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LONG-TERM CONSEQUENCES OF TECHNOLOGICAL CHANGE ON FOOD SECURITY:
The Case for Cereal Grain

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LONG-TERM CONSEQUENCES OF TECHNOLOGICAL CHANGE ON FOOD SECURITY: THE CASE FOR CEREAL GRAIN*

Randolph Barker, Eric C. Gabler, and Donald Winkelmann**

I. INTRODUCTION

National governments are confronted with the problem of maintaining adequate supplies of food to meet domestic demand. The problem has two elements: (i) maintaining an upward trend in food production that will allow per capita levels of food consumption to be maintained or preferably increased, and (ii) maintaining adequate year-to-year supplies of food to meet domestic requirements given the high degree of variation around the trend in domestic production due to weather, pest damage, and other factors. This conference is concerned principally with the latter of these two issues, and examines alternative strategies for managing year-to-year fluctuations in supply. Our paper is concerned with the long-term effect of the introduction of new crop technology on the magnitude of the deviations around the production trend. Does technological change result in greater stability or instability in crop yields?

By way of introduction in the first section we summarize the current view with respect to the projected long-term trend in food grain production and demand. The next four sections of the paper discuss those factors which influence variability in yield with emphasis in the role of technological change. The paper concludes with a brief examination of policy issues related to yield stability.

Our discussion will emphasize rice, wheat, and maize. These three cereals are major sources of energy and protein in developing countries and are the dominant commodities moving in international trade. They are, moreover, crops with which we are most familiar.

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II. PROSPECTS FOR INCREASING FOOD GRAIN PRODUCTION

Much has been written recently about the widening gap between projected trend in consumption and production in the developing countries of the world. The projections of the International Food Policy Research Institute (1977), The World Bank (1976), and the Asian Development Bank (1978) all estimate a substantial widening in the gap between food grain production and demand in the decade ahead. For example, the International Food Policy Research Institute study concludes that the shortfall in production of staple food crops in the developing market economies will range from 120-145 million metric tons by 1990. This is more than three times the shortfall of 37 million metric tons in the relatively good production year 1975 (IFPRI, 1977, p. 17).

The "gap" analyses described above are not predictions of what is to come, but indications of the pressures that are likely to occur in the system. At any given point in time supply will equal demand. The "shortfall" will be eliminated either by (i) increased importation, (ii) more rapid growth in production, (iii) a decline in the level of consumption, (iv) drawing from stocks, or (v) some combination of the first four. Herdt, Te, and Barker (1978) estimated input requirements for a gain in Asian rice production that would keep pace with the growth in demand. They concluded that the increased production could be achieved, but that it would require not only an intensification in irrigation and the use of modern inputs, but further gains from investment in research and new technology. These conclusions are probably relevant for other cereal grain crops as well. From our perspective, the conclusions suggest that in order to maintain or enhance rates of production growth there will be even more emphasis on use of modern inputs and expansion of infrastructure than has occurred in the past decade. The development plans of a number of countries are already beginning to reflect an increased emphasis on investment in modern agricultural technology and research.

We believe that yields will continue to increase. For this to happen, farmers must use even more intensive production strategies - more fertilizer, more careful husbandry, better moisture control, denser stands, and varieties that provide higher yield potential. The question that emerges is what will these more intensive practices imply for the annual variation in yields? Will the practices carry with them more stability or will they be a source of additional variability? This question is examined in the sections which follow.

III. FACTORS INFLUENCING VARIABILITY IN YIELD

Yield variability over time can be decomposed into trend, cyclical, and year-to-year components. Year-to-year yield variability is measured in this analysis in terms of the deviation of yield from a trend. Methods for determining the trend will be discussed subsequently. The <u>standard deviation</u> of

the distance of observations from the trend is calculated and this term is divided by the mean to determine the coefficient of variation. The standard deviation (or standard error of the regression) is a measure of absolute variance while the coefficient of variation is a measure of relative variance. In situations when the relative variance is reduced the absolute variance may actually increase. We consider both measures to be important. Policy makers planning national food security must concern themselves with actual volume of grain that can be imported and stored. But as production and yields trend upward, along with population, it is useful to know the relative change in yield variability.1/

Individual countries, like individual farmers, are most apt to be concerned with major downward deviations from trend or years of serious crop loss. However, they may exhibit different risk preference. For example, if there is a trade off between greater stability and higher yield, some countries may be more inclined than others to accept a greater degree of instability to achieve high yield.

