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9. ABSTRACT

This paper discusses rice environments and rice improvement efforts; it presents ideas that might assist efforts to produce improved rices for diverse lowland and upland conditions. Under a limited range of conditions, rice varieties of the IR8 plant type perform better than other varieties, but these first-generation modern varieties cannot withstand the environmental stresses in many rice-growing areas. The second-generation modern varieties are disease- and insect-resistant, but they still do not adapt to a wide range of environmental conditions. This suggests the need for different types of varieties and different approaches in producing them. Many scientiests believe that environment-specific varieties should be produced. They are attempting to develop a more precise definition of rice environments in terms of water depth, soils, rainfall, and temperature. The paper focuses on gap I--the gap attributed to differences between farmer environments and environments at experiment stations. In many instances the gap is quite wide. To better understand why the gap exists, this paper examines the general strategy being followed by rice breeders, the environments in which rice is grown in Asia, and the use of multilocation testing programs for evaluating breeding materials. Some conclusions are presented concerning the interrelationships of networks, environments, and breeding strategies for new technology.

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MULTI-SITE TESTS ENVIRONMENTS AND BREEDING STRATEGIES FOR NEW RICE TECHNOLOGY

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MULTI-SITE TESTS ENVIRONMENTS AND BREEDING STRATEGIES FOR NEW RICE TECHNOLOGY[1]

ABSTRACT

Rice varieties of the IR8 plant type perform better than other varieties under a limited range of conditions. But these first-generation modern varieties cannot stand the environmental stresses in many rice-growing areas. Disease and insect resistance was incorporated into a second-generation set of modern varieties, but the range of environmental conditions where they grow and yield well is not significantly greater. That suggests the need for different types of varieties and for a different approach to produce them.

Many scientists believe that environment-specific varieties should be produced to fit specific ecological zones. Attempts are underway to develop a somewhat more rigorous definition of rice environments, which considers characteristics such as water depth, soils, rainfall, and possibly temperature. This paper contains some thoughts about environments and rice improvement activities and presents some ideas that might assist efforts to produce improved rices for diverse lowland and upland conditions.

In recent years economists and agronomists in several national rice research programs have joined with International Rice Research Institute (IRRI) scientists in studying "constraints" that prevent farmers from achieving yields as high as those achieved by rice scientists on experiment stations. Figure 1 illustrates two distinct gaps between farmer's yield and experiment station yield.

Gap I, the "environmental effects," shows the difference between the maximum yield of the new rice technology under experiment station conditions and the potential yield in farmers' environments. Gap II shows the difference between farmers' actual yields and the maximum potential under their conditions. The constraints research is focused on gap II and has been discussed extensively elsewhere (/International Rice Agro-Economic Network/IRAEN, 1975).

This paper focuses on gap I -- the gap attributed to differences between farmer environments and experiment station environments. In some cases the

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[1]by Robert W. Herdt and Randolph Barker, agricultural economists, Department of Agricultural Economics, International Rice Research Institute, Los Baños, Laguna, Philippines. Paper presented at the International Rice Research Conference, IRRI, April 1976, and submitted to the IRRI Research Paper Series Committee 8 October 1976.

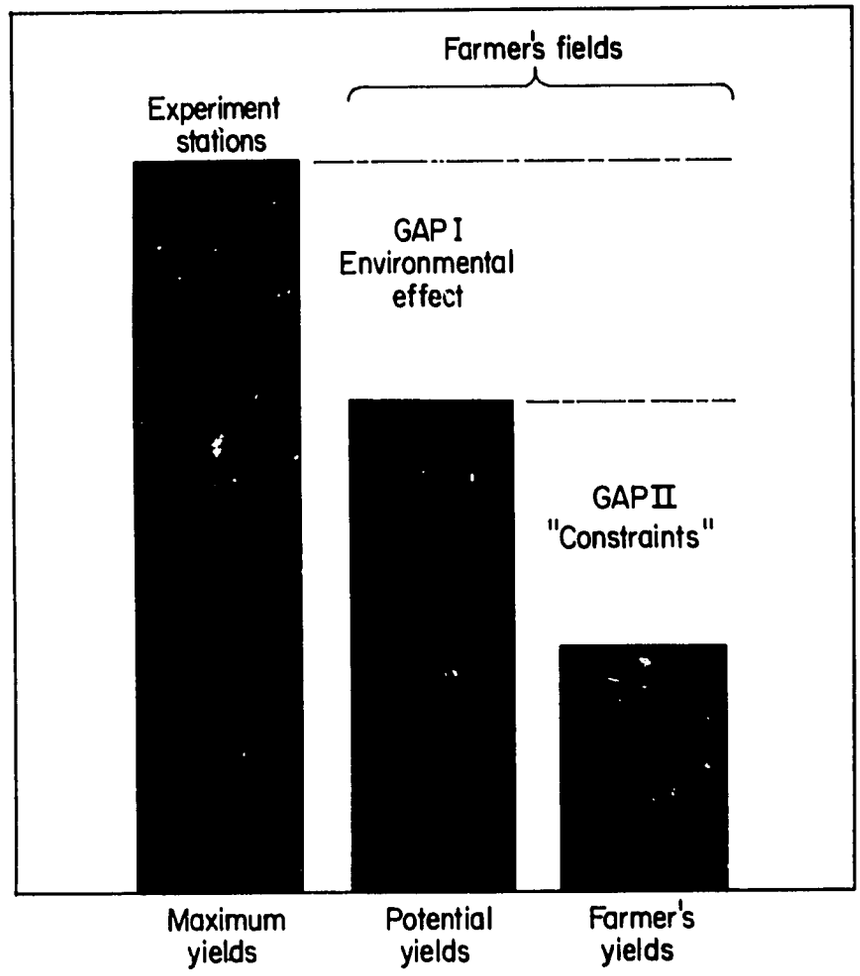


Fig. 1. A two-gap model for explaining the difference between the yield potential of modern semidwarf rice varieties and actual rice yields in tropical Asia.

gap between the experiment station yields and the maximum potential yields under most farmers' conditions may be just as wide as the gap between potential and actual farmers' yields. IRRI scientists continue to report 6-to 8-t/ha rice yields (IRRI, 1975), while the Philippines' average rice yield remains below 2 t/ha. In experiments of farmers' fields, yields consistently exceed 6 t/ha only during the dry season on farms close to IRRI. Yields of 4 t/ha on farms that receive maximum-level inputs are more common. That supports the existence of gap I, as well as gap II.

To better understand why such a gap between experiment station and farmers' fields is likely to exist in a given location, we examine the general strategy being followed by rice breeders, the environments in which rice is grown in Asia, and the use of multilocation testing programs for the evaluation of breeding materials. Finally, we attempt some conclusions about the interrelationships of networks, environments, and breeding strategies for new technology.

MULTI-SITE TESTS ENVIRONMENTS AND BREEDING STRATEGIES FOR NEW RICE TECHNOLOGY

PRESENT RICE BREEDING STRATEGIES

It appears that since the introduction in the mid-1960's of short, stiff-strawed, photoperiod-insensitive, fertilizer-responsive varieties such as IR8, breeding goals have been set in terms of plant characteristics or traits. IRRI's Genetic Evaluation and Utilization (GEU) program is described in terms of plant characteristics. More than 40 traits of rice have been characterized and scoring systems for each have been developed. Most breeders interviewed by Hargrove (1976) in his study of rice breeders in Asia named plant characteristics as crossing objectives.

Should rice improvement objectives be fixed in terms of plant characteristics or in terms of environments for rice production? This question perhaps exaggerates the issue, because regardless of how objectives are stated, the process is iterative -- environments suggest necessary characteristics, which in turn seem suitable for certain environments. A related question is whether all rice improvement programs in Asia should set their objectives in terms of the same guidelines.

The obvious answer to these questions is that the need is for varieties with characteristics most suitable for given environments. But that answer is not helpful for action. It seems that one may proceed either by (1) identifying characteristics that are desired for the target environments and building them into varieties designed for each environment, or by (2) testing out a wide diversity of promising cultivars in the target environments to identify those that perform well in each environment.

A scientist with some ideas about the characteristics a rice variety needs to perform well in a given environment is better able to produce such lines than someone who has little idea of the needed characteristics. There is, therefore, a natural tendency to design a plant with characteristics that seem to be appropriate for particular environments. However, the environmental factors within the areas where rice grows are extremely diverse. Many vary from year to year, and even within a year at a given location. Thus, attempts to match desired plant characteristics with particular environmental factors are subject to a high degree of uncertainty.

Part of the uncertainty occurs because in transferring one characteristic into a plant, others are also transferred. Plants with the desired characteristic will certainly be found in the resulting progeny, but unless the variety is screened in the environment for which it is intended, other traits that make the plant unsuitable to the intended environment may be overlooked.

This is certainly not an original concept. But it implies that in attempting to develop plants with specific characteristics that are believed suited to given environments, the materials must be extensively subjected to the conditions that exist in those environments.

When negative interactions between existing varieties and particular environmental factors are perceived, an attempt is made to modify plant characteristics and make them better suited to those environmental factors. As a result, breeding objectives are constantly changing. Since 1965, the semidwarf plant type has been highly desired, but it seems that an intermediate plant type may now displace the semidwarf.

