88	1.8	NR	32.5
	20 Jan 84	47	85	1.4	NR	30.2
			1985			
UPLW-1	17 Dec 84	58	100	1.2	4.6	27.0
	29 Dec 84	53	90	1.1	3.8	24.0
	15 Jan 85	50	84	0.8	3.0	21.0
C220-5	17 Dec 84	58	100	1.4	3.9	37.0
	29 Dec 84	53	90	1.1	3.3	34.0
	15 Jan 85	50	84	0.6	3.1	27.0
UPLW-3	17 Dec 84	49	86	2.0	6.0	29.0
	29 Dec 84	47	83	1.1	3.1	28.0
	15 Jan 85	45	80	0.6	2.2	20.0
INIA 66	17 Dec 84	49	86	1.0	4.2	24.0
	29 Dec 84	47	83	0.5	1.8	23.0
	15 Jan 85	45	80	0.2	1.2	15.0
SE		--	--	0.1	0.5	1.0
Mean	17 Dec 84	54	93	1.4	4.7	31.3
	29 Dec 84	50	87	1.0	3.1	27.3
	15 Jan 85	48	82	0.5	2.4	21.0

[a]Complete drying for harvest, physiological maturity will be earlier.
[b]NR = not recorded.



3. Relationship of 1,000-grain weight to change in postanthesis mean temperature. Circled points were omitted from the analysis.

Table 4. Effect of tillage and planting method on the yield (t/ha) of UPLW-1 wheat, Los Baños, 1982 DS.

Tillage treatment	Injecting with RIP[a]	Dibbling (hand)	Drilling (Planet jr. planter)	Mean
Zero	1.76	1.80	1.67	1.75
2 rototillings	1.74	1.82	1.61	1.72
Conventional	1.69	1.92	1.72	1.78
Mean	1.73	1.85	1.67	
CV (a) = 8.7%				
CV (b) = 10.3%				

[a]RIP = rotary injection planter.

bling, drilling, and injecting by a rolling injection planter [RIP]) were tested in Los Baños fields using UPLW-1. The experiment was sown on 24 Jan 1982 in a lowland ricefield. Grain yield was not affected by either tillage or planting method (Table 4). The experiment was irrigated, and therefore the effects that tillage may have had on moisture availability in a water-limiting situation, especially during emergence, would not have been exhibited.

Seeding rate and row width

Relative to wheat crops in temperate regions, number of spikes per m² in tropical regions is low. Three experiments were conducted to determine if spikes per m² could be increased by increasing seeding rate or reducing row spacing. An additional objective was to collect information on the physiological basis of yield response to density and row spacing.

On 27 Jan 1982, UPLW-1 was sown in 30-cm rows in a lowland ricefield in Los Baños to test 100, 150, and 250 kg/ha seeding rates. These rates were components of an experiment in which three N and three P rates were applied to the main plots. The same experiment was conducted in Cagayan in 1983-84. Seeding rate did not affect grain yield or yield components such as grain number and grain weight at either site.

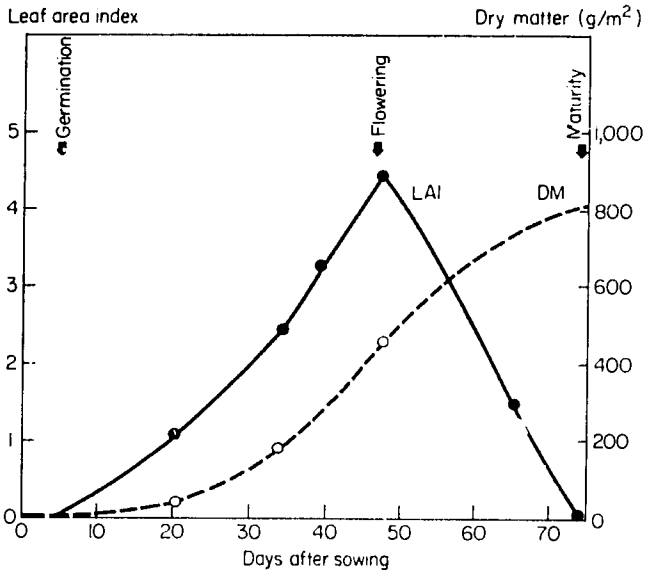
Another experiment was sown in Los Baños on 18 Dec 1985 to study the effect of seeding rate (100 and 170 kg/ha) and row spacing (10, 15, 20, and 25 cm) on grain yield. C213-15, a recently developed line from IPB, was used.