A wide range of environmental factors can influence variability in yield. Climatic factors such as temperature and rainfall have both direct and indirect (through disease and pests) impact. Technological changes can either enhance or mitigate yield variability and public policies in turn affect the rate of direction of technological change.

Climatic Change Over Time

Long-term changes in climatic variables may have a major impact on the magnitude of yield variability. Temperatures either above or below normal can affect yield variability. Thompson (1969) for example, argues that the wide variation in U.S. maize yields in the 1930s as compared to the 1940s was due to the unusually high temperatures in the 1930s. There is also a tendency for greater variability in precipitation to be associated with long-term cooling trend. The experts do not agree as to whether we are in a global cooling or warming trend. A recent study conducted jointly by a member of U.S. government agencies (National Defense University, 1978) has worked out five possible scenarios for climatic change to the year 2000 ranging from large global cooling to large global warming. Depending upon which of these conditions prevail, there would be a considerably different impact on regional grain production, but the impact on total world production would be relatively slight with gains in some regions being offset by losses in others. Of more interest from the standpoint of our present discussion, however, is the potential impact of these long-term trends on yield variability. For example, a large global cooling trend (by the year 2000 the mean northern hemisphere temperature would be about 0.6°C cooler than in the early 1970s) would increase the variability in the length of the growing season from year to year in the middle latitudes, would increase probability of droughts as well as severe cold spells in the higher

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1/ A. Siamwalla suggested that an estimate of the per capita yield variability would be more appropriate than the coefficient of variation.

middle latitudes, particularly Canada, and would increase the frequency of droughts in the Sahel region (National Defense University, 1978, p. 20). This scenario is perhaps the most unfavorable in terms of the effect on yield variability, but is given a probability of only one in ten of occurring. While yield variability is important regionally and nationally, there tends to be very little global variation as changes in one region are nullified by offsetting changes in another region. Of particular relevance, however, is whether the weather variability or balance favors the developed (largely temperate zone) or the developing (largely tropical) countries. The general concensus of the group of experts surveyed in this study is that there will be no radical change in global temperature by the year 2000 A.D.2/ There was a slight group bias toward global warming. The magnitude of change in yield due to weather is expected to be much smaller than the magnitude of increase due to technology, but the report does not investigate potentially stabilizing and destabilizing effects of technological change. This is the issue to which we now turn our attention.

Technology

There is a simple way to argue the relationship between yield and its stability. As yields approach zero the range over which they can vary necessarily declines. Or taken to a slightly more sophisticated level, as farmers take steps which permit yields to increase, they open the range of potential yields at the top but probably have little impact on the lower limits of the range. Yield increasing technology should then be associated with increasing variability from year to year particularly if we measure variability in absolute terms.

These conclusions, which might appear almost to be conventional wisdom, have been challenged in recent years. Analysis of U.S. data shows that yields were more stable in the decade of the 1950s and 60s than in the earlier decade of the 1930s and 40s. Over the same period yields have increased notably and, in the case of maize, dramatically. The U.S. Department of Agriculture made the following statement (see Thompson, 1975, p. 535):

> A comprehensive study published by this Department in 1965 evaluating the effects of weather and technology on corn yield for the years 1929 through 1962 concluded that through the use of better varieties and improved cultivation and fertilizer practices, man has reduced variation in yield in both good and bad weather.

However, others argue that the change in weather was the main factor accounting for more stable yields. We have already noted Thompson's (1969) observation in this regard with respect to corn yields. In a later paper Thompson (1975) comments on wheat saying that coefficients showing the effects

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2/ It should be pointed out that in this investigation of climate, and in the subsequent investigations of the impact of climatic change on crop production, trade, and prices, the experience of the panel of experts (nearly all of whom are from the western world) on developing country conditions appears to be extremely limited.

of weather on wheat yields would have been more heavily influenced by weather had the coefficients been developed during periods of high yields. In a personal communication, Thompson observed that we cannot conclude that more intense production practices have reduced variation in yields. Rather, it appears that for any given environment weather induced variability could be greater as production strategies are more intense.