Figure 2, reproduced from IRRI's 1974 Annual Report, shows the proportion in IRRI's annual replicated yield trials of entries with multiple resistance to six important diseases and insects. The data demonstrate how quickly the

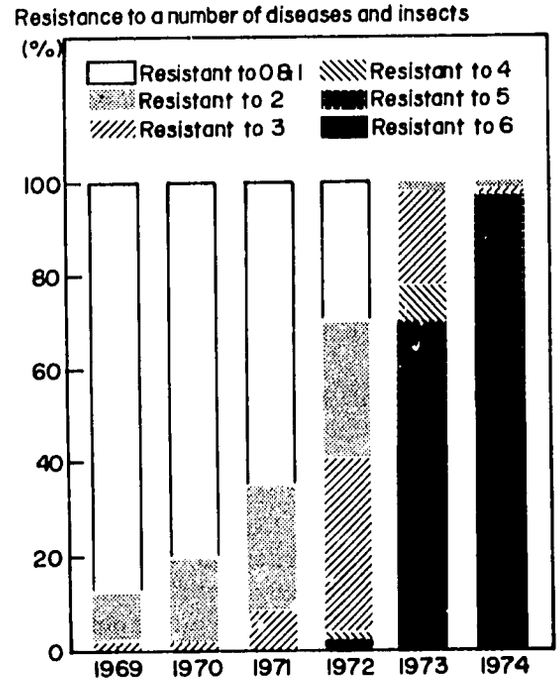


Fig. 2. Changes in proportion of entries in IRRI's annual replicated yield trials with multiple resistance to important diseases and insects (blast, bacterial blight, tungro, grassy stunt, brown planthopper, and green leafhopper). Each year trial consisted of about 185 entries.

goal of insect and disease resistance has been attained. This orientation to plant traits is being carried into the international testing program, but so far, little has been done to describe the environments of test sites.

Changes in rice-breeding objectives may reflect changes occurring in the rice-growing environments, the breeder's perception of what characteristics are needed for given environments, or changes in the environments for which the varieties are intended. Each objective carries with it the desire to meet a perceived problem or need, but by setting breeding objectives in terms of such plant characteristics, other problems may arise.

At IRRI, for example, problems seem to have arisen from overemphasis of characteristics such as dwarfness and photoperiod insensitivity in the first generation of varieties, and insect and disease resistance in the second generation. Let us consider in detail the potential "benefits and costs" of emphasis on plant characteristics for three cases -- insect resistance, growth duration, and plant height.

Insect resistance

The advantage of planting a variety that does not require insecticide is obvious. Asian farmers usually lack cash and hesitate to apply insecticides unless there is obvious insect damage. It is much better to have built-in protection.

Insect resistance, however, like most other good things, can be oversold. When a variety is promoted as being resistant to some insects, it is easy to forget that it is not resistant to others. As a consequence, research on multifactor, integrated, pest-control measures may lag when too much reliance is put on resistant varieties. Farmers may completely rely on plant resistance, and when crops are damaged by "other insects," the farmers are unhappy.

In the search for insect resistance, yield potential may be sacrificed. Demonstration plots where the early releases stand tall and the later releases are flattened by heavy wind and rains are commonly seen at IRRI. Recent IRRI varieties with multiple insect resistance have lower yield potential than IR8. More seriously, multiple resistance seems to have displaced yield performance (in any environment) as the criterion of success.

The problems with biotypes of the brown planthopper and the gall midge suggest that insect resistance, like resistance to wheat rusts and rice blast, must be dynamic to keep up with nature. A multifactor integrated approach to insect control will be necessary in dealing with the difficulties caused by insects in tropical rice.

Short-duration varieties

The great demand for short-duration varieties has come initially from farmers with good water control. With short-duration varieties, those farmers can increase the number of crops grown annually, spread their fixed costs over a

greater output, and thereby lower unit costs and increase profits.

Short-duration varieties also seem more suitable for rainfed double-cropping systems where the first crop is broadcast before the wet season begins. The second crop may be rice conventionally transplanted into puddled soil, or, if the wet season is not long enough for two rice crops, an upland crop. Short-duration varieties also escape the dry period that usually occurs toward the end of a wet season.

Short-duration varieties are not, however, suited for all conditions. Areas with an extended monsoon may not be able to take advantage of short-duration varieties, especially where water is deep or moderately deep over an extended period. Less obvious, but perhaps more critical, are the innate characteristics of short-duration plants. With only 80 or 90 days in the field, the plant growth stages are so crowded that every day in the plant's existence is critical. Drought, insect attack, or even careless hand weeding, at any critical stage of growth causes a setback in yield. Delay in transplanting hurts tillering; delay in application or fertilization at an inappropriate time reduces fertilizer efficiency. These problems are more critical for short-duration varieties than for long-duration varieties - because the plant has less time to recover before it moves into the next growth stage.

Moreover, farmers who rely on rainfall for their water supply are much less able to control the timing of their operations than are farmers with irrigation. Land preparation, transplanting, and, to some extent, weeding must wait until adequate water becomes available. These farmers also hesitate to commit fertilizer to the crop before they are reasonably sure of adequate water. Under such conditions, short-duration varieties may not be appropriate.

On the other hand, in some situations we have been too slow to realize the potential of short-duration varieties because of our concern for other characteristics such as insect and disease resistance. Recent surveys show that the early maturing IR747 and IR1561, are popular in Central Luzon in the dry season (Bernsten, 1976). Those lines were never released because they lacked resistance to tungro virus and there was concern that farmers would plant them in the wet season. There was underestimation of how quickly farmers would discover that the varieties were suited to dry-season but not to wet-season conditions. Perhaps, there is too much worry about protecting farmers, who all too frequently know best what is good for them or what works in their environment.

Plant height

The swing from semidwarf plants to intermediate types has been noted. The plant height, perhaps the easiest characteristic to manipulate, was the first characteristic recognized as critically affecting the ability of a variety to give really high yields. Obviously short-statured plants cannot grow well in deep water. Some years ago it was shown conclusively that even a modest increase in water depth substantially reduces the yield of IR8 (IRRI, 1973). Vast areas of the deltas of Thailand, Bangladesh, India, Burma, and Indochina are planted to tall, traditional varieties during the wet season when those areas have deep water.

However, farmers have a wide array of reasons for not planting the semidwarf varieties during the wet season. Susceptibility to cold damage was cited by farmers from Thailand's Central Plain (Suwanpimolkul, 1976). In Central Luzon, Philippines, according to the survey, 25% of farmers with irrigation grew traditional varieties in the wet 1974 season, while none of the same farmers grew them during the following dry season (Bernsten, 1976). In two operational research areas in Eastern India, water depth was only one problem the farmers cited for not growing modern varieties during the main monsoon season. Other factors cited were problems with pests and diseases and a reluctance to use fertilizer and other cash inputs, which farmers perceived as necessary with modern varieties.

These illustrations are not cited to indicate that plant characteristics are not important but to suggest that a preoccupation with plant characteristics, rather than with evaluation under specific environments, slows progress in rice improvement.

Is that a fair judgment? Some of the data collected by Hargrove (1976) supports the contention that breeders do not follow their own evaluation of the priority needs in the areas served by their experiment stations. Hargrove interviewed rice breeders in Asia and, among other things, asked them their breeding objectives in making each of a number of randomly selected crosses. Twenty-three different objectives were mentioned for 46 crosses, of which 5 were environmental factors -- adverse soils, adaptability, photoperiod sensitivity, and cold temperature or deep water. Eighteen plant traits were named as breeding objectives: e.g., growth duration, grain quality, resistance, seedling vigor, and seed dormancy. A total of 259 objectives were mentioned for the 46 crosses; more than 5 objectives per cross. Yield stability was mentioned most often, followed by lodging resistance, fertilizer response, grain quality, growth duration, disease resistance, and insect resistance (Table 1). All other objectives were mentioned in less than 3% of the total crosses. The environmental factors were mentioned 13 times in just 5% of the total crosses.

At a separate time during the interviews, Hargrove asked the breeders to rank, from among a list of eight factors, the four most important factors that limit rice production in the areas served by the experiment station at which they were located. Table 1 shows the relative importance of the limiting factors compared with the stated breeding objectives. The most frequently mentioned problem and objective are scored as 100, and all other problems and objectives are scored as a proportion of the one most frequently mentioned.

We attempted to match breeding objectives with the production-limiting problems to which they appeared to be most closely related.

Yield stability, the most frequently mentioned breeding objective, cannot be clearly related to any single production-limiting problem, perhaps because it relates to all those environmental factors that vary. At least four of the breeding objectives seem to be aimed directly at increased yield, which, like yield stability, is a general objective. Excessive monsoon cloudiness was the most frequently cited problem, and one for which there seems to be

Table 1. Relative frequency of factors limiting rice production mentioned by 12 Asian plant breeders and relative frequency of the stated breeding objectives that might overcome the limiting factors, 1975.