Regardless of seeding rate, tiller number increased as row spacing decreased (Table 5). However, increased tillering was accompanied by greater shoot mortality, as indicated by spikes per m² at maturity. Nevertheless, spikes per m² increased as row spacing decreased. Furthermore, there were more spikes when the seeding rate was higher.

Table 5. Effect of row sowing and seeding rate on wheat. Los Baños, 1986 DS.

Treatment	Grain yield (t/ha)	Dry matter (t/ha)		Maximum no. of shoots/m²	Spikes/m²	1,000-grain weight (g)	Grains/m²	Grains/spike
		Anthesis	Maturity					
Row spacing (cm)								
10	2.79	5.69	8.05	795	417	37.2	7,495	18.1
15	2.80	4.90	8.39	758	395	38.5	7,685	18.9
20	2.67	4.45	8.12	674	362	38.1	7,018	19.7
25	2.63	3.98	7.65	654	363	38.0	6,910	19.5
Seeding rate (kg/ha)								
100	2.77	4.58	8.24	701	338	39.6	7,091	20.8
170	2.67	4.79	7.86	739	427	36.3	7,463	17.4
Source of variation	df	Mean squares[a]						
Row spacing (RS)	3	0.06^{ns}	3.57**	0.73^{ns}	35,814**	5,710**	2.33^{ns}	1,108,758^{ns}	4.28^{ns}
Seed rate (SR)	1	0.08^{ns}	0.32^{ns}	1.14^{ns}	11,709^{ns}	61,342**	90.4**	1,105,795^{ns}	86.10**
RS x SR	3	0.06^{ns}	0.28^{ns}	0.62^{ns}	14,787^{ns}	2,374^{ns}	2.09^{ns}	516,669^{ns}	0.76^{ns}
Error	21	0.09	0.32	0.57	10,790	999	1.26	594,326	4.84
CV (%)		11.2	12.0	9.4	14.4	8.2	3.0	10.6	11.6

[a]** = significant at the 1% level, ns = nonsignificant.



4. Seasonal change in leaf area index (LAI) and dry matter (DM) of wheat. Mean over 2 seeding rates and 4 row spacings. Los Baños, 1986 DS.

In all treatments, the maximum leaf area index (LAI) was reached at flowering, after which it declined sharply (Fig. 4), largely because of tiller mortality. There was no difference in maximum LAI among treatments. Dry matter (DM) increase followed a typical sigmoid curve (Fig. 4). At anthesis, regardless of the seed rate, DM yield increased as row spacing decreased. At maturity, however, there was no difference in DM yields.

The advantage that narrow row spacing had in spikes per m^2 was offset by a decline in 1,000-grain weight. Similarly, the increase in spikes per m^2 at the higher seed rate was offset by a decrease in grains per spike as well as 1,000-grain weight. Consequently, grain yield did not differ significantly among the treatments (Table 5).

Thus, increasing plant density above that which can be obtained from 100 kg seeds/ha sown on 20-cm row spacings will not increase grain yield by compensating for the low spikes per m^2 commonly observed in lower latitudes. Similar conclusions were drawn by Midmore et al (12) from a study in Poza Rica, Mexico, at 19° N latitude, where the mean daily temperature ranged from 21 to 26 °C.

Irrigation

Four experiments were conducted at Los Baños in 1981, 1982, 1983, and 1985 DS to answer the questions: Will yields of wheat grown on residual soil moisture be sufficiently high to be competitive with alternative crops in early DS? If wheat does not yield well under rainfed conditions in low latitudes, what are the yield responses to irrigation applied at selected growth stages?

In the first year, three varieties — UPLW-1, UPLW-2, and C48-11 — were sown on 25 Dec 1980 in a lowland ricefield. There were two treatments: 1) rainfed, and 2) sprinkler irrigated at crown root initiation (CRI), booting, and flowering. Irrigation significantly increased grain yield over the rainfed treatment (Table 6). The increase was attributed to increased spikes per m^2 and to 1,000-grain weight. UPLW-1 produced the highest yield.

