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ABSTRACT

Rice productivity has increased more rapidly over the past two decades than throughout previous history. Modern varieties, fertilizer, and irrigation have contributed to these gains. Globally, production variability (coefficient of variation) is probably lower, although it may have increased in South America and parts of Asia. Production instability may be higher now than previously in Burma, China, India, and Indonesia, but lower in Bangladesh, the Philippines, Sri Lanka, and Thailand. Burma and Indonesia may show slight increases in rice yield variability, but the early period was one of low, stagnant yields, compared with the present period of high and increasing yields.

Adaptability and stability in modern varieties are correlated. Breeding for location specificity will contribute further to yield stability at the farm level. Second-generation modern varieties have higher levels of pest resistance than traditional varieties. Varietal resistance coupled with judicious use of pesticides will increase yield stability. However, increased use of fertilizer may increase yield variability as yield variance increases as N rates increase.

Farm-level data from both irrigated and upland rice areas show that improved agronomic practices, in aggregate, may result in an increase in the negative skewness of yield distributions. Therefore, modern variety technology need not place farmers in a less favorable risk situation, but instead may place them in a more favorable risk situation, depending on costs.

Modern rice improvement programs breed for high and stable yields. Inherent yield stability will improve with continuing selection for pest resistance and tolerance for adverse environments. Widespread collaborative testing of cultivars provides national programs the opportunity to select cultivars with desired traits for their locations and the choice to incorporate them in their own programs. Modern agronomic practices give farmers wider choices and flexibility in management, thus providing greater opportunity to adjust husbandry practices to the vagaries of the crop season as it unfolds.

Modern varieties are management responsive and, therefore, the production of these varieties is responsive to the uncertainties of the market and institutional environments in which they are produced. An analysis of socioeconomic factors influencing production is necessary to provide a balanced view of the variability sources in rice production.

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YIELD STABILITY AND MODERN RICE TECHNOLOGY

Modern technology has contributed substantially to productivity gains in agriculture in both the developed and the developing world (1, 6). However, there is no consensus whether this technology has increased or reduced production variability, an issue of central concern to food security analysts. This debate was rekindled by Mahra (30) and Hazell (21), who observed that production variability in cereals had increased in India and the USA since the mid-1960s, a period corresponding to a rapid expansion in modern technology. Hazell showed that an increase in positive yield covariance between states was a more important determinant of increased production variability in these two countries than were increased production variances of crops within states.

Hazell and others argue that increased production instability of food crops in the developing world is a consequence of 1) institutional factors, such as higher correlations among food crop prices, or supply restrictions due to poorly developed infrastructure; 2) agroclimatic factors such as droughts and floods; and 3) biotic factors largely associated with increased genetic uniformity within crops across regions. Few studies -- Ray (33) and Walker (41) provide exceptions — have attributed changes in production variability to the characteristics of the modern varieties (MVs) themselves and to the socioeconomic environment in which they are grown.

The nature of modern rice technology and its inherent implications for increasing or decreasing rice yield stability are discussed in this paper. First, we review the evidence of whether or not rice production stability in aggregate has increased in Asia with the adoption of MVs. Second, we examine experimental data to determine whether the components of modern rice technology are likely to stabilize or destabilize yield. Third, we use farm data to provide some insights on the impact of higher input technology, when managed by farmers, on yield distributions. Fourth, we review research strategies that are likely to result in second-generation MVs and methods of crop management having higher productivity and stability than first-generation MVs or traditional rice varieties.

Three terms need defining before proceeding:

- *Modern rice varieties*, also referred to as high yielding varieties or green revolution rices, were developed during the past two decades and are dwarf to semidwarf, photoperiod insensitive, and responsive to modern agronomic practices. Modern variety is the most appropriate term because these varieties may not give high yields high unless high levels of inputs are used or the varieties are grown in favorable environments. Also, these varieties may be adopted because of their early maturity or their insect and disease resistance as opposed to high yield, per se. In this paper, we use MV to indicate modern variety and OV to indicate older variety. OV includes traditional varieties and older products of hybridization or selection within traditional varieties, such as Peta and BE-3. These are commonly tall, photoperiod sensitive, and not very responsive to modern agronomic practices. Some varieties with traditional plant types have also been improved to exhibit characteristics intermediate between MVs and OVs and are referred to as intermediate varieties (IVs) in this paper; Pelita and Pankaj are examples.
- *First-* and *second-generation MV rices* need distinguishing. The first-generation MVs, typified by IR8, had the capacity to utilize fertilizer effectively. However, they were of long duration and lacked broad-spectrum disease and insect resistance. The second-generation MVs retain this fertilizer responsiveness and, in addition, are of shorter duration and have multiple insect and disease resistance, high yield potential, and improved grain quality. IR8, for example, has a fixed 130-d growth duration; the first really short duration MV, IR36, matures in 110 d; more recent varieties such as IR58 mature in about 100 d. This means that second-generation MVs use less water, are exposed to field hazards for a shorter period, and, most important, from a food-security viewpoint, can be harvested early enough to allow farmers to plant and harvest another crop during the same rainy season.

- *Changes in production stability* are measured in terms of changes in deviations around long-term trends over two periods, supposedly approximating before and after MV adoption. In most countries the area planted to MV rices is still expanding. Therefore, it is more appropriate to refer to the latter period as an adoption phase, not as a postadoption era. Changes are measured in terms of relative variability (coefficient of variation [CV]) and absolute variability (variance). In most cases, these measures were computed from standard errors of second-order polynomial time trends. This functional form was chosen because it does not assume a deterministic relationship between the variance of the dependent variable and time (22). In those few cases where trends were not significant, the mean and variance were estimated directly from the data set.

There is no consensus whether a relative or an absolute measure of production variability is the most appropriate. When differences in means between groups are large, the CV provides a useful comparative measure, because as a pure number it abstracts from the bias that larger mean values also normally have higher variances. However, there is no readily available statistic to determine whether two CV's are different in a statistical sense. The variance (or standard deviation) is more useful when a physical measure of variability, for example, for food security or buffer stock analysis, is required. Also, F tests are readily constructed to test for significance of differences between variances. As an extension, the probability of some amount falling below trend (say 5%) may also be estimated from the variance and standard probability tables. A recent and appealing alternative is to measure variability with respect to deviations from expectations (3).

AGGREGATE PRODUCTION STABILITY

Global production

Global rice production and yields have increased more rapidly since the late 1960s than in previous decades (Fig. 1). China (35%) and India (20%) together produce and consume more than half of the world's rice. Therefore, any fluctuation in yield or area planted to rice in these two countries has a major impact on the global picture. Thus, the shortfalls in global rice production in 1965-67 and 1971-72 can be traced to low rice yields in Eastern India (and Bangladesh) associated with severe drought.

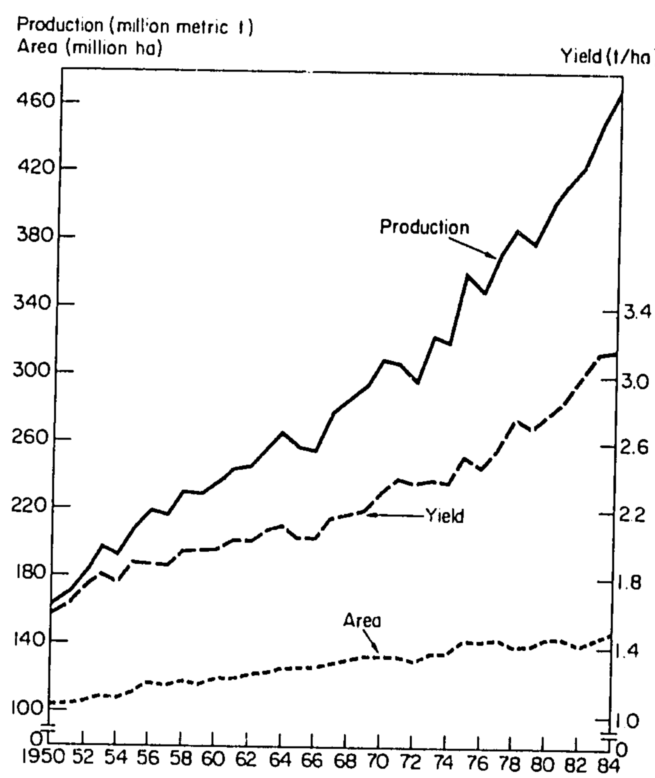
Despite the dramatic increase in global rice production (except China) from the 1960s to the 1970s and beyond, production variability did not increase, according to Hazell (22) (Table 1). In fact, the CV of global rice production declined from 4.0 to 3.8% between the periods 1960/61-1970/71 and 1971/72-1982/83. The CV of global rice production would have declined further in the second period had there not been a significant increase in the variability of rice area from year to year in Africa and South America.

Aggregate figures are difficult to interpret because they mask important differences between (and within) regions. Thus, Hazell also estimated changes in the mean and variability of rice production by geographic region for these two same periods (Table 1). The relative variability of total rice production decreased in Africa, Central America, and South and Southeast Asia but increased in South America, India, and East Asia over these two periods. The variance of rice production increased significantly in South America and India, but not in other regions. Yield variance also increased significantly in India and in East Asia.