Perceived rice production limiting factor	Relative frequency score[a]	Related breeding objective	Relative frequency score
		Yield stability	100
		Lodging resistance	93
		Fertilizer response	90
		Tillering	15
		Yield potential	8
Excessive monsoon cloudiness	100		
Drought	94	Drought tolerance	10
Diseases	84	Disease resistance	50
Insects	79	Insect resistance	40
Injurious soils	79	Adverse soils	10
Cold temperature	47	Cold temperature	10
Deep water or floods	26	Deep water	3
Others[b]	15	Others[a]	70
		Grain quality	75
		Growth duration	70

[a]The most frequently mentioned problem and objective are scored as 100; all other problem and objectives are scored as a proportion of the one most frequently mentioned.

[b]Each of "others" has a relative frequency of less than 15 objectives mentioned; nonshattering (13), alternate gene source (10), adaptability (8) grain or panicle weight (8), seed dormancy (8), seedling vigor (5), milling recovery (5), photoperiod sensitivity (3), deep water (3), threshability (3).

Source: T. R. Hargrove, preliminary research results based on an interview survey of 45 rice breeders throughout Asia (personal communication).

no clearly related breeding objective. All the other production-limiting problems could be related to the stated breeding objectives.

Surprisingly, all factors were given higher relative importance as problems than as breeding objectives. For example, drought was mentioned as a problem 94% as often as excessive cloudiness, but drought tolerance as a breeding objective only 10% as often as lodging resistance or fertilizer response. Injurious soils were identified as limiting production 80% as often as excessive cloudiness, but tolerance to adverse soils as a breeding objective only 10% as often as yield stability. Grain quality and growth duration were ranked relatively high as breeding objectives, perhaps because breeders perceived them as factors limiting adoption of new varieties.

This evidence supports the contention that breeding programs are not matching efforts to the problems believed to be most important. One reason may be that certain important production-limiting problems cannot be solved through breeding. Appropriate screening techniques may be a limiting factor, but one that breeders may overcome by working in the environment for which the varieties are intended.

One last problem with using plant characteristics as a basis for breeding objectives relates to the perceptions of farmers about varieties. As the final customer, the farmer determines which varieties are successful and which are not. As mentioned previously, there is often too much hesitancy in getting selections into the hands of farmers so that they can make their own judgment. As a result, before promising material can be judged by farmers, it must be passed by the production scientists. Therefore, there is often reliance on indirect information from farmers as to what they like or dislike about rice varieties - and then breeders provide the desired characteristics. Table 2 shows some recent data of this type.

Filipino farmers, all of whom had grown IR20 and other IRRI varieties or lines, were asked to compare the characteristics of other varieties with those of IR20. They were also asked which variety they preferred. Table 2 shows the proportion of farmers who preferred IR20 and those who preferred IR26, and who reported various characteristics of their preferred variety. It is not surprising that a high proportion of the farmers who preferred the varieties cited high yield and resistance to diseases as attractive characteristics. What was interesting to us was the substantial proportion citing negative characteristics of varieties they preferred. Thus, 56% of the farmers preferring IR26 stated that its seedlings were hard to pull especially as compared with IR20. Thirty percent claimed that IR26 shatters easily. Substantial proportions of those preferring each variety claimed that it was late maturing. However, none of these negative attributes prevented the farmers from planting and preferring the varieties. What may be most significant is that none claimed that the variety they preferred was low yielding (although they cited this characteristic about nonpreferred varieties). These data seem to indicate that while farmers' opinions may be useful, establishing breeding objectives on the basis of such opinions is undesirable.

Table 2. Proportion of 44 farmers reporting favorable and unfavorable plant characteristics of two preferred varieties.[a] Nueva Ecija, Philippines, 1976 dry season.

Negative characteristic	% of farmers reporting		Positive characteristic	% of farmers reporting	
	IR20	IR26		IR20	IR26
Susceptible to disease	6	0	Resistant or moderately resistant to diseases	88	74
Seedlings hard to pull	0	56	Seedlings easy to pull	53	0
Short panicles	0	0	Medium or long panicles	12	35
Short grain	18	9	Medium or long grain	18	17
Low yielding	0	0	High yielding	71	74
Shatters easily	6	30	Medium threshability	0	0
Hard to thresh	6	0	Easy to thresh	12	9
Tall	12	0	Short or medium height	6	26
Low tillering	0	4	High tillering	29	35
Poor eating or milling quality	0	0	Good eating or milling quality	6	13
Poor transplanting recovery	0	0	Good transplanting recovery	0	4
Hard to grow	0	9	Easy to grow	0	4
Requires more fertilizer (less responsive)	18	26	Requires less fertilizer (more responsive)	35	13
Late maturing	29	39	Early maturing	24	4
Few grains per panicle	0	0	More grains per panicle	6	0
Small seedlings	0	4	Vigorous seedlings	0	4
Susceptible to drought	0	0	Drought resistant	0	4

[a]23 farmers preferred IR26, 17 preferred IR20, 1 preferred IR28, 3 preferred IR30, 4 preferred IR1561, 1 preferred other lines. Some reported preferences for 2 varieties, so the total of preferred exceeds the total number of farmers.

THE ENVIRONMENTS IN WHICH RICE IS GROWN

This brings us to the issue of identifying the environments in which rice is grown. The concept of environment is extremely complex, with dimensions far beyond the rainfall-temperature-day length variables that are often used to measure certain aspects of the environment.

Moorman (1975) proposed a model that integrates the separate aspects of rice environments into a useful conceptual framework and ranks environments or "land" according to suitability for rice production. Land, in his terms, is used "as meaning a specific area of the earth's surface, the characteristics of which embrace all reasonably stable or predictable cyclic attributes related to atmosphere, soil, topography, and hydrology, the plant and animal population, and the results of human activity."

Some land is well suited to rice production while other land is not. Between the two extremes lay most of the land that might be planted to rice. Figure 3 illustrates Moorman's model. Most of the Class I land, that ideally suited

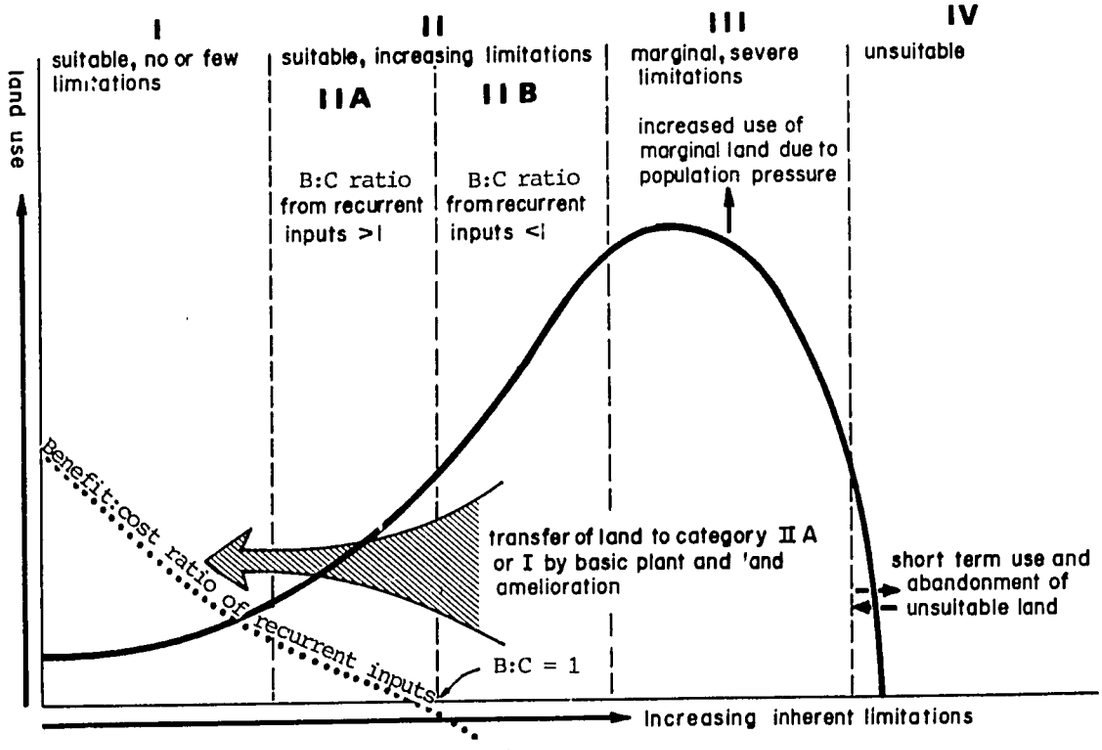


Fig. 3. Moorman's model of the relation of land in use for specific agricultural purpose and land quality.

rice production is already planted to the highly productive semidwarf varieties. Class II land is suitable for rice production but has increasing limitations. Sub-class IIA can be profitably planted to rice by the addition of purchased inputs such as fertilizer, chemicals, power, and labor. Category IIB land cannot be profitably farmed because the productivity is too low to yield a profitable return on purchased inputs. Class IIB and III are only farmed when resources have zero opportunity cost. Class IV is unsuited for production.