Table 6. Effect of irrigation on grain yield, spikes/m², and 1,000-grain weight.[a] Los Baños, 1981 DS.

Treatment	Grain yield (t/ha)	Spikes/m²	1,000-grain wt (g)
Growing condition			
Rainfed	1.76 b	315 b	34 b
Irrigated	2.26 a	361 a	36 a
Variety			
UPLW-1	2.25 a	344 a	35 b
UPLW-2	2.00 b	331 a	33 c
C48-11	1.77 c	268 b	37 a

[a]Within a treatment set, means in a column followed by a common letter are not significantly different at the 5% level by DMRT.

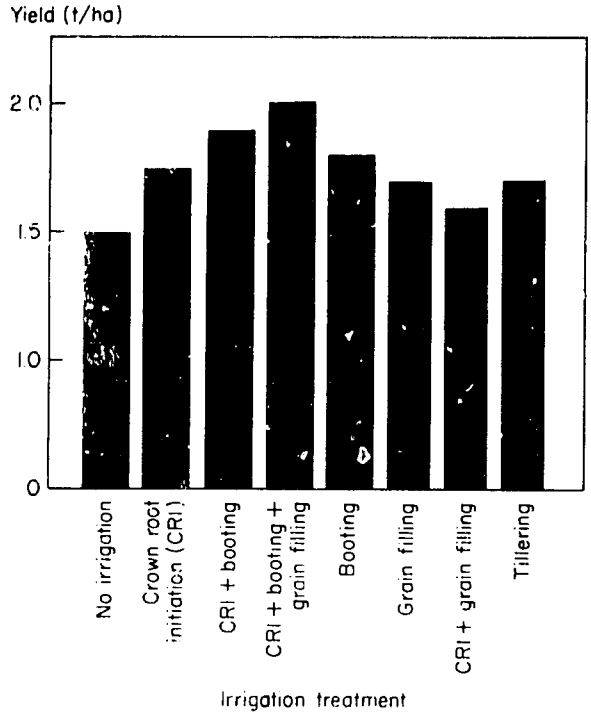
Table 7. Effect of time of irrigation on grain yield and yield components of wheat. Los Baños, 1982 DS.

Treatment[a]	Grain yield (t/ha)	Spikes/m²	Grains/spike	Grains/m²	1,000-grain wt (g)
Irrigation					
T_1	0.84	344	9.7	3352	25
T_2	0.92	345	10.3	3542	26
T_3	1.26	373	12.5	4670	27
T_4	1.18	366	11.5	4200	28
T_5	1.82	412	15.3	6283	29
Variety					
Trigo 1	1.10	326	12.0	3921	28
Trigo 2	1.28	410	11.6	4759	27
SE (a)	0.15	44	1.9	475	0.1
SE (b)	0.04	28	1.1	125	0.1

[a]Irrigation stages: T_1 = control (no irrigation), T_2 = at 15 d after emergence (DAE), T_3 = at tillering, T_4 = at booting, T_5 = at 15 DAE, at tillering, at booting, and at flowering.

In the next season, seeds of UPLW-1 and UPLW-2 were drilled in a well-prepared lowland field on 29 Jan 1982. The treatments were: no irrigation (T_1), irrigated at 15 d after emergence (DAE) (T_2), irrigated at tillering (T_3), irrigated at booting (T_4), and irrigated at 15 DAE, tillering, booting, and flowering (T_5). Irrigation was applied by surface flooding; amount of water was not measured. Grain yields of both varieties increased in response to irrigation (Table 7). Among the single irrigation treatments, irrigation at tillering was most beneficial, followed by irrigation at booting. These irrigations promoted grain setting as evidenced by increased grains per spike and grains per m^2.

In 1983, the experiment was repeated with additional irrigation treatments. UPLW-1 seed was sown on 3 Dec 1982 in a well-prepared upland field. The treatments were: no irrigation (T_1); irrigated at CRI (T_2); at CRI and booting (T_3); at CRI, booting, and grain filling (T_4); at booting (T_5); at grain filling (T_6); at CRI and grain filling (T_7); and at



5. Effect of time of irrigation on grain yield of UPLW-1. Los Baños, 1983 DS.

tillering (T_8). Three irrigations (T_4) gave the highest yield (Fig. 5). However, the response to irrigation was not as high as in the previous DS because more rain fell during 1983 DS. As a result, yield in the rainfed treatment was also high.