Another useful measure of production variability from a food security viewpoint is the probability that production will fall below a long-term trend. Thus, Hazell also estimated the probability that production would fall 5% or more below trend each year for each region and period (Table 1). The probability of a shortfall below trend was less in the second than in the first period except for South America and East Asia.

Rice production stability in Asia

Asia produces and consumes more than 90% of the world's rice, with 8 countries producing about 80% of the world's rice supplies. The changes in relative variability of



1. Global trends in production, area, and yield of rice, 1950-84 (15).

Table 1. Changes in mean and variability of total rice production by region, 1960/61-1970/71 (first period) to 1971/72-1982/83 (second period).[a]

Region[b]	Average production (thousand t)			Coefficient of variation of production (%)			F-ratio			Probability of a 5% shortfall below trend (%)[c]	
	First period	Second period	Change	First period	Second period	Change	Production	Area sown	Change	First period	Second period
World	119,971	155,031	29.2	4.0	3.8	4.3	1.52	2.45	0.88	na	na
Africa	2,248	2,798	24.5	5.8	4.1	28.2	0.81	3.25	0.95	19.2	11.3
Central America	642	912	42.1	11.1	6.5	41.5	0.68	1.81	0.20	32.6	22.1
South America	2,741	4,186	52.7	3.7	9.4	150.0	14.28	9.28	11.04	9.0	29.5
India[d]	31,682	42,562	34.3	6.5	7.6	18.0	2.51	3.61	1.48	na	na
South Asia	18,798	23,347	24.2	6.3	4.0	36.0	0.63	0.32	0.76	21.5	10.9
Southeast Asia	35,505	50,798	43.1	4.2	3.9	7.4	1.74	1.28	1.13	11.5	9.9
East Asia	19,832	17,620	11.1	5.3	8.6	60.8	2.04	0.26	4.96	17.3	28.1

[a]Source (22). China was not included in this analysis. [b]Regional definitions: Africa = Guinea, Guinea Bissau, Ivory Coast, Liberia, Malagasy, and Sierra Leone; Central America = Costa Rica, Cuba, Panama, Dominican Republic, and Trinidad; South America = Colombia, Ecuador, Guyana, Surinam, and Venezuela; South Asia = Bangladesh, Bhutan, Burma, Nepal, and Sri Lanka; Southeast Asia = Indonesia, Kampuchea, Laos, Malaysia, Philippines, Thailand, and Vietnam; East Asia = Republic of Korea and Japan. [c]na = not reported. [d]From (22); 1952/53-1964/65 = first period, 1967/68-1977/78 = second period.

rice production, area, and yield for these eight countries using FAO and USDA data sources and two periods are listed in Table 2. Eastern India, which is mainly rainfed, dominates Indian rice production.

Estimates from the FAO and USDA data sources are not always consistent. Compare, for example, changes in production stability in China, Indonesia, and Thailand; different conclusions are implied, depending on data source. Paulino and Tseng (32) discuss some of the reasons for the discrepancies between FAO and USDA data sets. Hazell (22) also comments on the unreliability of Chinese data from the 1960s to early 1970s; the inclusion (FAO) or exclusion (USAID) of Taiwan Province is another source of difference. No easy data conciliation is suggested for Indonesia or Thailand.

Stability estimates are also sensitive to the periods during which they are measured — compare the 11- and the 13-yr periods using the FAO data. Differences in conclusion as to whether yield variability increased or decreased in Burma and Thailand are implied, depending on the period.

The rate and extent of MV adoption vary markedly among (and within) Asian countries. So do policies that influence MV adoption (price policies, irrigation investment, research vs extension, etc). Therefore, the choice of period for time trend analysis must be country specific and based on structural shifts in MV adoption or major policy changes. Periods were, therefore, redefined based on changes in rice policies, programs, and MV adoption rates by country, and trends were reestimated (Table 3). On this basis, yield instability may have increased in Burma, China, India, and Indonesia in aggregate, but decreased in Bangladesh, the Philippines, Sri Lanka, and Thailand. Although Burma and Indonesia may show slight increases in yield variability, the first period in each

Table 2. Changes in coefficients of variation (CV) in production, yield, and area of rice in 8 major Asian rice-producing countries from 2 data sources over 2 periods.[a]

	Change (%) in CV								
	Production			Area			Yield		
	FAO		USDA	FAO		USDA	FAO		USDA
	A	B	A	A	B	A	A	B	A
Burma	18	4	22	30	21	7	21	66	27
Bangladesh	44	47	38	51	59	51	32	43	20
China	72	66	45	63	66	62	83	24	19
India	19	21	22	30	66	13	34	15	27
Eastern	2	4		3	65		6	5	
Southern	86	165		223	401		43	86	
Northern	55	13		4	59		33	11	
Indonesia	19	24	2	6	27	11	30	35	40
Philippines	47	50	51	2	0.4	23	63	62	68
Sri Lanka	15	20	13	90	58	69	48	25	27
Thailand	6	24	22	16	28	54	89	30	16

[a]CVs were computed from means and standard errors of second-order polynomial time trends except when time trends were not significant. Period A = decades 1961-71 and 1972-82, B = 13-yr periods 1959-71 and 1972-84. Sources: FAO production yearbook, various issues. USDA Foreign agriculture circular, USDA Foreign Agricultural Service, 9 September 1983.

case was characterized by stagnant low yields, while the recent period of MV adoption exhibits large and, in most cases, continuing yield increases (Fig. 2, 3).

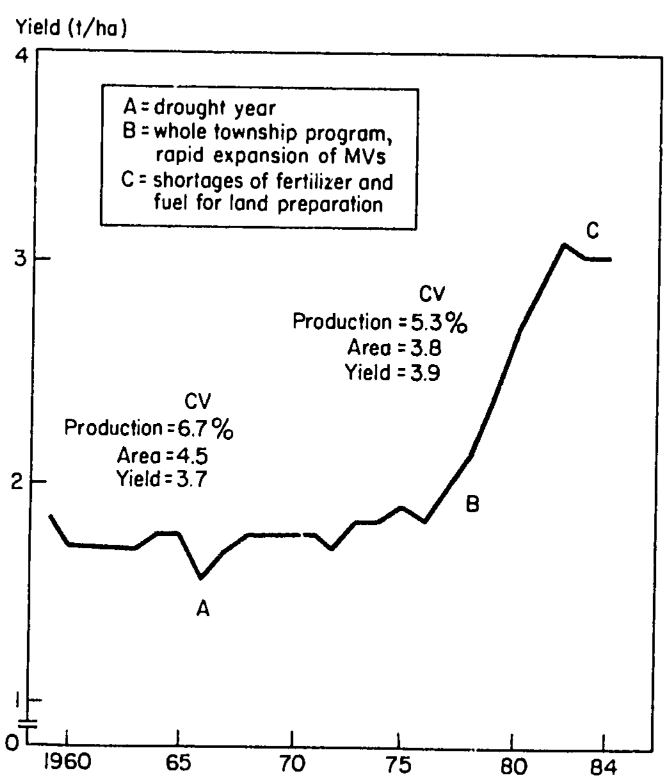
The same picture emerges on a regional basis within India (Fig. 4). Rice production variability has not markedly increased in eastern India, where yields remain stagnant, but has increased in the north and the south, where rice productivity has increased dramatically.

A problem with the trend analysis reported is that methods (and quality) of collecting and reporting national statistics may vary considerably over time and between countries. Therefore, part of the apparent change in variability may be due to changes in data collection practices as opposed to shifts in productivity, per se. Also, trend analysis is not an appealing technique to analyze changes in productivity and its components (i.e., area and yield) because factors that cause instability are not identified, measured, or included in the analysis. Clearly, more rigorous analysis is necessary to estimate the impact of technological change on stability parameters.