The argument that new technology stabilizes yields can be found in literature of the "green revolution." Reflecting on the likelihood of crop losses of the magnitude that occurred in 1965-67, Swaminathan (1972, p. 14) states:

> Besides the advantages gained in infrastructure and programme development, the most significant factors which provide room for optimism that drop in production of the magnitude witnessed during 1965-67 need not be permitted again even if the rainfall fails to the same or even greater extent, stem from recent scientific advances.

In a summary report of a conference on Climatic Change, Food Production, and Interstate Conflict sponsored by the Rockefeller Foundation (1976, p. 27) we find a statement that runs in much the same vein:

> To a great extent the human impacts of reduction in crop yields caused by climatic anomalies such as these that occurred in 1972 tend to be most severe in regions that have one or more of these characteristics:
>
> 1. crops are produced under conditions that are marginal at best in terms of precipitation and/or temperature;
> 2. modern agricultural technology has not been applied to an optimum extent;
> 3. crops are produced for local consumption by a large population;
> 4. the nation is not in a favorable financial position to compete in world food markets.

These recent statements are not accompanied by any evidence. By contrast, in a detailed study of the impact of technology on wheat production in Turkey, Mann (1977, p. 44) concludes: "It is important to note that while technology has raised yields, the possibility remains of substantial production variation due to weather. The range of this variation in terms of wheat is likely to expand considerably under improved technology."

We have conducted further analyses to determine whether or not the results support the above statements with respect to the stabilizing impact of the introduction of new technology, or the conclusions reached by Mann.

Three procedures for examining trend and estimating the variability of the deviation from the trend include: (i) fitting a trend line, (ii) taking first differences or alternatively fitting a regression equation with yield lagged one year as the dependent variable, and (iii) calculating moving

averages. Because of the short length of time series available for most countries, we chose to apply the first two methods. Choosing several locations a linear trend was fit to yields for the period 1955 to 1977 for rice and for a slightly different time duration in wheat. In the case of rice, the trends were fit separately for the period 1955-67 and 1967-77. In the latter period the trend variable used was 1/t instead of t to reflect the initial rapid increase and gradual leveling off in yield growth. The standard error of the regression and coefficient of variation (standard error divided by mean) were calculated for both time periods.

In the case of rice we also fit a regression for the two time periods with yield as the dependent variable and yield lagged one year as the independent variable. Measures of standard deviation and coefficient of variation using this method compared very favorably with the results obtained based on trends (Appendix Table 1). Estimates of variability based on deviation from trend are presented in the text (Table 1 and 2).

Two areas were chosen for wheat, the state of Nebraska and the Yaqui Valley, Mexico. More intensive production practices, mostly improved varieties and greater use of chemical inputs, have led to higher yields in both areas. Yields more than doubled (from a three year average of 2.14 tons per hectare in 1956-58 to 4.42 tons in 1976-78) in Mexico's irrigated Yaqui Valley and increased by some sixty percent (from a three year average of 1.19 tons per hectare in 1954-56 to 1.91 tons in 1974-76) in Nebraska's rainfed wheat area. In the case of Nebraska the standard deviation was constant while yields increased. In the case of the Yaqui Valley there was a substantial increase in the standard deviation.

TABLE 1

Linear regression results, yields on years, for two wheat producing areas (kgs/ha).

		R^2	Mean (t/ha)	SDR 1/ (t/ha)	Coefficient of Variation (%)
Nebraska:	1954-76	.45			
	1954-64		1.38	0.31	22.5
	1966-76		2.01	0.31	15.3
Yaqui Valley:	1956-78	.87			
	1956-66		2.52	0.29	11.2
	1968-78		4.12	0.42	10.2

1/ $[\Sigma (Di)^2/n-1]^{1/2}$ where Di is the deviation from trend.

Table 2 makes similar comparisons for rice based on four countries in South and Southeast Asia that have shown rapid increases in yield following the introduction of modern varieties. In all four cases the standard error of the regression coefficient increased with the introduction of the new technology. Since the introduction of modern varieties, severe crop loss has been experienced in some years as a result of insect damage in Indonesia, Pakistan, and the Philippines, drought in Sri Lanka and the Philippines, and floods in Pakistan and the Philippines.

TABLE 2

Change in yield variability accompanying increase in yield due to technological change for selected countries in Asia, 1955-67 vs. 1967-77.