The function of research and development activities is to transfer land from category IIB to category IIA or I (where this can be achieved using long-term sustained yield technologies). Moorman identified basic plant and land amelioration as the means of achieving such a transfer. Land amelioration is achieved in rice principally through irrigation development. The plant amelioration being carried on by rice breeders can produce plants suited to existing IIB land (environments) so that such land is shifted to the IIA category. These ideas provide a framework for defining environments more closely.

Participation in meetings where IRRI scientists have attempted to agree on a minimal list of variables by which to characterize rice environments has given us a sense of humility about such lists. Still, the concept is necessary for the present discussion. In Table 3 we present one possible list, noting which factors vary across locations, seasons, and years. Some biologists might argue over the inclusion of socioeconomic factors as environmental but since such factors importantly affect what technology will be used, they are considered environmental in this discussion. Each factor can take on many values, so the possible number of environments that can be described using this table is very large.

We feel that for rice production, some factors are more important than others. Water depth seems overwhelmingly important, and is the most common way of describing rice environments. Last year, we assembled the data shown in Figure 4 and Appendix Table 1.

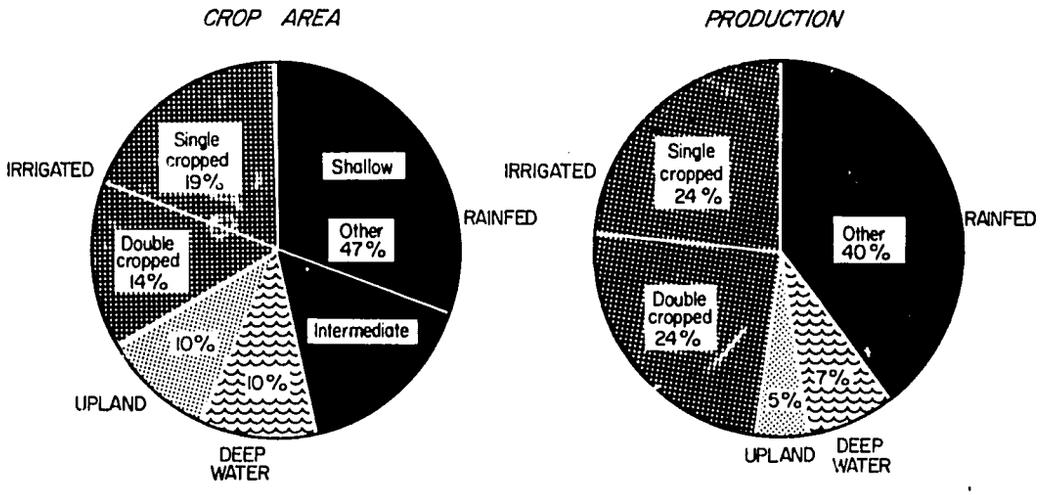


Fig. 4. Estimate of percent rice crop area and production by specified land type in South and Southeast Asia, early 1970's.

Table 3. A classification of the variability of environmental factors influencing rice production.

Factor	Subfactor	Variable		
		Across locations	Across seasons	Across years
Soils	Physical properties	x		
	Chemical properties	x		
	Biotic properties	x	x	
	Origin	x		
Geographic	Topography	x		
	Position	x		
	Photoperiod	x	x	
Water	Depth	x	x	x
	Rate of increase, decrease	x	x	x
	Temperature	x	x	
Climatic	Solar radiation	x	x	x
	Precipitation	x	x	x
	Air temperature	x	x	x
	Wind	x	x	x
Biotic	Competitive plants	x	x	x
	Dependent plants	x	x	x
	Insect predators	x	x	x
	Microbes	x	x	x
Socio-economic	Farmer knowledge	x		x
	Input and product prices	x	x	x
	Personal characteristics	x		

We estimate that 10% of Asian rice is grown in upland environments, 10% in deep water, 14% where water control is good enough for two crops of rice a year, 19% with supplemental irrigation in the wet season, and nearly 50% rainfed, with water ranging from shallow to intermediate in depth. These regional estimates reflect the importance of different environments in which rice is grown, but take into account only one dimension of the environment -- water depth.

Environments can also be identified by type of rice crop grown. Identifying environments in this way is similar to identifying them by depth of water, but it reflects some additional distinctions as well. A recent paper by Takaya (1975) classifies the rice cropping patterns to the physiographic features of the deltas (Table 4). Four distinct types of rice crops have been identified for each area. Although slightly different in local name, each type has common characteristics with the corresponding type in other deltas. Takaya (1975) identifies six common rice cropping patterns -- each of the four types grown alone plus premonsoon followed by postmonsoon rice and premonsoon followed by monsoon rice.

Table 4. Local names of four types of rice grown in four major river deltas of Asia.

River delta	Local name for			
	Transplanted monsoon rice	Broadcast monsoon rice	Premonsoon rice	Postmonsoon rice
Brahmaputra	Transplanted Aman	Broadcast Aman	Aus	Boro
Chao Phya	Transplanted Main season	Broadcast Main season	Early monsoon	None
Mekong	Transplanted Monsoon	Broadcast Monsoon	Negligible	Dry season
Songkoi	Tenth-month	Negligible	Negligible	Fifth-month

Source: Takaya, 1975

The predominant importance of water level in the deltas is reflected in Takaya's classification, but in nondelta rice areas, other factors are probably as important. Two other recent efforts in classifying rice environments have come to our attention. In Sri Lanka and Indonesia, scientists have identified a number of major types of rice environments on the basis of soil and rainfall patterns. In each case, they have estimated the area of rice planted in each

environmental category. Figure 5 shows the zones that have been identified in Sri Lanka with the estimated number of hectares of rice in each zone. Appendix Table 2 reproduces the information about each zone that has been assembled by rice scientists. An advantage of such a classification is that it is based on (1) one of the few unchanging environmental variables -- soils, and (2) rainfall, which is directly related to the all-important factor of water. Within each zone there is a limited degree of environmental variability, while between zones the variability is much higher. A similar system is being developed for Indonesia (Beachell and Morris, 1976). In these two countries, scientists now have a fairly firm idea of the relative importance of different rice environments.

One of the themes of our discussion has been that rice varieties will be better suited to the environment in which they were developed than to other environments. A simple empirical test of this idea is not difficult to devise. Table 5 shows the proportion of rice area planted to modern

Table 5. Proportion of total rice area planted to modern semidwarf rice varieties.

Country	Area (%) planted to modern semidwarf rice varieties									
	1965/ 66	1966/ 67	1967/ 68	1968/ 69	1969/ 70	1970/ 71	1971/ 72	1972/ 73	1973/ 74	1974/ 75
Philippines	-	2.7	21.2	40.6	43.5	50.3	56.3	54.0	63.2	61.5
Sri Lanka[a]	-	-	-	1.2	4.9	5.0	12.0	42.7	64.5	55.2
Indonesia	-	-	-	2.5	10.4	11.1	16.0	24.2	36.6	40.5
Pakistan	-	-	0.3	19.8	32.0	36.6	50.0	43.7	43.2	40.3
Malaysia (W)	10.3	15.4	23.1	20.9	26.5	31.4	37.1	38.1	37.4	35.6
Vietnam	-	-	-	1.7	8.4	20.0	25.7	30.9	31.4	31.0
India	-	2.5	4.9	7.3	11.3	14.5	19.1	22.1	25.6	29.5
Nepal	-	-	-	3.7	3.8	5.7	6.3	16.1	17.1	18.6
Bangladesh	-	-	0.7	1.6	2.6	4.6	6.7	11.1	16.1	14.6
Laos	-	0.1	0.1	0.3	0.3	8.1	7.5	7.5	7.5	7.5
Thailand	-	-	-	-	0.1	0.4	1.3	4.6	5.6	6.5
Burma	-	-	0.1	3.5	3.1	4.0	3.9	4.4	5.1	6.6

[a]IR and BG series.

Source: Dalrymple, 1976.