In 1985 DS, an experiment was sown on 23 Dec 1984 to evaluate the response of UPLW-1, UPLW-2, UPLW-3, and a promising line (C220-5) to declining water availability during the grain filling period, a common situation where rains stop and irrigation water supply decreases with time after planting. Frequent light irrigations were applied until 30 DAE; irrigation and rainfall during this period totaled 162 mm. At flowering, a line source sprinkler was used to apply an irrigation gradient. The experiment involved 5 moisture regimes; cumulative post-44 DAE water applications were 101 mm in regime 1, 90 mm in regime 2, 65 mm in regime 3, 36 mm in regime 4, and 0 mm in regime 5.

UPLW-3 and C220-5 produced higher grain yields than UPLW-1 and UPLW-2 at all levels of water availability (Table 8). UPLW-3 had higher grain yield than C220-5 in regime 5, suggesting that UPLW-3 has maximum tolerance for a decrease in water availability.

The irrigation experiments showed that, when sown in early DS, wheat can produce 1 t/ha grain yield without irrigation. Maximum yield can be obtained by applying irrigation at CRI, booting, and grain filling. However, the number of irrigations and the stages of their application for achieving high water use efficiency and grain yield depend on stored soil water at sowing and on rainfall during the crop season.

Table 8. Effect of irrigation regime after flowering on grain yield (t/ha) of wheat varieties. Los Baños, 1985 DS.

Irrigation regime	UPLW-1	UPLW-2	UPLW-3	C220-5	Mean
1	1.87	1.71	2.00	2.00	1.89
2	1.64	1.54	1.76	1.88	1.71
3	1.58	1.51	1.74	1.73	1.64
4	1.42	1.31	1.73	1.72	1.54
5	1.37	1.17	1.75	1.41	1.42
Mean	1.57	1.45	1.79	1.75	1.61

Source of variation	df	Mean squares[a]
Variety	3	0.513**
Regime	4	0.495**
Variety × regime	12	0.029**
SE (variety)		0.045
SE (regime)		0.047

[a]** = significant at the 1% level.

Proper timing of small applications can improve extraction of stored soil water and water use efficiency. For example, Ghildyal (9) reported that a single irrigation applied at 33 DAE increased soil water use by 25% and grain yield by 81%. To improve irrigation practices for rice grown after wheat, further empirical studies on local soils are needed.

Fertilizer

Several experiments were conducted in Los Baños and Cagayan to determine the response of wheat to fertilizer (quantity and time of application). N fertilizer response was of major interest. The first fertilizer experiment was sown on 27 Jan 1982 in Los Baños to determine the sensitivity of wheat to 3 N rates (40, 80, and 120 kg/ha) and 3 P rates (0, 13, and 26 kg/ha). All the P and half of the N were soil-incorporated just before sowing. The remaining N was applied at 20 DAE. P fertilizer did not increase grain yield, but N increased yield up to 2 t/ha (Table 9). The agronomic efficiency of 80 kg N/ha was 13 kg grain/kg N. Higher N rates induced lodging and decreased agronomic efficiency (8 kg grain/kg N). The increase in grain yield was due mainly to increased grains per m^2. Grain weight did not respond to either element.

The experiment was repeated in Cagayan in 1984 DS. All treatments except those involving 120 kg N/ha were retained. All fertilizer was incorporated in seed rows and covered with a thin layer of soil before the seeds were sown. As in Los Baños, grain yield response to P was not significant (Table 10). The response to 40 kg N/ha was significant, and the efficiency was 11 kg grain/kg N. However, the response from 80 kg N/ha was not significantly higher. N fertilizer increased spikes per m^2 and grains per m^2 but had no effect on 1,000-grain weight.

To test the effect of N rate and time of application, two experiments were sown in Los Baños on 3 December during

Table 9. Grain yield and yield components of wheat as influenced by N rate. Data are mean over P rates. Los Banos, 1982 DS.