		R^2	Mean (t/ha)	Standard Error of Regression (t/ha)	Coefficient of Variation (%)
Indonesia:	1955-67	0.69	1.74	0.03	1.7
	1967-77	0.89	2.43	0.10	4.3
Pakistan:	1955-67	0.70	1.35	0.05	3.6
	1967-77	0.85	2.13	0.12	5.8
Philippines:	1955-67	0.66	1.22	0.06	4.9
	1967-77	0.39	1.64	0.15	8.8
Sri Lanka:	1955-67	0.47	1.54	0.09	5.6
	1967-77	0.85	2.19	0.11	5.0

One must be extremely cautious in drawing conclusions given the very short length of time series data available. Furthermore, we are considering only yield and not total production, one crop and not total food, and in some cases only one small region in a country. But the evidence does suggest very strongly that the introduction of new technology results in greater yield variability particularly in absolute terms. It is useful to examine the effects of specific elements of the technology in greater detail to determine whether steps can be taken to enhance yield stability.

Moorman (1975) provides a useful framework for conceptualizing the various types of technological change. He ranks environment or "land" according to its suitability for rice production. We generalize his framework here to include cereal grains. Land, in his terms, can be taken as meaning "a specific area of the earth's surface, the characteristics of which embrace all reasonably stable or predictable cycical attributes related to atmosphere, soil, topography, the plant and animal population, and the results of human activity."

Some land is well suited to cereal grain production while other land is not (Fig. 1). Most of Class I land is already planted to highly productive

cereal grains including new semi-dwarf varieties of rice and wheat. Class II land is suitable for crop production, but has increasing limitations. Sub-Class II-A differs from II-B in that the productivity in II-B is too low to yield a profitable return to purchased inputs.

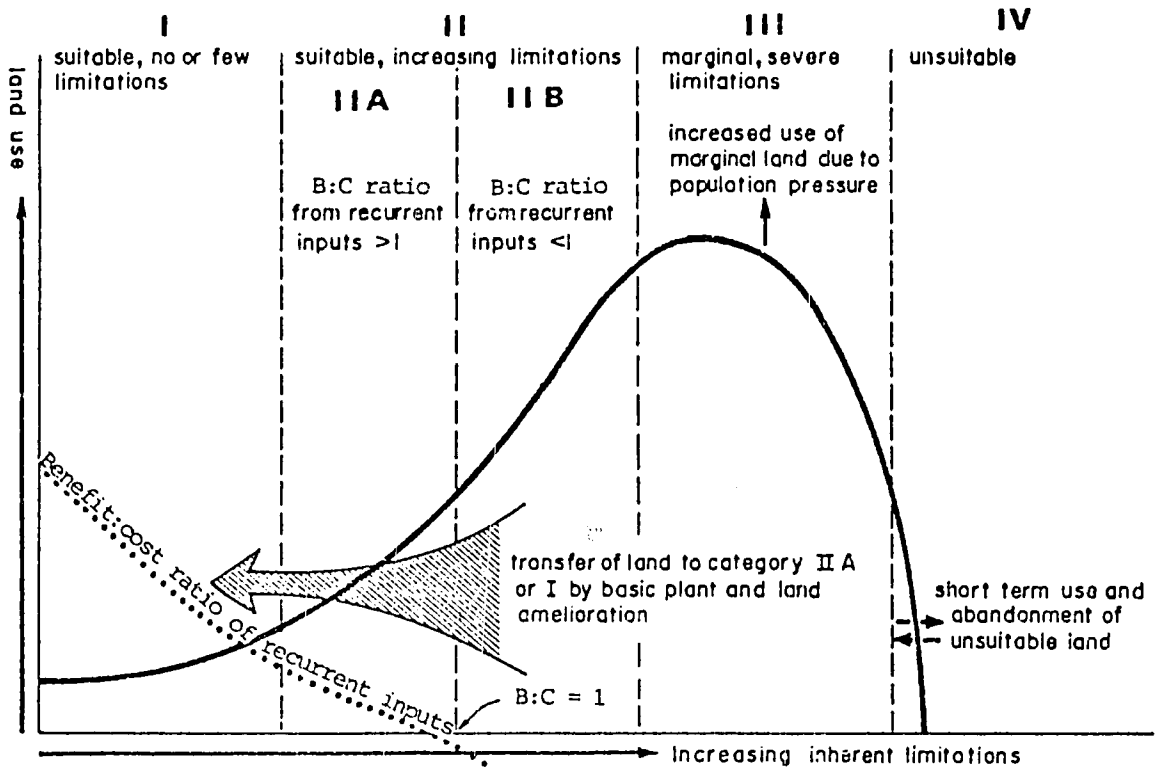

Fig. 1 Moorman's model of the relation of land in use for specific agricultural purpose and land quality.