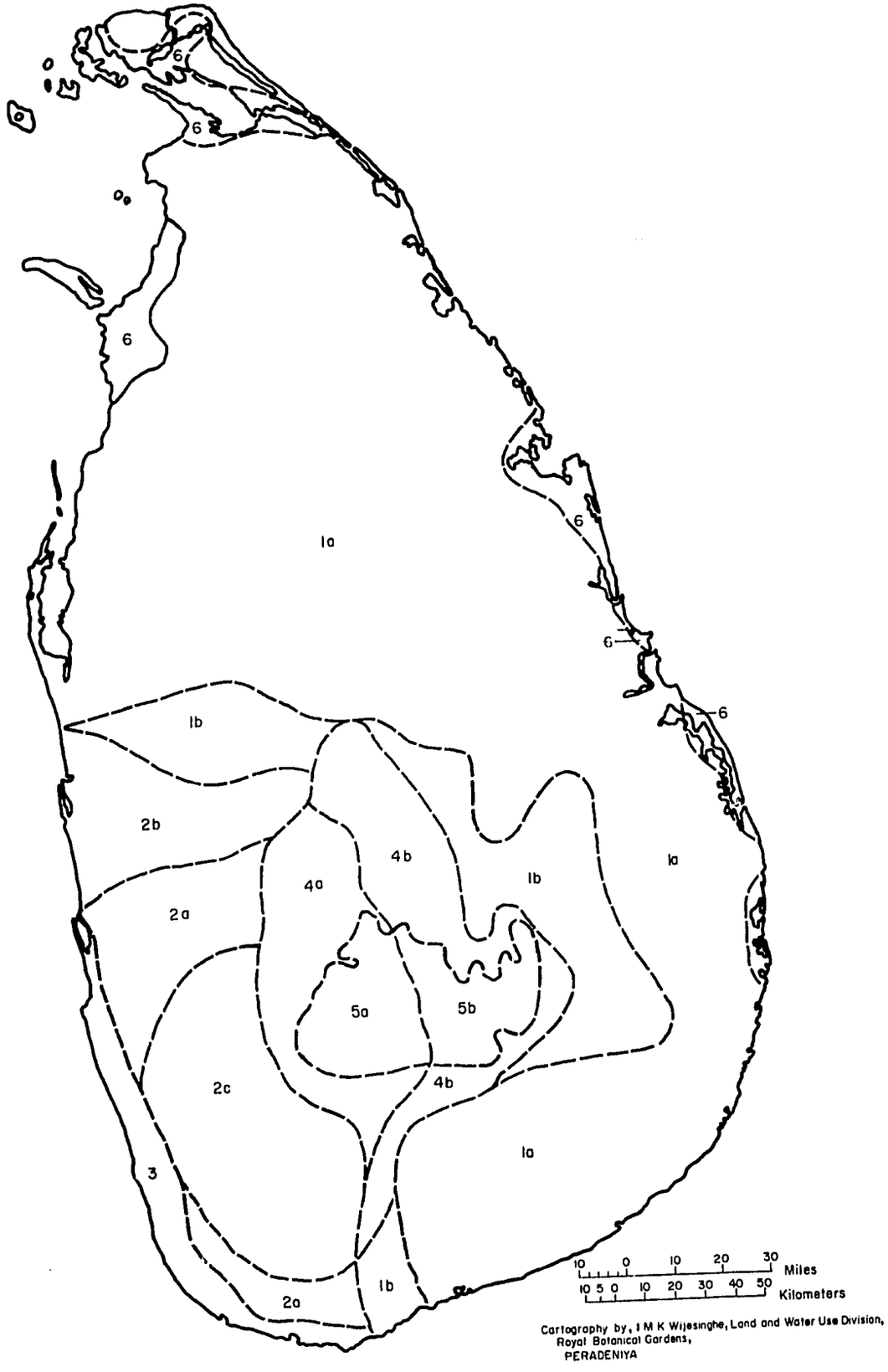
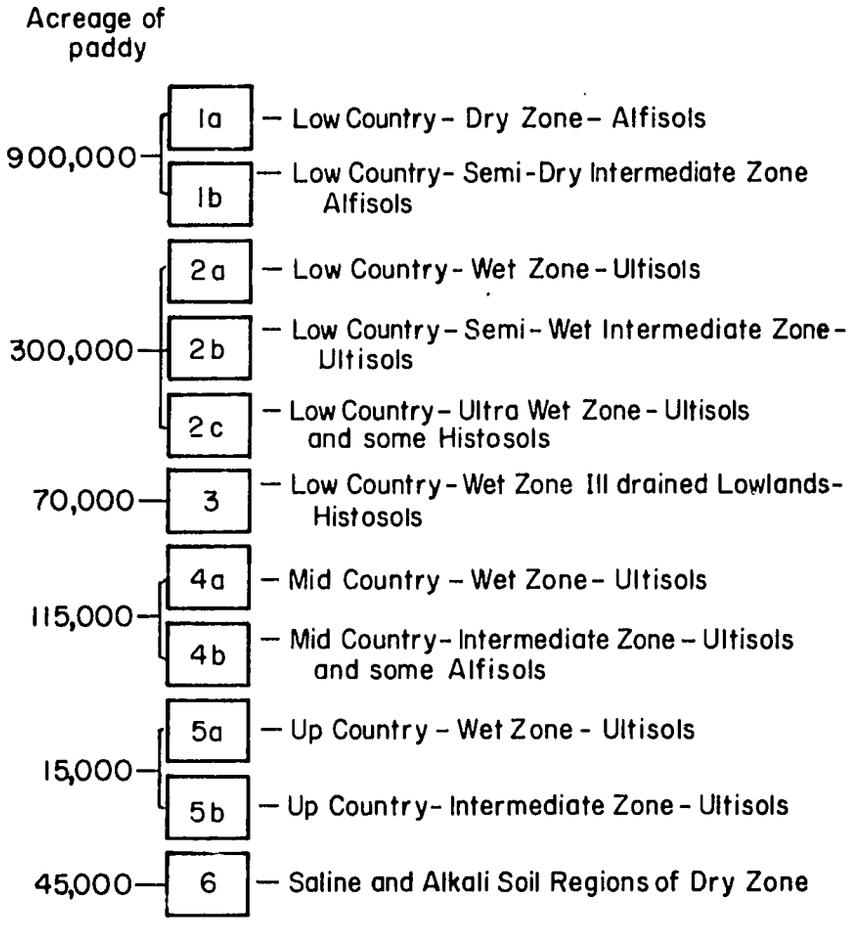
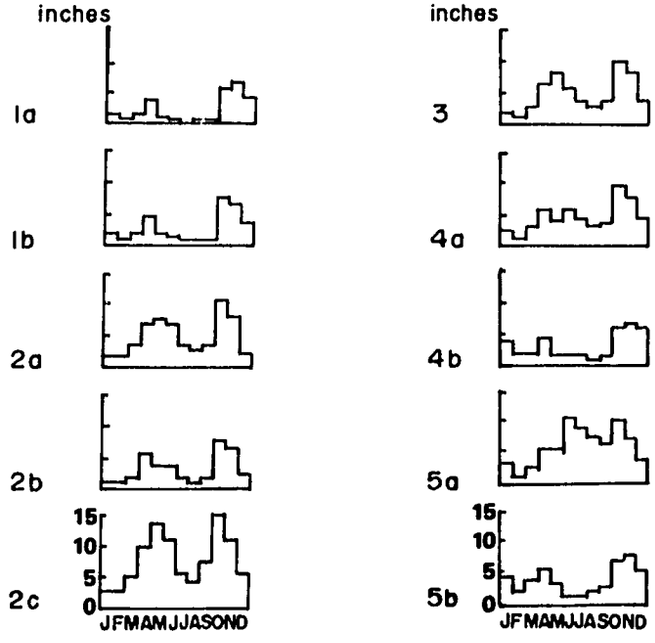


Fig. 5. MAIN AGROCLIMATIC AND SOIL REGIONS, SRI LANKA

AGROCLIMATIC SOIL REGIONS FOR RICE AND REGIONAL RAINFALL, SRI LANKA



Monthly histograms of 75% probability for respective regions.



semidwarf varieties in 12 Asian countries. Most of the available semidwarfs originated from IR8 or other IRRI varieties or lines. The Philippines has the highest proportion of area planted to semidwarfs among the countries shown, Sri Lanka, with the popular BG series has the second highest, and Pakistan the third highest proportion. Much of Pakistan's rice is grown under conditions similar to those of the Philippines' dry season. Malaysia and South Vietnam have the fifth and sixth largest percentages of rice land planted to semidwarfs. In countries with rice environments quite different from those of the Philippines, particularly countries with little irrigation and large river deltas, such as Bangladesh, Thailand, and Burma, much less land is planted to semidwarf varieties.

Even within the Philippines, the IRRI varieties tend to perform better in an environment similar to IRRI's than in different environments. One part of the constraints research mentioned earlier involved placing experiments in farmers' fields to obtain yields as high as possible. Table 6 shows that wet-season highest yields in Laguna were nearly 2 t/ha higher than those in Nueva Ecija even though the 1975 and 1976 weather was good and the level of inputs expected to result in maximum yields was used. The Nueva Ecija sites are 200 km north of IRRI while the Laguna sites are less than 25 km from IRRI. Thus, it appears that IRRI-developed technology performs better in the Philippines than elsewhere, and, within the Philippines, better near IRRI than far from it.

Table 6. Farmers' yields and highest yields in constraints experiments on farmers' fields, Philippines.

Year	Yields (t/ha)							
	Laguna				Nueva Ecija			
	Dry season		Wet season		Dry season		Wet season	
	Farmers	Highest	Farmers	Highest	Farmers	Highest	Farmers	Highest
1974[a]	4.2	6.8	3.8	5.8	-	-	1.7	2.4[d]
1975[b]	4.2	6.8	3.6	5.3	4.5	6.6	3.2	4.4
1976[c]	4.4	6.1	3.9	5.9	4.0	6.5	2.8	4.4
Average	4.3	6.6	3.8	5.6	4.3	6.6	2.6	3.8

[a]On 6 dry-season and 10 wet-season sites in Laguna and 10 sites in Nueva Ecija.
[b]On 9 dry-season and 20 wet-season sites in Laguna, 3 dry-season and 11 wet-season sites in Nueva Ecija.
[c]On 12 dry-season and 14 wet-season sites in Laguna, 9 sites in Nueva Ecija.
[d]Severe typhoons reduced yields substantially.