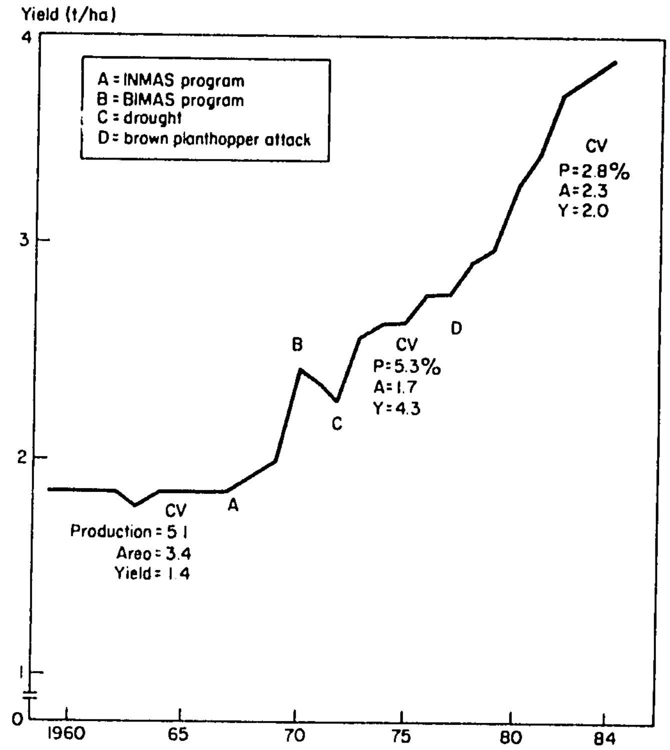
Table 3. Changes in coefficients of variation (CV) in production, yield, and area of rice in eight major rice-growing countries for periods before and during MV rice adoption.[a]

	Period		Change (%) in CV		
	First	Second	Production	Area	Yield
Bangladesh	1959-73	1974-84	- 56	- 52	- 58
Burma	1959-76	1977-84	- 21	- 17	4
China	1959-77	1978-84	15	- 46	37
India	1959-73	1974-84	32	61	30
Eastern	1959-70	1971-82	3	25	- 1
Southern	1959-68	1969-82	132	410	66
Northern	1959-69	1970-82	- 7	61	- 2
Indonesia	1959-67	1978-84	- 45	- 33	49
Philippines	1955-65	1975-84	- 36	- 33	- 64
Sri Lanka	1959-75	1976-84	- 64	- 51	- 60
Thailand	1955-65	1966-84	- 55	- 55	- 36

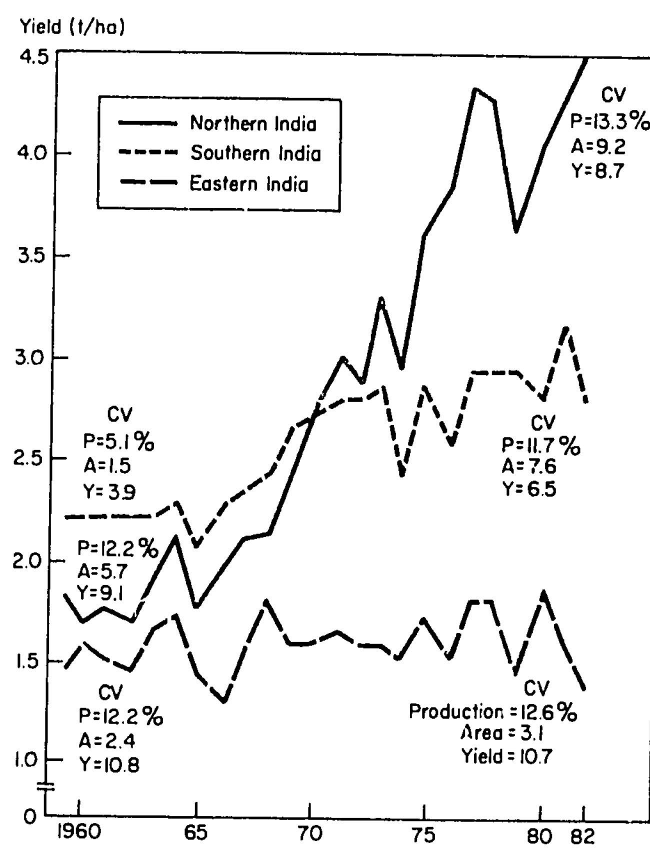
[a]CVs were computed from means and standard errors of second-order polynomial time trends except when time trends were not significant.



2. Trends in rice yield and coefficients of variation (CV) of production, area, and yield in Burma.



3. Trends in rice yield and coefficients of variation (CV) of production, area, and yield in Indonesia.



4. Trends in rice yield and coefficients of variation (CV) of production, area, and yield in India.

Carlson (4) examined the causes of rice yield variability using panel data from 13 Asian countries and concluded that the CV of both rice yield and total production decreased significantly with higher MV adoption and irrigation development. Ray (33) examined instability in Indian agriculture and showed that weather and price variables were significant determinants of yield and production stability in rice production. However, variables associated with technological change, e.g., MV adoption and irrigation rate, were not included in the analysis, other than through a trend variable.

COMPONENT TECHNOLOGY AND YIELD STABILITY

Coffman and Hargrove (5) and Carlson (4) discuss how the morphology of MVs influences the comparative yield stability of MVs and OVs. We do not duplicate this effort here, but we provide evidence of the association between MV traits and yield stability. Traits examined are: 1) evidence of varietal adaptability over space and its relationship to stability within locations, 2) performance under water stress conditions, 3) duration-yield relationship, 4) pest resistance, and 5) fertilizer responsiveness.

Stability and adaptability

Much of the success of MV rices is attributed to the benefits of multilocational testing, which has led to the identification of widely adapted cultivars. Adaptability may be important to crop improvement scientists, but breeding for wide adaptability also has associated costs. Because selection is based on multilocation performance, cultivars selected may not necessarily be the best for any specific location where they are recommended. Yield stability refers to the performance of a genotype with respect to changing environmental factors over time at a given location. Adaptability refers to the performance of a genotype with respect to environmental factors that change across locations (14).

Plant breeders place considerable confidence in the multilocation testing process as a means of selecting new cultivars. Of course, final genotypic selection is not based only on multilocation performance within a single year. Cultivars are normally selected as varieties after at least 3 yr of testing. But advancement of cultivars within a selection program does depend primarily on multilocation, within-year results.

It is implicitly assumed that adaptability is highly correlated with stability. Whether or not this is true is a central issue in the effectiveness of the breeding process in producing genotypes that have stability as well as high yield. Optimization of crop improvement research in identifying stable cultivars may depend on this correlation. If this is not so, the acceptance of multilocation performance as a proxy for time series performance in cultivar selection requires reexamination.

There is a very large body of literature for the major cereal crops on the interaction between genotype and environment. This work received strong impetus from Finlay and Wilkinson (16) and Eberhart and Russel (12). However, these and other studies make no distinction between the concepts of stability and adaptability. Evenson et al (14) used analysis of covariance to test whether the two parameters were related using a set of rice genotypes selected from the first 3 yr of irrigated rice yield trials of the International Rice Testing Program (26) and several years' results of similar trials conducted by the All India Coordinated Rice Improvement Program (AICRIP). They found contrasting results for the two data sets: no relationship between adaptability and stability in the IRTP data set, but a strong positive correlation between the parameters in the AICRIP data set. Given the short time span of the IRTP data and the implausible stability coefficients obtained for some of the genotypes, we retested the hypothesis using Evenson's model and data from 10 yr of IRTP trials.

The genotypes included in the analysis were those tested in IRTP nurseries for a minimum of 4 yr. IRTP trials are designed for frequent turnover of entries as new improved material becomes available. Thus, only a few of the several hundred cultivars tested during the past decade have been retained for a 4-yr period or longer. Data from the upland rice yield trials and the irrigated lowland trials were analyzed to provide two contrasting sets of genotypes tested under different ecological conditions.

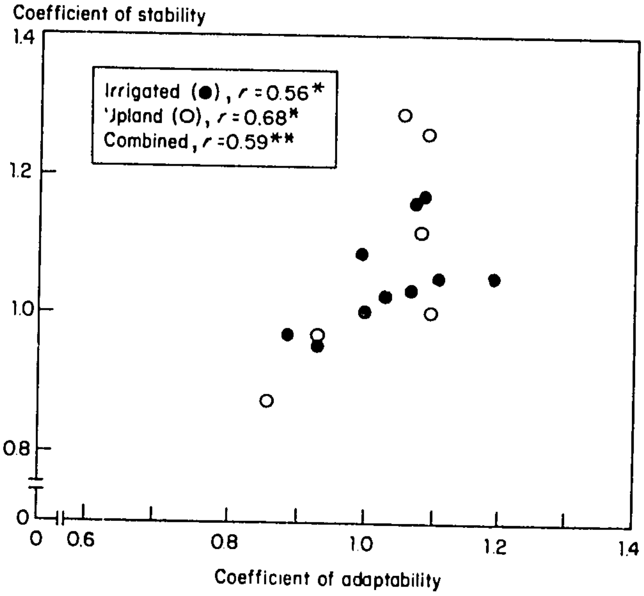
Low coefficients of adaptability or stability indicate a relatively low yield differential for a cultivar across sites or years, respectively. A high coefficient indicates that the cultivar performs poorly in low yield environments relative to its performance in more favorable environments. The coefficients of individual cultivars varied from as low as 0.86 for adaptability and 0.87 for stability (IR6115-1-1-1) to as high as 1.06 and 1.29 for IR2061-522-6-9 (Table 4). The coefficients of adaptability and stability were positively correlated among the set of entries from both the irrigated and upland yield trials (Fig. 5).

The coefficients of stability tended to be higher than the coefficients of adaptability in both cultivar sets. These data and those of Mackill et al (29), who showed that the regression coefficient of cultivar yields versus site mean yield remain consistent across entries in international rainfed lowland rice trials in which large hydrological variation occurs, add weight to the contention that cultivar adaptability and stability are highly associated. The adoption of widely adapted varieties at best buys time for national programs working to develop varieties with high and stable performance under specific ecological conditions and market preferences.