Technological change results in the transfer of land from category II-B to II-A or I where it becomes profitable to use recurrent inputs such as fertilizer and chemicals. Moorman identified basic plant and land amelioration as the means of achieving such a transfer. Land amelioration can be achieved through factors that improve soil, moisture, or temperature conditions - for example, soil conservation measures, irrigation and drainage, the construction of vinyl seedbeds. Plant amelioration carried on by the breeders can produce plants suited to existing on II-B land (environments) so that such land is shifted to II-A. Land classes (environments) can differ by season. Thus in the case of rice the development of new varieties in many cases resulted in a shift from II-B to II-A land in the dry season but not in the wet.

The transition from II-B to II-A or I land does imply a higher level of technology inputs and higher yields, but not necessarily greater stability in yields. For example, the development of irrigation facilities would reduce crop losses due to moisture stress, but the accompanying intensification of cropping practices may result in greater crop loss due to insects and diseases. Further, in Asia we can observe that improvements in rice and wheat varieties have not only raised yields, but have allowed rice to move north and wheat to move south

into areas that were formerly thought to be marginal for both. This movement is very evident in South Asia and in China.

Based on the above framework, in the sections which follow we single out three components of technology for further discussion: (i) water control, (ii) agronomic practices including the application of recurrent inputs, and (iii) plant breeding. What are the potentially stabilizing and destabilizing characteristics of each of these components?

IV. WATER CONTROL

There are several classes of infrastructure which affect the stability of cereal grain yields. The most obvious of these relates to water control, including both irrigation and drainage. Other types of infrastructure include roads, electrical power, and grain storage facilities. Our discussion in this section will focus on irrigation.

There will be substantial addition to the world's irrigated area over the next decade. Massive projects are now being scheduled in China, India, and Pakistan. Smaller projects will be implemented throughout much of Asia and in other regions where, like Asia, there is little opportunity left for expansion of cultivated land area except at very high cost. The cost of irrigation is also rising, but nearly all governments heavily subsidize irrigation development, and hence the cost is not reflected in higher food grain prices. It has been estimated that for South and Southeast Asia as a whole over the next two decades more than half of the expected future growth in rice production will be due to the application of technology in the irrigated area (see Barker and Herdt, 1978). But for some countries (e.g. Indonesia, Pakistan, Philippines, and Sri Lanka) this figure will exceed 75 percent.

What impact does irrigation have upon the variability in crop yields? We have already noted that while irrigation may potentially reduce moisture stress, it is frequently associated with an intensification of crop production and input use which is destabilizing. Thus, one cannot say a priori that irrigation development results in greater yield stability. In fact, we have already seen in Table 1 that in the past decade wheat yields have been higher but more variable in the irrigated Yaqui Valley of Mexico than in rainfed Nebraska.

Further analysis was conducted to determine the impact of irrigation on rice yield variability. A linear trend was fit to time series data for: (i) selected countries in Asia from 1955-56 to 1976-77, (ii) selected states in India from 1960-61 to 1975-76, and (iii) rainfed and irrigated yields in the Philippines over the period 1960-61 to 1974-75. The mean, standard error of the regression, and coefficient of variation were calculated and the data for countries and states ranked according to the percent of the rice area irrigated (Table 3).

Table 3. Rice yield variability for selected locations in Asia ranked according to the percent area in irrigation.