Source: IRRI Statistics and Agronomy Departments.

MULTILOCATION TESTING

Multilocation testing programs are often viewed as a solution to the problem of developing varieties suited to many different environments. Such efforts are becoming important in the total world rice-improvement effort. The All India Coordinated Rice Improvement Program (AICRIP) has been functioning for a decade. The International Rice Testing Network (IRTP) was recently organized to "formalize and develop a network of scientists working with diverse germ plasm under a wide range of agroclimatic and cultural conditions. The primary function of networks such as IRTP is exchange and dissemination of a wide diversity of genetic materials. Such exchange is envisioned, will "speed the development .... of a continuous flow of improved rice varieties genetically tailored to grow well under a range of conditions."

The results of multilocation tests are generally evaluated both within individual locations and across all locations where the tests were conducted. Yield per hectare and rank of yield are the criteria most often used to evaluate entries in the yield trials. Sometimes locations are grouped by geographic region, but usually they are not.

When entries are evaluated within a location, the entries that perform well and those that perform poorly are clearly identified. Scientists in the location then exploit the materials that perform well, either by directly transferring them to farmers, or, more often, by crossing them with local materials. Thus, evaluation within a location has immediate payoff, but also has some possible drawbacks. Entries that give outstanding performance in one test during one season will not necessarily perform the same over a series of seasons, nor will they necessarily perform well in similar locations with a different configuration of the variable environmental factors. The tests are evaluated across locations in an attempt to measure the performance of entries under a variety of environmental conditions.

When entries are evaluated for performance across many greatly different locations, those that perform relatively well across the whole range of environments are identified. The implication is that widely adapted varieties that perform well across many locations are preferred to varieties that do not (but may perform well in certain locations). The impression is that evaluation across sites overcomes the problems associated with single-site evaluation, and can lead to a multiplier effect -- more research information about performance with less input than would be required with single-location, multiyear testing.

One assumption behind this implication is that the environmental variability across the test sites represents the environmental variability across the sites where farmers produce rice.

The IRTP test sites in Asia are implicitly assumed to represent the 14% dry season irrigated, the 19% wet season irrigated, and the 57% rainfed rice land ranging from deep to shallow water on which rice is grown in Asia (the upland and deep-water areas have separate tests). The truth is that most tests are conducted under relatively well-controlled shallow water conditions, during both the wet and the dry seasons. The test sites probably represent fairly well the irrigated and shallow rainfed areas that have good water control and no major soil problems -- possibly 30% of the land planted to rice (most of which is already planted to semidwarf varieties). There is clearly a gap between yield on some of the IRTP sites and the yield potential in the surrounding farms.

A second assumption of most cross-location analysis is that entries that perform well across locations will also perform well over several seasons in a given location. This assumption is critical if multilocation testing is to have a multiplier effect, but we know of few efforts to test it. Of great interest, therefore, are the efforts of Evenson et al. (1976) to test this assumption for a number of rice varieties entered in to series of multi-location yield tests using an adaptation of the stability coefficient approach of Finlay and Wilkenson (1963). The stability coefficient as defined by those researchers for, say the ith variety, is the b_i coefficient in the equation

$$y_{it} = a_i + b_i \bar{y}_t$$

where y_{it} is the yield of entry i at location t and $\bar{y}_t$ is the average yield of all entries at location t. An entry that gave exactly the mean yield at each location would have $a_i = 0$ and $b_i = 1$. Highly stable entries would have the same yield regardless of the mean yield at a location and so would have b_i values close to zero. If those entries also had high average yields, i.e. high a_i, they would be more desirable than entries with equally high average yields but with less stability -- the latter being indicated by b_i values greater than 1.

Evenson et al. (1976) have used a similar concept but substitute the average yield of the two highest yielding entries at each location ($MAXY_t$) for the average yield of Finlay and Wilkenson (1963). A high value of the stability coefficient indicates that an entry yields poorly where maximum yields are low, and very well where maximum yields are high, or, in other words, that it only performs well in a good environment. Conversely, a low value for the stability coefficient indicates that an entry performs well where maximum yields are low and not so well where maximum yields are high.

The above measure has generally been applied to data from multilocation tests, but can also be used to measure stability within a location if data for the location are available for several years. The more years, the better the test of stability within a location. In most yield tests, the same varieties are not kept for many years so the data base is limited. However, the number of observations for a given location can be increased through use of the data for each replication. Following this line of argument, a set of the following equations were fitted:

$$y_{it} = a_i + b_i' \, MAXY_t + c_{i2} L_2 + c_{i3} L_3 + \ldots c_{in} L_n$$

where the L's are dummy variables representing the locations at which the tests were conducted. The b_i' coefficient measures the stability of entry i when the yield difference solely attributed to different locations is taken account of through the c's. Thus b_i' measures stability across time at a location.

A second set of equations were fitted:

$$Y_{it} = a_i + b_i'' \, MAXY_t + d_{i2}T_2 + d_{i3}T_3 + \ldots . \, d_{im}T_m$$

where the T's are dummy variables representing the years over which the tests were conducted at each site. The b_i'' measure the stability of entry i when yield variation solely attributed to different years is taken account of through the d's. Thus b_i''measures stability across locations holding constant the effect of time, and b_i' measures stability across time holding constant the effect of locations, while b_i measures both effects.[1]

These models were applied to yield data of 22 rice varieties tested at 16 locations in more than one of the first, second, or third International Rice Yield Nurseries (IRYN) and to yield data of 12 rice varieties tested at 28 locations in more than 1 year of coordinated trials conducted by the All India Coordinated Rice Improvement Program. Data from individual replications were used for the IRYN tests. Table 7 and Figure 6 show the estimated coefficients of stability across time (b') and stability across location (b'').

It is readily apparent that little correlation exists between the b'' and b' from the IRYN data while the AICRIP data show a much higher degree of correlation (Fig. 6). These results should be read with caution because we may not have sufficient environmental variance over time to have a high degree of confidence in the b'estimates. Nonetheless, they do have potentially important implications, suggesting that selecting for stability across a wide range of locations like those in the IRYN test may not be a good way to select for stability to environmental variance over time within a location, while testing over a more limited range may be a better procedure.

One apparent problem with the IRYN data is that all locations are grouped together regardless of their similarity. Hence, varieties that are stable perform relatively the same in environments as diverse as those of Taiwan, Indonesia, and West Bengal. But stable varieties are also usually relatively low yielders. It is usually possible to find varieties that perform better in particular locations than in all locations. Another problem is that certain environments are more densely covered by test sites than others, and hence the cross-location evaluation is biased toward conditions in those densely covered environments.

What is needed is a method for grouping the test sites into classes that are somewhat homogenous, but in which the variability between locations within the group approximates the variability that farmers in one of the locations might experience over time. Evenson and colleagues (1976) are now working on analysis along these lines.

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[1]In a later version of their paper, Evenson et al. have defined b'' as the adaptability coefficient and b' as the stability coefficient.

Table 7. Estimated coefficients of stability across time (b') and of stability across location (b'') for two multilocation rice variety tests.[a]

1st, 2nd, 3rd IRYN[b]			AICRIP[c]		
Cultivar	b'	b''	Cultivar	b'	b''
IR8	-1.598(.174)	.622(.049)	Local variety[d]	.557(.040)	.681(.041)
Pelita	-1.288(.350)	.848(.085)	Tainan 3	.568(.065)	.822(.066)
IET 2938	-.458(.187)	.591(.061)	Padma	.621(.065)	.938(.045)
Jayanti	.061(.141)	.722(.042)	Hanusa	.624(.069)	.741(.054)
IR26	.099(.150)	.485(.055)	Kash Siung 68	.730(.056)	.934(.053)
C4-63	.149(.172)	.827(.057)	Jaya	.758(.046)	.899(.042)
IR841-36-2	.190(.151)	.764(.052)	Vijaya	.797(.070)	.945(.055)
IR2061-213-2-16	.217(.202)	.987(.063)	TN1	.807(.046)	.890(.045)
PMI 6624-257-1	.388(.140)	.894(.041)	IR8-64-3-1	.863(.046)	.890(.041)
SPR6726-134-2-26	.408(.147)	1.052(.047)	IR8	.884(.033)	.900(.033)
KT 29	.412(.120)	.765(.047)	IR4-67-2-3	.976(.044)	.927(.044)
BIPLAB	.432(.162)	.763(.039)	Cauvery	1.105(.067)	1.104(.042)
BG 90-2	.637(.133)	.848(.040)			
Chiaung-Sin-yu-6	.639(.179)	.673(.053)			
BKN 6809-74-4	.660(.069)	.706(.039)			
RP4-14	.688(.108)	.496(.048)			
IR2071-588-6	.783(.165)	.621(.263)			
IR2070-747-6	.799(.209)	.440(.056)			
IR1529-680-3	.931(.100)	.743(.042)			
CICA 4	1.181(.099)	.423(.057)			
IR578-95-1-3	1.250(.151)	.670(.059)			
IR630-27-1-1	1.671(.146)	.678(.058)			

[a]Standard error of each coefficient is given in parentheses.
[b]International Rice Yield Nursery.
[c]All India Coordinated Rice Improvement Program.
[d]Variety chosen by scientist at each location as the best local variety -- different for each location.