Table 4. Coefficients of adaptability and stability of rice cultivars tested 4 yr or more in the International Rice Testing Program (IRTP) yield nurseries.[a]

Cultivar	Stability		Adaptability	
	Irrigated lowland			
IR42	1.08	.07	0.99	.06
BR51-282-8	1.05	.09	1.10	.06
IR54	1.16	.10	1.07	.09
IR8	1.03	.06	1.06	.04
IR26	0.97	.07	0.89	.08
IR36	0.96	.04	0.93	.03
MRC-603-303	1.01	.07	1.00	.05
MTU3419	1.16	.11	1.08	.08
IR1561-228-3-3	1.02	.09	1.02	.07
IE + 2845 (RP-1899-25-4)	1.05	.08	1.18	.07
	Upland			
IR1529-430-3 (IR43)	1.12	.08	1.08	.08
IR2035-242-1 (IR45)	0.96	.16	0.93	.99
MRC172-9	1.26	.25	1.09	.11
C22	1.00	.16	1.09	.12
IR2061-522-6-9	1.29	.15	1.06	.15
IR6115-1-1-1	0.87	.08	0.86	.18
IR52 (IR5853-118-5)	1.06	.09	0.90	.14

[a]All coefficients significant at the 1% level. Method of analysis and further interpretation of these coefficients are found in (14). Data extracted from Final Reports of IRTP Nurseries for 1974 to 1983. IRRI, Philippines.



5. Relationship between the coefficients of adaptability and stability of rice varieties internationally tested a minimum of 4 yr in IRTP. Irrigated yield trials significant at the 10% level, upland yield trials at 10%, and combined data at 1%.

Mean yields across IRTP trials

IRTP trials have been well distributed over a range of low to high-yielding sites and growing seasons (Fig. 6); there has been no tendency for trial mean yields to be clustered within a narrow yield range. Also, neither the means nor the variances of the trial mean yields increased over time, indicating there has been no tendency to move to high yielding sites in more recent years.

Although there is a wide spread between the CVs and mean yields, they are, over all, negatively related; the CVs of trials tend to decrease as site means increase. Also, on average, the CVs for upland rice trials were higher at any mean yield level than the CVs of irrigated yield trials. One reason for this may have been the inherently greater within-site variability in upland trials, since the water holding capacity of the soil is sensitive to small variations in soil properties.

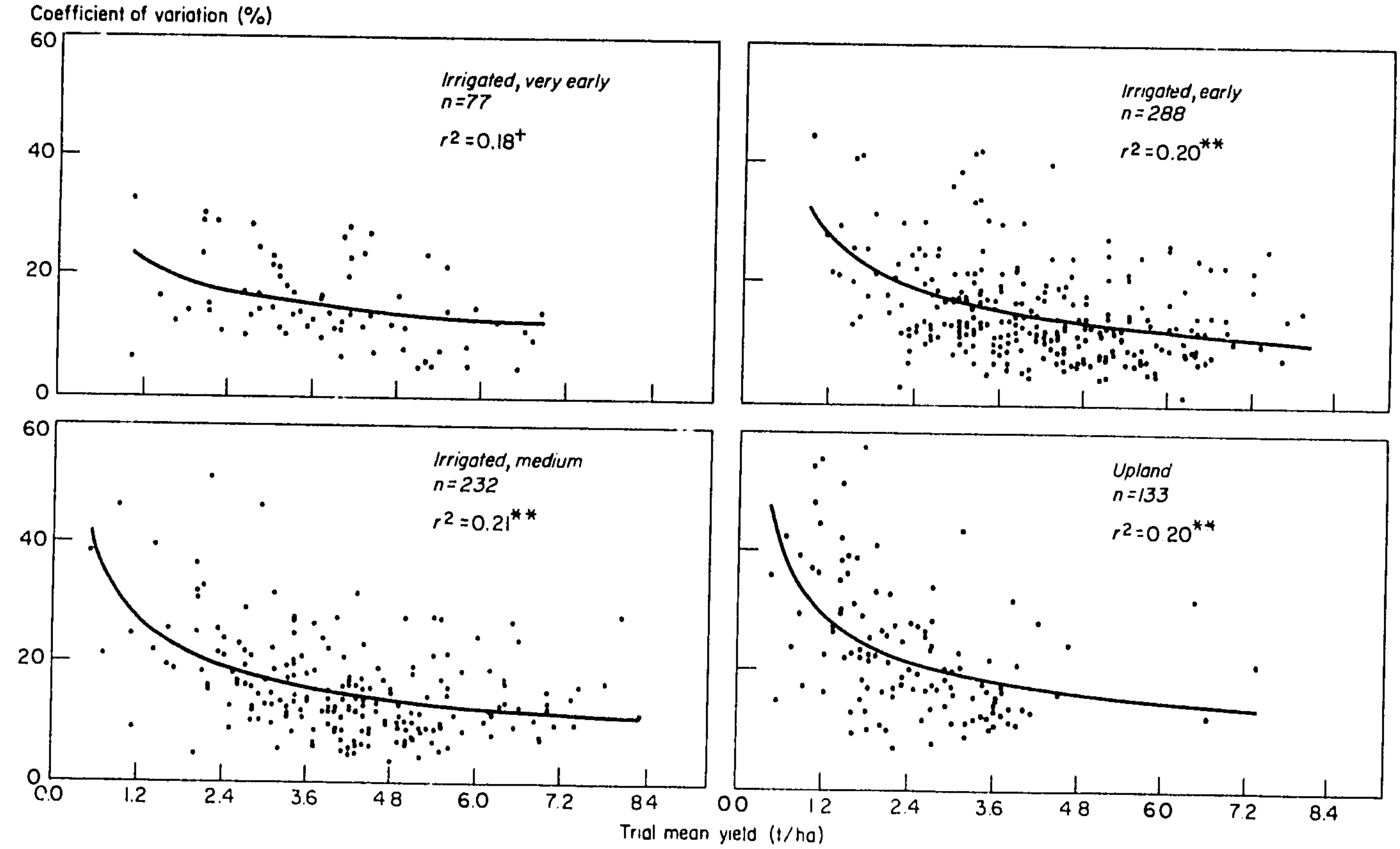
MV and water-stressed environments

An irrigated ricefield is one of the most physically homogeneous, nutritionally buffered ecosystems. Most environmental disturbances may be avoided, enabling yields to be increased without substantial increases in yield variability. In contrast, upland ricelands represent a highly variable agroecosystem. Rice grown on such lands, which have no surface water storage capacity, is subject to highly variable internal water status, since the rice plant lacks efficient root water uptake and shoot conservation mechanisms. Average yield levels may be increased in such conditions, but the lack of control of the most critical nutrient (water) suggests that yield variability is likely to increase as yield increases. The same may apply to flood-prone and deep water rice environments. Differences among rice growing environments in the extent to which major yield determinants can be controlled suggest that yield and yield stability questions must be focused on specific rice environments.

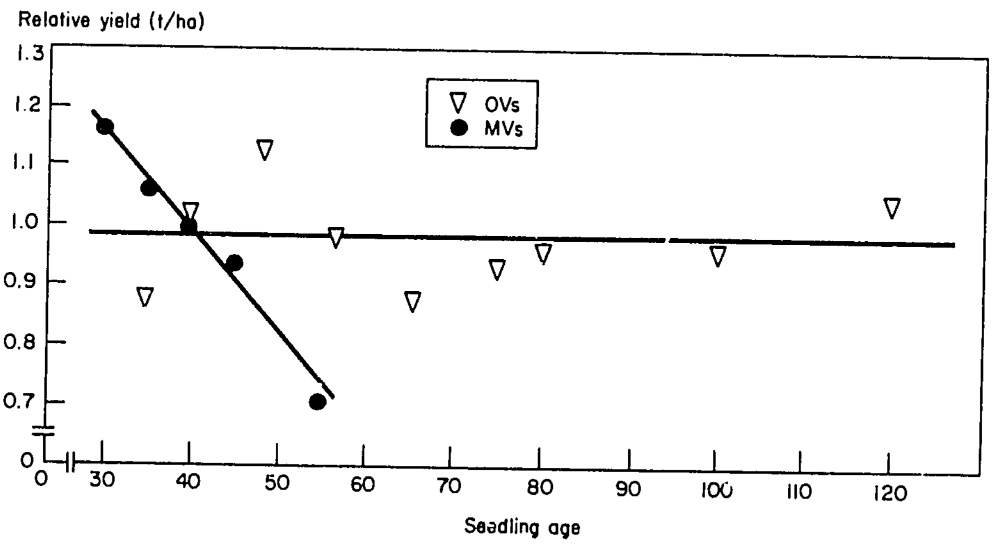
MV rices respond to higher nutrition and assured water supply by producing higher grain yield per crop and per field day. But where water control is inadequate, the structure and function of the MV rice plant may predispose it to be more severely affected by water deficit or excess than OVs. In some drought-prone environments, the shorter stature, shallower root system, higher tillering, and photoperiod insensitivity of MVs may result in severe damage or crop failure.