N rate (kg/ha)	Grain yield (t/ha)	Spikes/m²	1,000-grain wt (g)	Grains/m²
0	0.98	361	27	3,684
40	1.69	419	27	6,270
80	2.04	456	27	7,576
120	2.02	453	27	7,562
SE	0.04	44	0.2	145

Table 10. Effect of N on grain yield and yield components of wheat. Data are mean over P rates. Cagayan, 1984 DS.

N rate (kg/ha)	Grain yield (t/ha)	Spikes/m²	1,000-grain wt (g)	Grains/m²
0	0.98	248	30	3175
40	1.44	293	32	3906
80	1.40	301	31	5197
SE	0.30	37	1.4	972

Table 11. Grain yield of wheat as affected by rate and time of N application. Los Baños, 1983 DS.

N rate (kg/ha) at		Grain yield (t/ha)[a]	
Sowing	30 d after sowing[b]	Irrigated	Rainfed
0	0	0.95 d	0.69 c
40	0	2.06 a	1.98 a
20	20	1.69 bc	2.04 a
80	0	1.91 ab	1.88 ab
40	40	1.90 ab	1.57 b
0	80[c]	1.52 c	1.98 a
120	0	1.67 bc	1.68 ab
60	60	1.61 bc	1.98 a
CV (%)		11.2	13.5

[a]Means followed by a common letter are not significantly different at the 5% level by DMRT. [b]Topdressed. [c]Broadcast when rain occurred or when irrigated.

1983 DS. One experiment was completely rainfed, whereas the other was frequently irrigated. Treatments and grain yields for both experiments are summarized in Table 11.

N application significantly increased grain yield in both experiments. However, there was no response beyond 40 kg N/ha. The agronomic efficiency at 40 kg N/ha was 25 kg grain/kg N in the irrigated experiment and 31 kg grain/kg N in the rainfed experiment. Higher N fertilizer rates induced lodging and reduced grain yields slightly. The reasons for higher N use efficiency in this season relative to earlier seasons are not clear. There was no evidence to suggest that splitting 40 kg N/ha improved agronomic efficiency. That grain yields in the two experiments were similar once N was applied suggests that soil water in the rainfed experiment became available to the plant due to increased growth after N application.

Another fertilizer experiment was conducted in Los Baños during 1986 DS. UPLW-3 was sown on 28 Dec 1985 with 3 treatments: 100-22-40 kg NPK/ha applied at sowing (T_1), 50-11-20 kg NPK/ha applied at CRI (20 DAS) and an equal amount at booting (T_2), and 100-22-40 kg NPK/ha applied at CRI (T_3). Grain yield was slightly reduced when the fertilizer application was delayed as in T_2 (Table 12). The full basal fertilizer application resulted in maximum DM production, whereas later application caused more spikes per m² and higher harvest index. This was accompanied, however, by reduced grains per spike. There were no differences amont treatments for 1,000-grain weight.

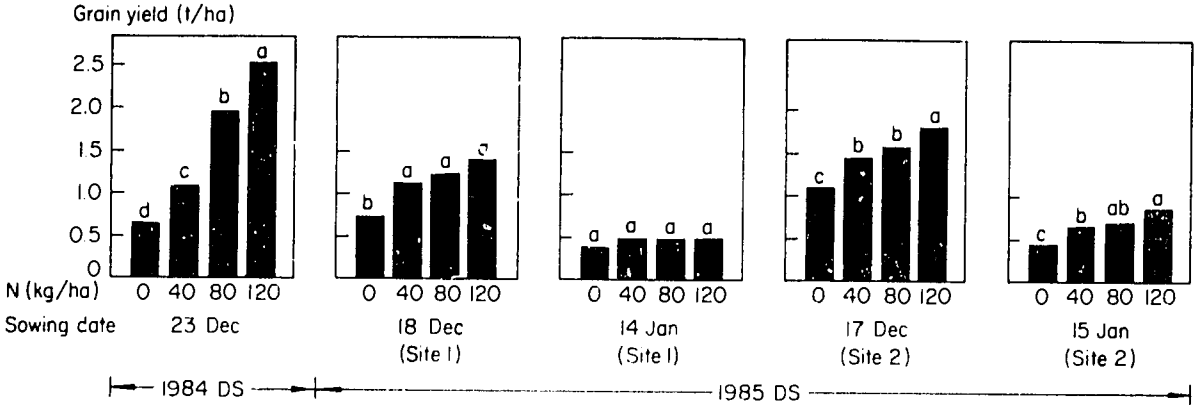
To study the interaction of N with sowing date, another set of experiments was conducted in 1984 and 1985 DS in lowland fields in Cagayan. Sowing dates and sites are given in Figure 6. Sowing dates were in main plots of a split plot design. Four N treatments (0, 40, 80, and 120 kg N/ha) were applied to subplots at sowing.