Source: Evenson et al., 1976.

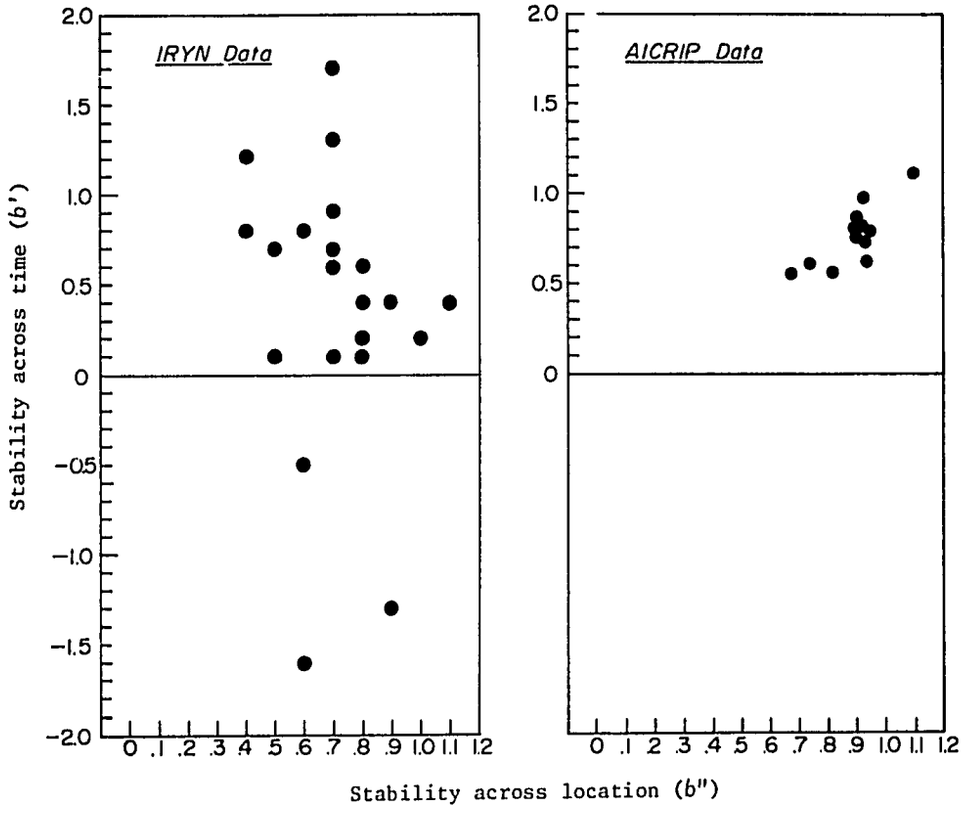

Fig. 6. Relationship of stability across time and location.

TOWARD A RICE TECHNOLOGY DEVELOPMENT SYSTEM

We have so far

1. Suggested that attention be paid to both the yield gaps: gap I - the the difference between potential yields under farmer's conditions and those under experimental conditions, and gap II - the difference between the farmer's actual yields and the potential yields under their conditions.

2. Discussed the idea of setting plant breeding goals in terms of environments instead of in terms of plant characteristics and have presented some alternative ways in which rice enrivonments are classified and described.

3. Presented a preliminary analysis of multilocation yield trial data that indicates that when all locations are considered together, there is little correlation of yield stability across locations with yield stability across time in a location.

These data and discussions suggest that the scientists and institutions involved in improving rice technology should think about how a system of technology development ought to work, and what the role of each of its components ought to be.

Figure 7 illustrates one way of thinking about the system. Four types of

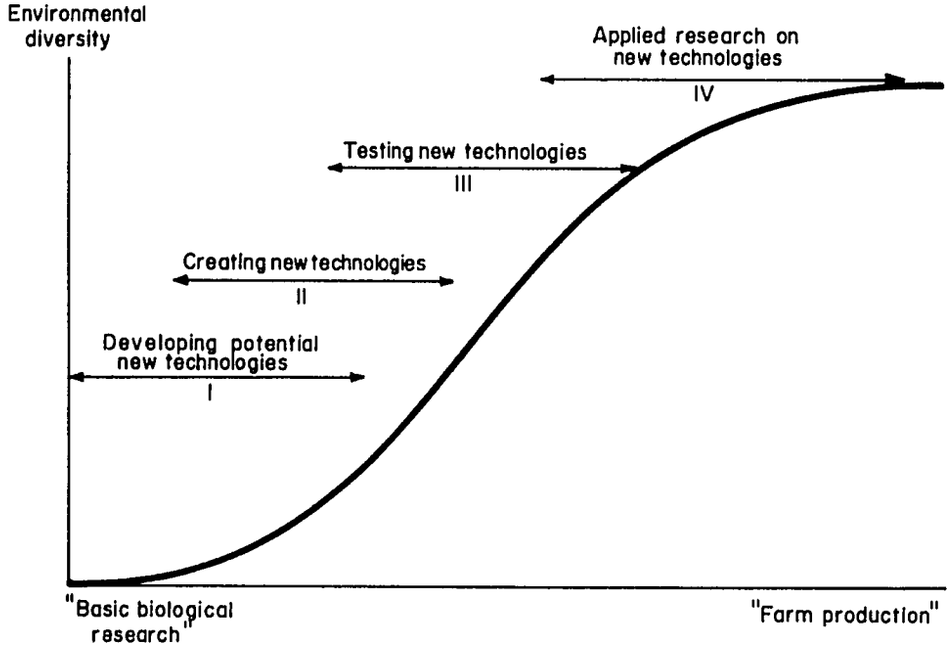

Fig. 7. The relationship between components of an agricultural research system and the degree of environmental diversity in which each component should be operated.

research activity between "basic biological research" and farm production are identified. As we have seen, rice production takes place under a very wide range of environmental diversity -- represented on the vertical axis in the figure. The research to develop new technologies that might raise production potentials (Type I research) can take place in a narrow range of environments, because it requires highly controlled laboratory conditions. The intermediate steps of creating, testing, and applying new technologies (Types II, III, and IV) should occur over an increasing range of environmental diversity. One would expect some overlapping among these types of research, and of course, differences of opinion in classifying various research activities, but conceptually, the idea of a continuum from basic biological research to farm production would probably be accepted by most agricultural researchers.

Once the ideas of a research continuum and environmental diversity are recognized, it becomes more apparent that all rice research institutions should not attempt to perform all types of reseach. The development of easily transferable technologies that require costly research inputs should be concentrated.

For example, to identify sources of resistance to a particular type of stress new lines may be tested for their reaction to it in either diverse or similar environments. The tests may continue as long as the particular stress being observed occurs in each location. This function may be effectively carried out in a rather limited number of locations where effective measurement of both the degree of stress and the reaction to the stress can be insured. This activity probably falls into Type II research in Figure 7. Because it may require costly facilities and highly trained staff, it is wise to concentrate it in relatively few locations.

Tests of more advanced lines for potential adoption by farmers might be considered Type III research. They should be conducted in environments representative of the conditions under which the rice is expected to be grown. To shorten the time consumed by multiseason testing at a location, enough environments should be included in the tests to represent the kind of diversity that farmers in those environments will experience. Furthermore, results from similar environments must be grouped together for analysis and not be pooled with results from entirely different environments. This is where networks and environments need to be carefully related.

Research to measure the gap between potential and actual yields under farmers' conditions should be conducted under farmers' conditions. In planning the research for the constraints project, we stressed the need to select sites representative of areas and conditions that are important rice-producing areas. However, we have not specified those environments.

In this regard, the Agro-Economic Network measuring constraints is similar to the IRTP. Both networks need to emulate the example set by Sri Lanka and Indonesia. They should define the environments where rice is being grown; identify the relative importance of different environments; and concentrate research where the potential payoff is the largest. That is more difficult to do internationally than nationally, because it requires a closer definition of environmental variables to enable scientists to group environments across nations rather than within nations. One way to start might be to agree upon a specific prototype procedure, such as that used in Sri Lanka or Indonesia and follow this procedure in classifying environments in other Asian countries.

In conclusion, we quote from an article by Jennings (1975):

> "The wheat and rice production packages are clearly environment specific even though the area of impact may be broad. They originally were directed toward the areas of favored soil, water, and climate as the fastest way to increase food production rapidly."
> "....Breeders need greater recognition of the importance of conducting station, regional, and demonstration-yield trials. ....It is essential that breeders expose their materials to severe selection pressures. .....We need to bring together greater tolerance to a wider range of diseases, pests, cold, heat, moisture supply, and soil problems. .....This problem [of limited adoption] is directly related to the multiple stresses of water, weeds, and pest characteristics of large production areas -- but relatively absent on experiment station."