Early maturity is a necessary character in rice-growing areas with a short wet season (WS). The shorter duration of a MV may enable it to better fit the limited period of available moisture and escape the terminal water stress that would affect a late-maturing OV during flowering or grain filling. The strong preference of a large proportion of Philippine rainfed rice farmers for early maturing (105-115 d) rices may be attributed to the stability enhancement of drought escape.

In other drought-prone environments, however, which experience relatively long rainy periods but highly erratic rainfall distribution, (e.g., northeast Thailand and the Cagayan Valley, Philippines), the short-duration, photoperiod-insensitive varieties are highly unstable and clearly inappropriate (18). Short-duration varieties are genetically programmed to proceed through each successive



6. Relationship between mean yield and coefficient of variation for IRTP yield trials, 1975-81. + = significant at the 10% level, ** = significant at the 1% level.



7. Grain yield of MV and OV rices expressed as ratios relative to yields from 40-d-old seedlings, Solana, Cagayan (18).

growth stage (e.g., tillering, floral initiation, spikelet development, flowering) in a limited time. Severe and prolonged drought interrupts this development, resulting in drastic yield reduction. A photoperiod-sensitive variety flowers in a certain month regardless of when it is planted. When planted at the normal time early in the growing season, it passes through a long preflowering phase. This longer vegetative period enables more effective drought recovery before the plant enters the sensitive reproductive phase. Short-duration, photoperiod-insensitive varieties, however, have little phenological buffering. Growth lost at one stage cannot be as effectively compensated.

Planting old seedlings is common in drought-prone areas with erratic rainfall, since farmers can transplant only when adequate water collects in the bunded field, a highly unpredictable event. MVs tend to respond poorly to late transplanting, while the yields of photoperiod-sensitive OVs are unaffected (Fig. 7). Therefore, OVs remain dominant in many Asian drought-prone areas with erratic rainfall.

Another large proportion of Asian riceland is subject to severe and unpredictable water excess, including flash floods prompted by extreme rainfall events (typhoons, cyclones) on the fields in lower landscape positions with restricted drainage, and deep prolonged flooding for a major portion of the crop growth. Genetic adaptation to these conditions is possible through incorporation of the traits of submergence tolerance and deep water adaptation into new rice varieties. However, current MVs are not sufficiently adapted to cope with these stresses, and local varieties continue to be grown in most flood-prone areas.

The instability of MVs in these drought-prone and flood-prone situations has precluded their adoption on more than 50% of Asian ricelands. In the more favorable areas, where MVs are currently grown, whether MV cultivation will result in greater yield instability will depend on the nature of the yield-limiting stress.

Pest management

Coffman and Hargrove (5) observe that insect and disease pressures on rice are among the highest within the staple food crops. The rate of the continuous process of genetic adaptation of rice pests to the crop seems to increase with the intensification of rice technology as wider areas are planted asynchronously to single varieties, as double- and triple-cropping increase, as higher rates of fertilizer are used, and as irrigation increases. This places greater stress on the role of maintenance research to defend yields than is necessary for most other crops. Therefore, as discussed in the final section of this paper, breeding for multiple insect and disease resistance is the core of most rice improvement programs. In this section, the potential impact of modern agronomic practices on yield stability — recognizing that varietal resistance is a key to the success of improved pest management techniques — is discussed.

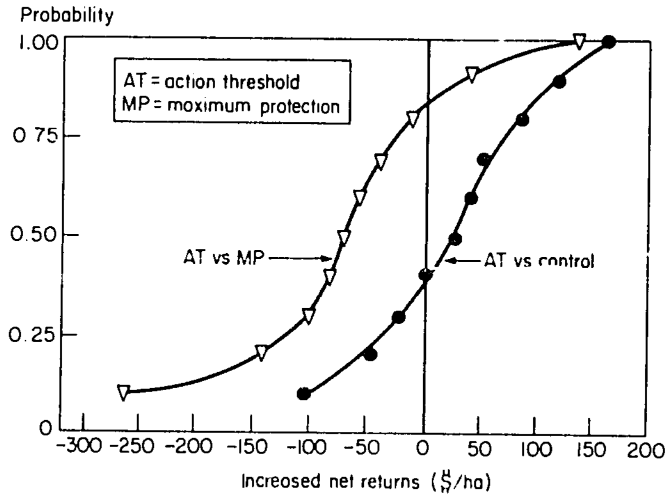
Insect management. Prophylactic application of broad-spectrum insecticides, as formally recommended in most extension programs, is expensive, often ineffective because of pest resistance and resurgence, and environmentally hazardous. These shortcomings led to the concept of integrated pest management (IPM), which involves the selection of insect-resistant varieties, the judicious use of insecticides when the insect population reaches the economic threshold level, and cultural practices designed to lessen pest pressure (23).

The on-farm benefits of three insect control strategies — no insecticide application, action thresholds, and prophylactic sprays — were evaluated on insect-resistant rice varieties over 5 yr in the Philippines (37). The net benefits were similar across treatments; however, CV's were less with the untreated and the action threshold plots

Table 5. Net benefits and coefficients of variation (CV) of insect control practices in rice, Philippines, 5 wet seasons.[a]

	Untreated	Action thresholds	Prophylactic spray
Net benefit ($/ha)	426	436	428
CV (%)	15	23	31

[a]Calculated from (37). Assumed exchange rate U.S.$1=P18.75.



8. Probabilities of stated increase in net returns from alternative insecticide treatments, farmers' fields, Iloilo, Philippines, 1976-79 (24).

(Table 5). One reason for the similarity in net benefits was that the yields of the zero treatment plots tended to be less than those of the treated plots. However, costs were higher with the action threshold treatment, mainly because of surveillance costs, and with the prophylactic treatment, because of insecticide costs. The Philippine Ministry of Agriculture and Food reports that threshold spraying was more profitable than preventive sprays in 75% of 105 on-farm trials. Herdt et al (24) similarly found that the net returns from insecticide applications based on action thresholds dominated alternative insect control measures (Fig. 8).

Consistent with Carlson's (4) impressions, a strategy of combining insect-resistant varieties and selective use of insecticides reduces production variability in rice below the level expected under traditional insect management strategies. However, IPM technology is also more complex than farmer's current practices (19). Therefore, training and extension must be integral components of IPM technology, and surveillance costs must be recognized (28).

Diseases. Varietal resistance continues to be the main disease management strategy for rice in Asia. Fungicides have not become part of disease management in South and Southeast Asia, although they have in temperate regions (e.g., Japan and Korea). Clearly, disease outbreaks, such as the rice tungro virus (RTV) outbreaks in parts of Indonesia in 1981, will continue to occur and cause yield losses. However, modern breeding strategies, which include genotype selection at specific high-stress locations, have ensured that new materials are available, or in the pipeline, to combat diseases when they become potentially serious problems. One example was the availability of IR56 to replace IR36 in regions of Indonesia where the latter had become susceptible to the brown planthopper, the vector of RTV.

Management techniques may also reduce the likelihood of disease infestation with intensified rice production. For example, the concept of varietal rotation between WS and dry season (DS) crops has been introduced in Indonesia to reduce the probability of RTV (31). Varietal (and gene) rotation as a strategy for disease management requires well developed agricultural research, extension, and seed propagation systems. It becomes feasible as the expertise of national rice programs increases, which is the case in Asia (27).

Weed management. Modern rice varieties are shorter, more erect, and thus less weed competitive than taller, drooping OVs (8). This, in principle, implies increased yield variability in MVs in situations where weeds are a problem or are inadequately controlled.

The most dramatic recent change in weed management in rice in Asia was the rapid and widespread adoption of herbicides. This shift in weed control techniques was promoted by a combination of technical and economic factors — the synthesis of selective herbicides such as butachlor and thiobencarb that effectively control weeds in irrigated and shallow rainfed lowland rice, coupled with falling real prices of herbicides and increasing labor costs for weeding (9).

Under some circumstances, shifting to herbicides may increase yield variability compared with systems where hand weeding dominates. This would be the case if the supply of herbicides were interrupted or constricted, or if their price increased drastically, and labor were not available or too costly to substitute for chemical weed control (5). Another factor is the erratic effectiveness of currently marketed herbicides under moisture stress. A third factor would be the problem induced if a buildup occurred in herbicide-resistant weed species and as weed populations shifted with herbicide use over time (40). In practice, these have not been major problems in rice when herbicides were viewed as a component of weed management. A combination of crop rotation, water management, tillage practices, and nonselective herbicides allows the control of such weeds should they occur, particularly in nonwater-stressed environments (S.K. De Datta, IRRI, 1985, pers. comm.).

A major weed control problem in rice persists in less favored rainfed and upland environments. Herbicides that are consistently effective in ricefields under both wet and dry conditions have yet to be found. Labor inputs for hand weeding (often more than 30 d/ha) are costly, and while tillage and interrow cultivation may be effective, many upland rice farmers lack the power or money for timely tillage or cultivation. Therefore, the major destabilizing effects of weeds in rice cultivation will continue to be in the low yielding adverse, as opposed to the more productive irrigated and shallow rainfed, rice environments.