On all dates except one, N application and amount significantly influenced grain yield (Fig. 6). Grain yields in 1984 DS were much higher and the crops more N responsive than in 1985 DS. In 1985 DS, experiments at both sites experienced water deficits, with the late-planted crop the

Table 12. Effect of time of fertilizer application (100-22-40 kg NPK/ha) on yield and yield components of wheat. Los Baños, 1986 DS.

Treatment		Grain yield (t/ha)	Dry matter (t/ha)	Harvest index	Spikes/m²	1,000-grain wt (g)	Grains/spike
T_1 = all basal		2.51	7.18	35.0	460	31.8	17.2
T_2 = 1/2 at CRI + 1/2 at booting		2.31	4.80	48.3	532	32.5	13.4
T_3 = all at CRI		2.65	5.95	45.7	572	31.8	14.8
Source of variation	df				Mean squares[a]		
Treatment	2	0.112**	5.64**	199.0ns	12823*	0.731ns	14.9*
Error	6	0.00764	0.351	41.6	2482	0.262	1.54
CV (%)		3.5	9.9	15.0	9.6	1.6	8.2
SE		0.06	0.42	4.56	35.2	0.36	0.87

[a]* = significant at the 5% level, ** = significant at the 1% level, ns = nonsignificant.



6. Grain yields of UPLW-1 at four N levels, Cagayan, 1984 DS and 1985 DS. Columns headed by a common letter are not significantly different at the 5% level by DMRT.

most adversely affected. In general, late-planted crops had lower yields and were less N responsive than early-planted crops, which suggests that N fertilizer does not overcome the reduction in growth due to higher temperature.

These fertilizer experiments demonstrate, under conditions suitable for good crop development and depending upon the initial fertility level, that wheat responds to more than 40 kg N/ha and that applying all fertilizer at sowing or at an early growth stage is advantageous. Under the conditions of these experiments, evidence of P response was not detected.

Intercropping

An exploratory experiment was conducted in Los Baños in 1986 DS to evaluate the feasibility of intercropping wheat with a traditional and adapted crop such as maize. Because wheat maturity is short and growth is relatively poor in the lower latitudes, intercropping it with relatively longer maturing maize may increase the efficiency of space and radiation. Six of the eight treatments in the experiment were intercropped combinations of wheat and maize. Wheat was sown on 19 Dec 1985 in rows 15 cm apart at a seeding rate of 170 kg/ha. Maize row spacings were established at 120, 150, and 180 cm by planting every 8th, 10th, and 12th row with maize. Maize was planted at 2 densities (30,000 and 50,000 plants per ha [pph]) at these spacings. Maize monoculture (60,000 pph at 60-cm row spacings) and a wheat monoculture were included.

Grain yields of both wheat and maize were reduced in intercrops relative to monocrops (Table 13). The reduction was more in maize than in wheat. Maize population did not affect maize yield, but wheat grain yield was high when maize population was low. Maize row spacing affected maize yield but not wheat yield. Maize yield was higher with closer row spacing. The total productivity of the land (expressed as land equivalent ratio) was high when maize population was low. The interaction between population and row spacing was nonsignificant. A part of the reduction in wheat yield was due to periodic removal of plants infected with foot rot and corn earworm. Also, there was partial lodging in intercropped wheat.

Table 13. Grain yields and land equivalent ratios for wheat + maize intercrop, Los Baños, 1986 DS.