Jennings (1975) comments on the resources required for this kind of research, as follows:

> "....the requirements for a sustained assault on unsatisfactory food production are disarmingly simple. These include a team of scientists dedicated to a common goal, a comprehensive collection of germ plasm, abundant labor, land, and power to till it, assured water supply, a sprinkling of simple seed rooms, and greenhouses, and money for massive practical training of young researchers in materials and methods. These basic inputs, coupled with enlightened administration coordinating applied research on limiting problems, the means to test experiment station results directly on farms in diverse areas, and a mechanism for functional linkages to national research programs are essential for success."

LITERATURE CITED

Beachell, H. M., and R. A. Morris. 1976. Rice varietal improvement requirement, strategies and priorities for Indonesia. Paper presented at the International Rice Research Conference, April 1976. International Rice Research Institute, Los Baños, Philippines. (mimeo.)

Bernsten, R. H. 1976. Rice farming in Central Luzon: input usage cultural practices and yield constraints. Paper presented at a Saturday seminar, March 20, 1976. International Rice Research Institute, Los Baños, Philippines. 9 p. (mimeo).

Dalrymple, D. G. 1976. Development and Spread of High Yielding Varieties of Wheat and Rice in the Less Developed Nations, USDA, Foreign Agricultural Economic Report No. 95, fifth edition.

Evenson, R. E., J. C. O'Toole, R. W. Herdt, W. R. Coffman, and H. E. Kauffman. 1976. Risk and uncertainty as factors in crop improvement research. Paper prepared for the Conference on Risk and Uncertainty, March 9-13, 1976. CIMMYT, Mexico. (mimeo.)

Finlay, K. W., and G. N. Wilkinson. 1963. The analysis of adaptation in a plant breeding programme. Aust. J. Agric. Res. 14:742-754.

Hargrove, T. R. 1976. The diffusion of genetic materials, the objectives, and the sociological characteristics of rice breeders in India. Paper presented at a Thursday seminar, July 1, 1976. International Rice Research Institute. 17 p. (mimeo.)

International Rice Agro-Economic Network (IRAEN). 1975. Methodology for assessing rice yield constraints, March 1975. IRAEN Working Paper 2.

International Rice Research Institute. 1973. Annual report for 1972. Los Baños, Philippines. 246 p.

International Rice Research Institute. 1975. Annual report for 1974. Los Baños, Philippines. 384 p.

International Rice Testing Program (IRTP). 1975. Preliminary report of the second International Rice Yield Nursery (IRYN), April 1975. International Rice Research Institute, Los Baños, Philippines.

Jennings, P. R. 1975. Rice breeding and world food production. Pages 95-98 in P. H. Abelson, ed. Food: politics, economics, nutrition and research. Am. Soc. Adv. Sci., Washington, D. C.

Moorman, F. R. 1975. Agricultural land utilization, and land quality. International Institute of Tropical Agriculture, Ibadan, Nigeria. (unpublished paper).

Suwanpimolkul, S. 1976. Socio-economic constraints on rice yields in parts of Suphanburi Province, Thailand, wet season, 1974. Paper presented at a Saturday seminar, March 13, 1976. International Rice Research Institute, Los Baños, Philippines. 16. p. (mimeo.)

Takaya, Y. 1975. Rice cropping patterns in Southern Asian Delta. Southeast Asian Stud. 13(2):256-281.

Appendix Table 1.[a] Definition of area in rice production in South and Southeast Asia by water control.

Region	(1970/71, 71/72, 72/73) Area (thousand ha)	% world area	Prodn. (thousand mt)	Yield (thousand kg/ha)	Definition of area by water control: Irrigated (%)	Rainfed (%)	Upland (%)	Deep water (%)	Second crop in rice (%)	Area in HYV 1972/1973 (%)
Southeast Asia	26,223	19.7	53,203	2.0	29	58	8	5	10	21
Burma	4,810	3.6-1/2	7,965	1.7	17	81	1	1	1	4
Indonesia	8,159	6.1	19,582	2.4	47	31	17	5	19	27
Malaysia (West)	544	0.4	1,517	2.8	77	20	3	0	50	38
Philippines	3,157	2.4	4,951	1.6	41	40	11	0	14	56
Thailand	6,941	5.2	13,047	1.9	11	80	2.5	6.5	2	5
Vietnam (South)	2,612	2.0	6,141	2.4	15	60	5	20	5	32
South Asia	49,900	37.5	84,613	1.7	37	47	7	9	6	23
Bangladesh	9,470	7.1	15,333	1.6	16	39	19	26	10	11
India	37,123	27.9	61,963	1.7	40	50	5	5	5	25
Nepal	1,227	0.9	2,483	2.0	16	76	9	0	0	15
Pakistan	1,480	1.1	3,393	2.3	100	0	0	0	0	43
Sri Lanka	600	0.5	1,441	2.4	61	37	2	0	25	34
TOTAL	76,123	57.3	137,816	1.8	34	51	8	7	7	22

[a]If readers disagree with any of the figures in this table, they are requested to provide us with better figures.

Appendix Table 2. Rice breeding objectives for the respective edaphic regimes in Sri Lanka.

Climatic zone and soil region	Edaphic regime	Area (ha)	Yield target (t/ha)	Range of duration (months) Maha	Yala	Special consideration	Plant ideo-type
1. Low country dry zone and semi-dry intermediate zone	1. Major irrigation	160,000	6.5	3-1/2 - 4-1/2	3 - 3-1/2	High pest and disease resistance	Short erect type with high fertilizer response
Alfisols 1a and 1b*	2. Minor irrigation	100,000	3.8-5.6	3 - 3-1/2		Adaptable to semi-irrigated conditions during early growth	Intermediate type with high fertilizer response at moderate fertilizer level
	3. Rainfed Manawari	50,000	2.3-2.6	3 - 4	-	Drought tolerance and high root vigor	Early shading habit and high fertilizer response at low fertilizer level
	4. Rainfed Chena	50,000	2.1-2.3	3 - 4	-	Drought tolerance and high root vigor	Early shading habit and high fertilizer response at low fertilizer level

Appendix Table 2. (cont'd.)

Climatic zone and soil region	Edaphic regime	Area (ha)	Yield target (t/ha)	Range of duration (months) Maha	Range of duration (months) Yala	Special consideration	Plant ideo-type
2. Low country wet zone and semi-wet intermediate zone, including ultra wet regions	5. (a) Irrigated and no flood hazard	30,000	4.1-5.2	4 - 6	3-1/2 - 4-1/2	i. High pest and disease resistance ii. Tolerance to bronzing iii. Tolerance to low phosphate	Intermediate type with high fertilizer resistance at moderate fertilizer level
Ultisols 2a, 2b, & 2c*	5. (b) Irrigated with some flood hazard					i. Flood tolerance at early stages of growth ii. Tolerance to bronzing iii. Tolerance to low phosphate	Intermediate type with high fertilizer response at moderate fertilizer level
	6. Rainfed, stream fed and spring fed	80,000	2.6-3.6	4 - 6	3-1/2 - 5	i. High pest and disease resistance ii. Tolerance to bronzing iii. Photo sensitivity (for some tracts in Kurunegala District) iv. Tolerance to low phosphate	Early shading and intermediate plant type with high fertilizer response at moderate fertilizer level

Appendix Table 2 (cont'd.)

Climatic zone and soil region	Edaphic regime	Area (ha)	Yield target (t/ha.)	Range of duration (months) Maha	Yala	Special consideration	Plant ideo-type
3. Low country wet zone ill-drained lowlands Histosols 3*	7. Swampy, marshy, flood prone	28,000	2.1-3.1	4 - 6 and 3-3-1/2	4-1/2 - 6-1/2 3 - 4	i. High pest and disease resistance ii. Flood tolerance at all stages of growth iii. Tolerance to salinity at tidal elevations iv. Photo sensitivity v. Tolerance to bronzing	Intermediate to tall plant types with high fertilizer response to low fertilizer levels Non-lodging and medium tall types for low elevation in bog soils
4. Mid-country wet and intermediate zone Ultisols 4a & 4b*	8. Terraces, slopes and narrow valleys, stream and spring fed	46,000	4.6-6.4	4-4-1/2	3-1/2 - 4	i. Adequate panicle development before flowering in order to ensure proper sink size ii. Tolerance to low phosphate	Intermediate type with high fertilizer response to moderate fertilizer levels

Appendix Table 2. (cont'd.)

Climatic zone and soil region	Edaphic regime	Area (ha)	Yield target (t/ha)	Range of duration (months) Maha	Yala	Special consideration	Plant ideo-type
5. Up country wet and intermediate zone Ultisols 5a & 5b*	9. Narrow valley spring fed	6,000	2.6-3.1	4 - 4-1/2	3-1/2 - 4	i. Cold tolerance ii. Tolerance to low P.	High photo synthetic efficiency
6. Salino-Alkali 6*	10. Irrigated & semi-irrigated, rainfed	18,000	4.1-5.2	3-1/2 - 4	3	Resistance to saline/or alkali conditions	Intermediate type with high fertilizer response to moderate fertilizer levels

*Refer to map on main agroclimatic and soil regions for paddy, Figure 5.

Source: Department of Agriculture, Sri Lanka.