Fertilizer rates and yield variability

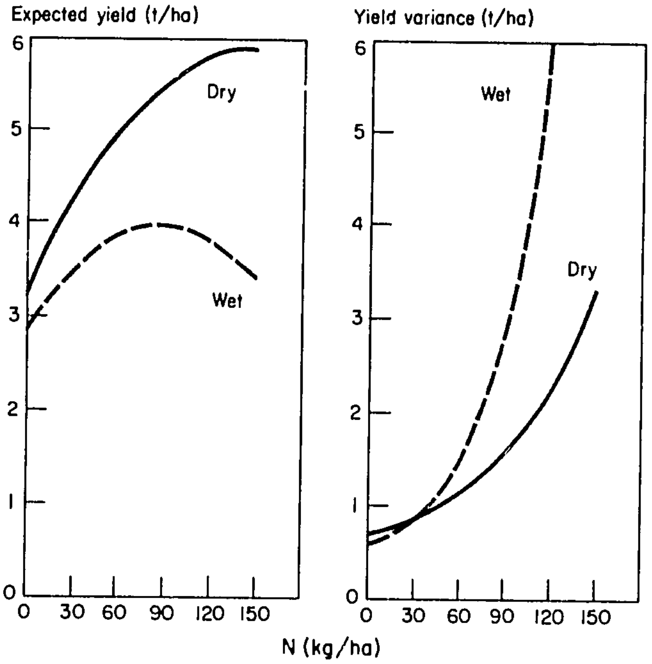
Rice yield variability is known to increase as N fertilizer rate increases (13). This variability is induced through strong interaction between applied N and the levels of random factors such as solar radiation, water regime, and pest incidence (8).

N rate, yield, and yield variability. The relationships between mean yield and N rate, and between yield variability and N rate were estimated from N response trials in Laguna by IRRI's Agronomy Department. IR36 was selected for analyses because 1) it had the longest sequence of usable data (1976-84), and 2) it was one of the most popular irrigated rices in tropical Asia in the early 1980s. The relationship between N rate and yield variability was estimated via a random coefficient model, as described by Smith and Umali (38).

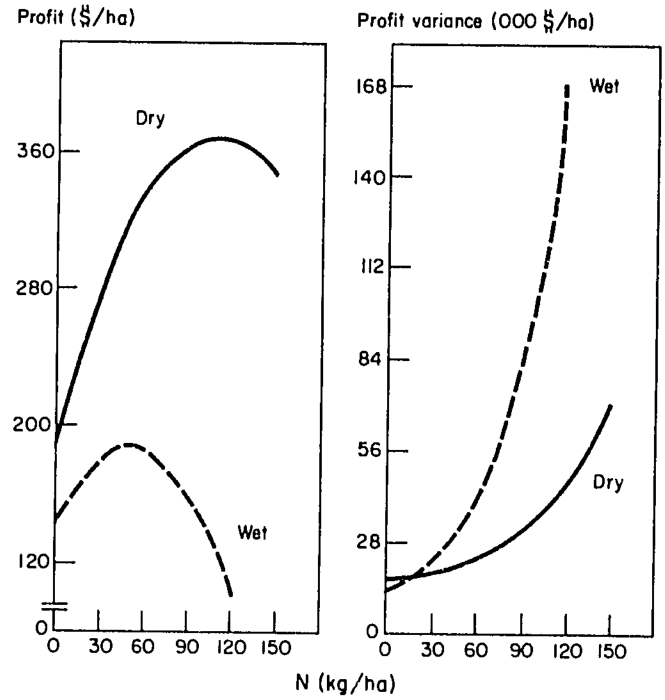
The maximum expected yield of IR36 was 4.0 t/ha at 86 kg N/ha in WS and 5.9 t/ha at 147 kg N/ha in DS. Yield variance increased with N rate more rapidly in WS than in DS (Fig. 9). The risk-neutral, high-profit N rate was 51 kg N/ha in WS and 110 kg N/ha in DS at current farmer-effective prices and a 100% interest charge on fertilizer cost.

N rate and risk. The low-resource farmers' concern to avoid risk may make them unwilling to apply the high-expected-profit N rate, because, although profit increases as N increases (up to a point), so does profit variability (Fig. 10). A useful rule of thumb is that farmers are prepared to incur additional risk (as measured by the standard deviation of outcome) provided that the increase in risk is less than twice the increase in net benefit resulting from the change in technology (35). If the trade-off is more than 2, the innovation is unlikely to be attractive to most farmers.

The change in the standard deviation of profit induced by a marginal reduction in N rate from the optimal level exceeded 20:1 in both WS and DS. Thus, if risk is a determinant of fertilizer use, it is unlikely that a moderately risk-averse farmer would apply the high-profit N rate. The N rates where the trade-off between stability and level of profit was 2:1 were 35 kg N/ha in WS and 92 kg N/ha in DS, implying a 31 and 16% reduction, respectively, in N rate below the high-profit level to accommodate risk aversion. However, these reductions in N rate imply less than a 5% reduction in yield but a larger 20-27% reduction in yield variance. Expected profit was reduced



9. Relationships between N rate and yield, and between N rate and variance of yield for IR36, wet and dry seasons, Laguna. Sources: Flinn and Velasco (17), and derived from IRRI Agronomy Department long-term N fertility experiments.



10. Relationships between N rate and profit, and between N rate and profit variance of IR36, wet and dry season, Laguna. Sources: Flinn and Velasco (17), and data derived from IRRI Agronomy Department long-term N fertility experiments.

only 2% or less, while the standard deviation of profit was reduced more than 10% when risk-averse decision criteria were used (Table 6).

This positive analysis of risk is not consistent with that of Rosegrant and Herdt (34), who reported that risk considerations did not materially reduce farmers' fertilizer rates in irrigated rice in Central Luzon. The importance of risk as a factor influencing the farmer's fertilizer choice remains a matter of contention. Nonetheless, there is agreement that increasing N fertilizer rates contributes to increased yield instability in rice. However, if risk aversion is important and farmers choose lower than the highest-profit N rates, yield variability will also be reduced, resulting in lower yield CV's than if profit maximization were assumed.

Table 6. Risk-neutral and risk-averse optimal N rates for IR36, for wet and dry seasons, Laguna, Philippines (17).[a]

Factor	Unit	Wet season	Dry season
	Risk neutral		
Optimal N rate	kg/ha	51	110
Yield	t/ha	3.80	5.81
Yield variance		1.23	1.92
Net return[a]	$/ha	188	371
	Risk averse[b]		
Optimal N rate	kg/ha	35	92
Yield	t/ha	3.61	5.60
Yield variance		0.90	1.53
Net return	$/ha	184	366
	Difference, risk averse vs risk neutral		
Optimal N rate	%	31	16
Yield	%	5	4
Yield variance	%	27	20
Net return	%	2	1

[a]Exchange rate U.S.$1 = P18.75. [b]Calculated at N rate where marginal change in standard deviation of net benefit is twice the change in net benefit (See [35]).

ON-FARM YIELD STABILITY

The characteristics of modern rice technology (i.e., MVs plus management) may lead to higher and more stable yields under experimental conditions. However, the important point is whether these same practices stabilize or destabilize yields under farmer management. Farmer's yields and yields under improved technology were compared for an irrigated and an upland site to determine the nature of this relationship.

Farmers' practices and those recommended by the Ministry of Agriculture and Food for irrigated rice in the Philippines were compared over the period 1974-78 (25). Farmers in Central Luzon, the study site, grew MVs such as IR20, IR36, and IR42, and applied fertilizer but at lower rates on average than recommended. The Mindanao dryland site contrasts with the highly productive irrigated site in Central Luzon. In Mindanao, the rice was rainfed upland. Most farmers still grew OVs; others (associated mainly with a rural development project) grew recommended IVs such as UPL Ri-5 and UPL Ri-7 (39). Few OV growers applied fertilizer, while most IV growers did. Thus, the Luzon example allows a comparison of more intensive and less intensive application of modern rice technology under favorable irrigated conditions, while the Mindanao example provides a comparison of traditional and improved rice culture under less favorable upland conditions.