Maize planting density and row spacing	Grain yield (t/ha)		Land equivalent ratio		
	Wheat	Maize	Wheat	Maize	Total
		Intercrop			
50,000 maize pph					
120 cm	1.12	2.23	0.53	0.62	1.15
150 cm	1.11	1.81	0.52	0.49	1.01
180 cm	1.27	1.38	0.60	0.37	0.97
30,000 maize pph					
120 cm	1.44	1.84	0.68	0.50	1.18
150 cm	1.42	1.84	0.67	0.49	1.16
180 cm	1.31	1.38	0.62	0.36	0.98
		Monoculture			
Maize	--	3.88	0	1.0	1.0
Wheat	2.31	--	1.0	0	1.0

Source of variation	df	Mean squares[a]	
Treatment	6	0.480**	2.95**
Population	1	0.293**	0.88ns
Row spacing	2	0.00162ns	0.90*
Population × row spacing	2	0.6485ns	0.10ns
$SE_{\bar{X}}$		0.12	0.34

[a] * = significant at the 5% level, ** = significant at the 1% level, ns = nonsignificant.

This experiment suggests it is possible to obtain high yields of wheat as well as a traditional low latitude crop (maize) by intercropping. However, further study is needed.

CONCLUSIONS

With present wheat cultivars, it is possible to obtain grain yields of 2 t/ha or more. Among varieties tested, UPLW-3 was most productive. However, even under the best weather and soil conditions in these experiments, the number of grains per m^2 was too low for yields to exceed 3.0 t/ha

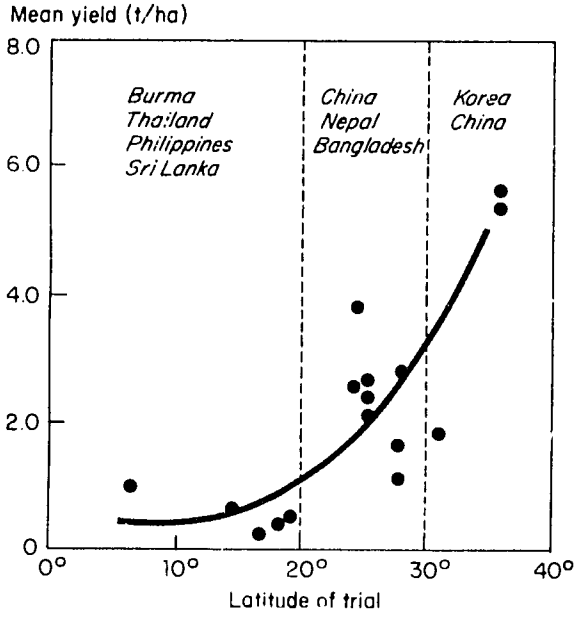
regularly. Increase in seeding rate resulted in more spikes, but this was negated by reduced grains per spike. As postanthesis temperature increased, grain weight declined.

Both N and irrigation increase yield by increasing grains per m^2. N fertilizer is necessary to increase yield, but, given the limited yield potential, rates exceeding 80 kg/ha are seldom likely to be economic. Even though wheat is regarded as a relatively drought-tolerant species, it will respond to irrigation. One to three well-timed irrigations will probably be most cost-effective on many soils. More empirical fertilizer and irrigation research is needed to determine optimum practices for local conditions.

LOOKING AHEAD

If wheat is to be commercially produced in the lower latitudes of Southeast Asia, it must fit into local cropping systems. Identification of potential wheat areas, as well as determination if wheat can replace presently cultivated crops, are required. If wheat is to be grown on irrigated lowland fields during DS in regions such as the northern Philippines where its yield potential is 2.5 t/ha, then it must replace irrigated rice, tobacco, garlic, and vegetables, or be grown on fields not presently used after WS rice. If wheat is to replace a crop, it has to be more remunerative than the replaced crop. If wheat is to be grown on presently uncropped land after WS rice, areas where small quantities of water are available for one or two irrigations must be identified. As a method to use water and other physical resources most efficiently, intercropping wheat with traditional postrice crops should be evaluated. The attractiveness of wheat as a commercial crop will also depend on government programs, particularly with reference to extension, marketing, and price policies. A main reason for low wheat yields at lower latitudes is poor tillering and poor tiller survival. High tiller mortality contributes to rapid leaf area reduction and low spikes per m^2. Future wheat varieties should be selected for high tillering capacity and high tiller survival ratio. Clearly, there is a need for cultivars better adapted to the agroecologies of Southeast Asia, and breeding can develop them. Analyses cited by Evans (6), however, indicate that genetic improvement of yield potential has contributed only 50% to long-term yield increases in temperate zones. The remaining increases have come from improved management.