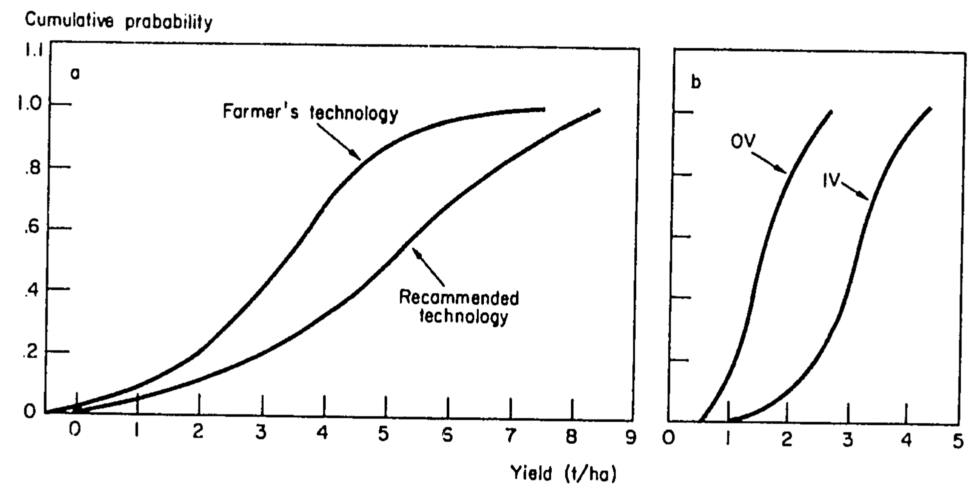
Yields under improved technology dominated the farmer's technology at both the irrigated and upland sites (Fig. 11). Thus, the probability of reaching a target yield exceeding the average yield was higher with improved practices. Mean yields were significantly higher with the higher-input technology (Table 7). Although yield variances increased significantly with application of new technology, the relative variability (i.e., the CV) of farmers' practices and of improved practices were similar at both locations.

The distribution of farmers' irrigated rice yields was normal ($\sqrt{b}$ = -0.04), while the yield distribution with recommended technology was negatively skewed ($\sqrt{b}$ = -0.43). The yield skewness changed from strongly positive ($\sqrt{b}$ = 0.47) to slightly negative ($\sqrt{b}$ = -0.16) with the adoption of improved upland rices and associated crop management. These shifts in yield skewness with modern rice husbandry are consistent with the observation of Day (7) and Barker et al (2) that the tendency toward negative yield skewness increases with improved technology. This implies that yield risk is less than indicated by the variance because the probability of the yield exceeding the mean is greater than 0.5. Therefore, new rice technology may place farmers in a more favorable risk situation, depending on costs.

The upland rice data were cross-sectional and do not permit an analysis of time-series variability, which is of concern to farmers. As such, these results must be treated with caution. For example, OV upland rices yielded higher than IV and MV rices under severe moisture stress in our 1985 on-farm trials in Batangas, Philippines. Therefore, although farm yields may generally become more negatively skewed with improved technology under favorable conditions, it may not be so under adverse conditions.

INCREASING STABILITY OF MODERN RICE TECHNOLOGY

According to the Food and Agriculture Organization, a 2.8%/yr production increase over the period 1980-2000, compared with the 2.4%/yr growth rate achieved during



11. Smoothed cumulative distribution of yields in farmer's fields with farmer's practices and recommended practices. a) Irrigated: MV farmers versus MV recommended technology. b) Upland: OV farmers versus IV farmers (39).

Table 7. Mean rice yields and yield distributions on farmers' fields at irrigated lowland and upland rainfed sites in the Philippines.[a]

Item	Years	Sample size (n)	Mean yield (t/ha)	Variance	Coefficient of variation (%)	Skewness $\sqrt{b_i}$
		Irrigated lowland, modern varieties, Central Luzon				
Farmer's practice	1974-77	76	3.80	2.03	37	- 0.04
Recommended practice	1974-77	76	5.22	4.78	42	- 0.43
Difference			1.42*	2.75*	5	
		Upland rainfed, Zamboanga del Sur, Mindanao				
Older varieties	1983	55	1.41	0.38	44	0.47
Improved varieties	1983	124	2.61	0.87	35	- 0.16
Difference			1.20*	0.49*	9	

[a]Sources: Central Luzon irrigated rice data extracted from IRRI Agronomy Department files. Agronomic details of this research reported by De Datta et al (10); upland rice data derived from Tautho et al (39). Agronomic details of upland rice research and extension in Zamboanga del Sur found in annual reports of the Zamboanga del Sur Development Project, Philippines. * = significant at the 5% level. Differences in means based on t-test and differences in variances on F-ratios.

1960-80, will be required to balance rice supply and demand in the year 2000. Most of this increased rice will be produced and consumed in Asia. Competition for land in Asia for other crops, livestock, and nonagricultural uses is resulting in a shrinking supply for rice cultivation. Therefore, the only pathway open to most Asian countries to increase rice production is through higher productivity and increased cropping intensity. This can be achieved only by technological advances including improved water management, fertilizer management, and other agronomic practices and by the continued selection of rice varieties capable of responding to these inputs.

Rice improvement programs

Modern rice varieties will continue to be grown under more intensive management systems. Therefore, pest adaptation problems will continue to be a threat to high yields and to yield stability. Research managers recognize the importance of breeding for multiple disease and insect resistance to counter the dynamic threat of pest infestation. Thus, recently released MVs possess higher levels of pest resistance than previously released ones (Table 8).

Increased capacity and continued growth in collaboration with and between national and international rice programs allow wider and more rigorous testing of promising cultivars for pest resistance and for adaptability to adverse environments than was previously possible (27). Breeders ensure that yield potential is not jeopardized when selecting cultivars for release because of their superior pest resistance. Therefore, in developing new varieties with greater yield stability, yield potential is not compromised.

Advances in biotechnology will dramatically increase plant breeders' capacity to incorporate resistance from wild relatives into domesticated rices. Indeed, these wild relatives are the only major source of resistance to some diseases, particularly viruses. To this extent, the conservation of indigenous rice species in the International Rice Germplasm Center (IRGC) at IRRI ensures that the diverse collection of rice germplasm will be maintained and will remain available to national rice scientists in the future. In 1986, IRGC had more than 78,000 of the estimated 100,000-120,000 varieties of rice grown in the world, plus more than 2,000 wild rices. Extensive collaborative work is under way to collect and conserve most of the remaining varieties.

Rice production programs, such as IRRI's Germplasm Evaluation and Utilization (GEU) program, are also working to develop improved varieties adapted to unfavorable rice environments. The focus (at IRRI) is shifting to areas where current MVs are less suited. As a result, greater emphasis is now placed on breeding for tolerance to physical (droughts, floods, low temperatures) and physiochemical (e.g., acid sulfate soils, saline soils) factors and to soils with other mineral deficiencies and toxicities.

Table 8. Disease and insect reactions[a] of IR varieties in the Philippines. Source: G. S. Khush, IRRI Plant Breeding Department.

Variety	Reaction to									
	Blast	Bacterial blight	Grassy stunt	Tungro	BPH[b] biotype 1	BPH[b] biotype 2	BPH[b] biotype 3	Green leafhopper	Stem borer	Gall midge
IR5	MR	S	S	S	S	S	S	R	MS	S
IR8	S	S	S	S	S	S	S	MR	S	S
IR26	MR	R	S	MR	S	S	S	R	MR	S
IR22	S	R	S	S	S	S	S	S	S	S
IR24	S	S	S	S	S	S	S	R	S	S
IR26	MR	R	S	MR	R	S	R	R	MR	S
IR28	R	R	R	R	R	S	R	R	MR	S
IR29	R	R	R	R	R	S	R	R	MR	S
IR30	MS	R	R	R	R	S	R	R	MR	S
IR32	MR	R	R	R	R	S	R	R	MR	S
IR34	R	R	R	R	R	S	R	R	MR	S
IR36	R	R	R	R	R	R	S	R	MR	R
IR38	R	R	R	R	R	R	S	R	MR	R
IR40	R	R	R	R	R	R	S	R	MR	R
IR42	R	R	R	R	R	R	S	R	MR	R
IR44	MR	R	S	R	R	R	S	R	MR	S
IR46	R	R	S	R	R	S	R	R	MR	S
IR48	MR	R	R	R	R	R	S	R	MR	S
IR50	MS	R	R	R	R	R	S	R	MR	S
IR52	MR	R	R	R	R	R	S	R	MR	—
IR54	R	R	R	R	R	R	S	R	MR	—
IR56	R	R	R	R	R	R	R	R	MR	—
IR58	R	R	R	R	R	R	S	R	MR	—
IR60	R	R	R	R	R	R	R	R	MR	—
IR62	MR	R	R	MR	R	R	R	R	MS	—
IR64	MR	R	R	R	R	MR	R	R	MR	—
IR65	MR	R	R	R	R	R	S	R	MR	—

[a]R = resistant, MR = moderately resistant, S = susceptible, MS = moderately susceptible. [b]BPH = brown planthopper.

Second-generation MVs have better tolerance for soil stresses than earlier varieties (Table 9). It is not known whether the shift toward breeding for adverse environments will increase or decrease production stability, as few modern varieties have been adapted to these areas. Within existing rice areas, mean yields should improve. However, yield instability may increase, as yields will continue to be low when severe floods or drought occur, irrespective of yield potential. It is not unusual for the crop not to be planted in many upland and drought-prone rainfed lowland environments because of extreme water conditions. Varieties better adapted to unfavorable environments may extend the margin of rice cultivation, therefore increasing production instability.

Genetic uniformity

Coffman and Hargrove (5) have discussed the concern that the common ancestry of MVs (particularly for the dwarfing gene) may contribute to increased production variability due to cytoplasmic uniformity. They also observe that this may not necessarily be so, because second-generation MVs have more diverse parentage than first-generation MVs. For example, IR36 can be traced back to 13 varieties from 6 countries, and IR64 to 20 land races from 8 countries (20).

Of greater concern is the issue of large areas being planted to one, or to closely related varieties, which increases the probability of insect and disease outbreaks. For example, IR36 was grown on some 11 million ha of ricelands in South and Southeast Asia each year in the early 1980s. This is not to criticize t. . .ariety. Rather this attests to the varieties' adaptability, and demonstrates farmers' preference for IR36 over other available varieties. The real concern is the lack of alternate varieties that are better suited to these farmers' specific conditions.

The problem of large areas planted to single varieties should decrease as national rice programs breed and select varieties better adapted to local conditions. This capacity is aided by IRTP (26), which coordinates an international network to provide national programs with a wide range of rices to evaluate under their own conditions. For example, 29 of the IRTP nurseries in 1986 were tailored to specific environmental conditions and stresses (Table 10). Most entries in these nurseries were bred by national program scientists. This is an important (and often unrecognized) advance over earlier strategies, which favored selection of varieties for wide adaptation. The sharing of germplasm also enhances sustainability of future rice yields by introducing new lines to the nurseries each year to ensure that plant breeders have access to a

Table 9. Reactions[a] of IR varieties to adverse soils.

Variety	Reaction								
	Wetland soils							Dryland soils	
	Toxicities					Deficiencies			
	Salt	Alkali	Peat	Fe	B	P	Zn	Al and Mn toxicities	Fe deficiency
IR5	4	6	5	6	3	5	5	5	4
IR8	4	6	5	8	4	4	4	4	4
IR20	5	7	4	5	4	3	3	5	4
IR22	5	6	4	3	3	3	3	5	5
IR24	3	5	4	3	3	3	4	4	3
IR26	5	6	6	6	3	2	6	3	4
IR28	7	5	5	4	3	3	5	5	6
IR29	6	6	4	4	3	5	3	4	0
IR30	5	6	3	3	3	3	3	0	0
IR32	5	7	5	5	3	3	5	5	[illegible]
IR34	5	3	3	3	3	3	3	0	0
IR36	3	3	3	3	3	6	3	2	2
IR38	5	5	4	5	3	3	3	4	5
IR40	5	6	4	3	3	3	3	0	0
IR42	3	4	3	4	2	2	4	5	5
IR43	4	7	5	5	4	3	3	3	3
IR44	3	5	4	4	3	3	4	4	4
IR45	4	6	5	4	3	3	4	4	4
IR46	3	3	4	4	2	5	3	3	4
IR48	4	7	[illegible]	4	2	3	5	3	4
IR50	4	4	3	5	3	3	3	4	4
IR52	3	4	3	3	3	3	3	5	4
IR54	4	5	3	5	2	2	3	4	4
IR56	3	4	3	5	3	3	4	0	0
IR58	3	4	4	4	4	4	3	0	0
IR60	3	4	4	6	3	5	5	0	0
IR62	4	5	4	3	0	4	6	0	0
IR64	3	3	4	5	4	4	4	0	0
IR65	5	5	4	4	5	5	5	0	0

[a]0 = no information. 1 = almost normal plant, 9 = almost dead or dead plant. Based on greenhouse and field tests conducted by IRRI's Soil Chemistry Department.

diverse collection of germplasm. The main objective of these nurseries is not to provide materials for direct release to farmers but to provide national programs with a range of germplasm they can evaluate for desired traits and selectively use as parents in their own breeding programs.

Crop and soil management

Efficiency and sustainability in rice production will continue to be enhanced through the dual strategies of breeding input-efficient varieties and improving crop and soil management.

Soil health research addresses the problems of toxicities, nutrient imbalances, and yield maintenance under increased cropping intensity. As rice production is intensified, a progression of mutual deficiencies — N, P, Zn, and possibly S — is likely (8). The International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER), a network of national rice programs, IRRI, and the International Fertilizer Development Center, specifically addresses issues of soil fertility in rice. INSFFER collaborators conduct research to increase the efficiency of nutrient use (by promoting integrated nutrient supply systems involving organic and biological

Table 10. International Rice Testing Program (IRTP) nurseries for 1986 (36).

		Trials	Maturity (d)		Estimated max no. of entries
			Tropics	Temperate	
		Nurseries for target environments			
		Irrigated			
Yield	IRYN-VE	International Rice Yield Nursery — Very Early	90-105	115-130	30
	IRYN-E	International Rice Yield Nursery — Early	105-120	130-145	30
	IRYN-M	International Rice Yield Nursery — Medium	120-140	145-165	30
Observational	IRON VE	International Rice Observational Nursery — Very Early	90-105	115-130	70
	IRON-E	International Rice Observational Nursery — Early	105-120	130-145	185
	IRON-M	International Rice Observational Nursery — Medium	120-140	145-165	110
		Rainfed upland			
Yield	IURYN-E	International Upland Rice Yield Nursery — Early	90-110		30
	IURYN-M	International Upland Rice Yield Nursery — Medium	110-140		30
Observational	IURON-E	International Upland Rice Observational Nursery — Early	90-100		120
	IURON-M	International Upland Rice Observational Nursery — Medium	110-140		180
		Lowland			
Yield	IRRSWYN-E	International Rainfed Rice Shallow Water Yield Nursery — Early (0-50 cm water depth)	90-125[a]		25
	IRRSWYN-M	International Rainfed Rice Shallow Water Yield Nursery — Medium (0-50 cm water depth)	125-160[a]		30
Observational	IRRSWON-E	International Rainfed Rice Shallow Water Observational Nursery — Early	90-125[a]		30
	IRRSWON-M	International Rainfed Rice Shallow Water Observational Nursery — Medium	125-160[a]		180
	IRDWON	International Rice Deep Water Observational Nursery (50-100 cm water depth)	—[b]		95
	IFRON	International Floating Rice Observational Nursery (100 cm water depth)	—[b]		30
	ITPRON	International Tide-Prone Rice Observational Nursery	110-160[a]		70
		Nurseries for specific stresses			
Temperature	IRCTN	International Rice Cold Tolerance Nursery	100-140	120-160	185
Soil	IRSATON	International Rice Salinity and Alkalinity Tolerance Observational Nursery			90
	Acid Upland	Acid Upland Screening Set			75
	Acid Lowland	Acid Lowland Screening Set[c]			95
Diseases	IRBN-Upland	International Rice Blast Nursery (Upland-adapted lines)			40
	IRBN-Lowland	International Rice Blast Nursery (Lowland irrigated and rainfed lines)			340
	IRBBN	International Rice Bacterial Blight Nursery			240
	IRTN	International Rice Tungro Nursery			175
Insects	IRBPHN	International Rice Brown Planthopper Nursery			250
	IRWBPHN	International Rice Whitebacked Planthopper Nursery			100
	IRSBN	International Rice Stemborer Nursery			80
Nematode	IRUSS	International Rice Ufra Screening Set			45

[a]Some photoperiod-sensitive entries. [b]Photoperiod sensitive. [c]Includes phosphate fertilizer.

sources of fertilizer in addition to mineral fertilizer), and to maintain rice yields under intensified cropping. Such programs will lead to increases in the stability and sustainability of rice production.

A notable shift in research philosophy among national and international programs should also lead to increased stability of rice-based farming systems. Researchers now accept that it is necessary to adapt and modify technology to meet the needs of specific agroclimatic environments before farmer adoption is likely to proceed. Basic to this approach is the view that the stability and sustainability of farming systems can be enhanced if farmers are offered a range of technical options rather than a single predetermined package, and if farmers participate in the technology evaluation process (11). This is a quantum shift in philosophy from the tendency to advocate broad recommendations thought to suit the majority of farm environments.

SHARING KNOWLEDGE

A discussion of how knowledge sharing among national and international agencies may reduce instability in rice production is beyond the scope of this paper. Developing human resources (and research facilities) remains the key to generating locally adapted varieties and systems of crop management. It also provides the research system with increased capacity to recognize problems and to respond to them before they become crises. Part of this development is the generating and sharing of knowledge to increase national and international agencies' capacity to solve immediate field problems through appropriate applied and adaptive research programs, and to harness advances in science and technology to solve field problems and further raise the levels and sustainability of rice yields.

TECHNOLOGY AND POLICY

This paper focused on variability in rice production and technical attributes that may influence rice production stability. This bias is not surprising, since IRRI's primary expertise is to help provide the inputs and to work with national programs as they develop more productive rice technology. Policy issues, whether related specifically to rice or to other sectors that interact closely with rice, were not addressed. These issues would include market imperfections and other nontechnically induced causes of rice production variability, either through yield or area effects.

These factors may be more important determinants of rice production instability than technology, per se. The methodology necessary to definitively encompass the causes of production instability seems poorly developed or applied. IRRI recognizes the critical importance of rice production instability as a concept in designing rice research strategies and policies, and seeks to combine its interest with others to address this question in an integrated manner.

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