Figure 7 shows wheat yields from the International Rice-Wheat Integrated Trials (IRWIT) extending from 6° to 40° N latitude. Our data show that wheat yields at latitudes below 20° N are not 1 t/ha or less, as Figure 7 suggests. Yields from the same wheat cultivars grown in Los Baños with good crop management were much higher than mean yields at corresponding latitudes in IRWIT. Agronomic research and breeding efforts for low latitudes should be balanced. Good crop management includes not only optimal tillage, planting, geometry, fertilizer, and crop protection,



7. Effect of latitude on grain yield in the International Rice-Wheat Integrated Trials (2).

but also identification of suitable land and seasons in which wheat yields are least depressed. While agronomic yield improvements tend to be more incremental (e.g., small increases from plant density, N and P fertilizer, weed control, etc.) and less impressive than lumpy gains made periodically by introducing new genetic recombinations, good agronomic research must complement wheat improvement programs in a concerted effort to increase the attractiveness of wheat as a postrice crop for Southeast Asian farmers. It is the challenge to agronomists to identify and overcome those yield-limiting factors that can be modified by management.

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REFERENCES CITED

1. Asana, R. D., and R. F. Williams. 1965. The effect of temperature stress on grain development in wheat. Aust. J. Agric. Res. 16:1-13.
2. Carangal, V. R., and D. P. Garrity. 1974. Rice-wheat collaborative research. IRRI Internal Program Review. (mimeo.)
3. Centro Internacional de Mejoramiento de Maiz y Trigo. 1985. Wheats for more tropical environments: a proceedings of the international symposium, September 24-28, 1984, Mexico. Mexico. 354 p.
4. Centro Internacional de Mejoramiento de Maiz y Trigo. 1985. World wheat facts and trends. Report three. A discussion of selected wheat marketing and pricing issues in developing countries. Mexico.
5. Chinoy, J. J. 1947. Correlation between yield of wheat and temperature during ripening of grain. Nature 159:442-444.
6. Evans, L. T. 1981. Yield improvement in wheat. Empirical or analytical. Pages 203-222 *in* Wheat science — today and tomorrow. L. T. Evans and W. J. Peacock, eds. Cambridge University Press, London.
7. Evans, L. T., I. F. Wardlaw, and R. A. Fischer. 1975. Wheat. Pages 101-149 *in* Crop physiology. Some case histories. L. T. Evans, ed. Cambridge University Press, London.
8. Fischer, R. A. 1983. Growth and yield of wheat. Pages 129-154 *in* Potential productivity of field crops under different environments. International Rice Research Institute, P.O. Box 933, Manila, Philippines.
9. Ghildyal, B. P. 1979. Soil water flux and evapotranspiration in the presence of a shallow water table in a Mollisol. Pages 159-171 *in* Soil physical properties and crop production in the tropics. R. Lal and D. J. Greenland, eds. John Wiley and Sons, New York.
10. Liboon, S. P., and R. A. Morris. 1986. Response of four wheat cultivars to planting dates and fertilizer in the Cagayan Valley. Philipp. J. Crop Sci. 11(1): 37-45.
11. Midmore, D. J., P. M. Cartwright, and R. A. Fischer. 1982. Wheat in tropical environments. I. Phasic development and spike size. Field Crops Res. 5:185-200.
12. Midmore, D. J., P. M. Cartwright, and R. A. Fischer. 1984. Wheat in tropical environments. II. Crop growth and grain yield. Field Crops Res. 8:207-227.
13. Rotor, A. V. 1985. Problems and benefits of reintroducing wheat in the Philippines. *In* Wheats for more tropical environments: a proceeding of the international symposium, September 24-28, 1984, Mexico. Centro Internacional de Mejoramiento de Maiz y Trigo, Mexico.
14. Sofield, I., L. T. Evans, M. C. Cook, and I. F. Wardlaw. 1977. Factors influencing the rate and duration of grain filling in wheat. Aust. J. Plant Physiol. 4:785-797.
15. Yoshida, S. 1983. Rice. Pages 103-128 *in* Potential productivity of field crops under different environments. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

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