	Percent Area Irrigated 1973-75	Percent Area in Modern Varieties 1974-75	R^2	Mean (t/ha)	Standard Error (t/ha)	Coefficient of Variation (%)
		Selected Countries in Asia (1955-56/1976-77)				
Bangladesh	11	15	0.56	1.64	0.11	6.4
Burma	16	6	0.46	1.60	0.11	7.0
Nepal	17	18	0.52	1.88	0.10	5.5
Thailand	24	7	0.16	1.80	0.13	7.2
India	39	28	0.61	1.55	0.11	7.0
Indonesia[a/]	39	40	0.99	2.07	0.04	1.9
Philippines[a/]	40	62	0.98	1.40	0.10	7.1
Sri Lanka[a/]	50	67	0.95	1.88	0.09	5.0
Malaysia	63	37	0.85	2.57	0.13	5.0
Pakistan[a/]	100	39	0.87	1.75	0.06	3.5
		Selected States in India (1960-61/1975-76)				
Uttar Pradesh	16	30	0.25	1.13	0.16	13.8
Bihar	24	12	0.03	1.26	0.22	17.3
Orissa	26	7	0.25	1.13	0.16	14.4
West Bengal	26	17	0.15	1.74	0.14	7.9
Tamil Nadu	87	69	0.68	2.56	0.22	8.5
Andhra Pradesh	100	77	0.65	2.10	0.14	6.5
		Rainfed and Irrigated Areas in the Philippines (1960-61/1974-75)				
Rainfed rice	0	50	0.41	1.27	0.11	9.3
Irrigated rice	100	79	0.78	1.78	0.11	6.0

a/ In these conditions the following function was fit to account for the non-linear trend due to the rapid introduction of new technology:

$$Y = a + bT + cV + dTV$$

where: Y = national yield
T = straight line trend, T = 1 in 1955-56, 2 in 1956-57 etc.
V = 1 until the year prior to the introduction of modern varieties (year 5). Thereafter, V = 1/T - S - 1 (i.e. if modern varieties are introduced in 1967, 1966 = 1, 1967 = 1/2, 1968 = 1/3, etc.).
TV = interaction term
a,b,c,d = constants

By comparison with the straight line trend (see Appendix Table 1) this function increases the R^2 and lowers the variability.

Among ten countries analyzed there was a tendency for the percent area in modern varieties, yield, standard error, and coefficient of variation to increase with an increase in the percentage of rice area irrigated. Among the states of India, the percent area in modern varieties and yield also increased with irrigation, but the standard error showed no trend and the coefficient of variation declined. Essentially the same pattern prevailed for irrigated vs. rainfed rice in the Philippines.

In India it is interesting to compare the states of Bihar and Tamil Nadu. Bihar in Eastern India has one of the most difficult environments for rice production and the high variability of rice yields is a reflection of the frequent occurrence of severe floods and droughts. Most of the rice land in the South Indian state of Tamil Nadu is irrigated. The average yield is more than twice as high as in Bihar, but the absolute variability in yield is essentially the same.

The results in Table 1 and 3 indicate that expansion of irrigation does not result in greater yield stability. Part of the reason may be that irrigation development in South and Southeast Asia does not include a level of infrastructure investment that permits substantial control of water. Most of the irrigated area is still subject to flooding, droughts, and salinity.

It might be hypothesized that with a more intensive development of infrastructure yields would be less variable. In the case of Asian rice, the most highly developed infrastructure and the highest yields are found in East Asia. Investments in irrigation and drainage virtually eliminate the likelihood of crop damage due to either flood or drought. Investments in roads, electricity and grain storage facilities have brought the farmers closer to the consumers. encouraging the use of more intensive production practices. One needs to be cautious in comparing yield variability in East Asia with that in South and Southeast Asia. The former region lies almost entirely in the temperate zone where temperature is the main source of yield variability, while the latter regions lie in the tropics where moisture and pests are the main source of yield variability. Nevertheless, it is interesting to observe that the standard error of the regression for the East Asian countries (Table 4) is higher than that for the South and Southeast Asian countries (Table 3) while the coefficient of variation falls in about the same range for both. This again suggests that higher yields and more intensive use of modern technology increases the absolute yield variability. However, there is not notable concern with variability in crop production in East Asia because these countries have developed transportation, communication, and storage facilities, and have the financial capacity to deal with food security problems.

V. AGRONOMIC PRACTICES

A wide range of agronomic practices falls under the heading of new technology and can have either a stabilizing or destabilizing effect on yields. This will depend upon the particular mix of practices which at any one location and at any given time makes up the package of new technology. In a general

TABLE 4

Yield variability from trend for three countries in East Asia, 1955-56 to 1976-77.

	Percent Area Irrigated 1973-75	R^2	Mean (t/ha)	Standard Error (t/ha)	Coefficient of Variation (%)
Japan	96	0.78	5.12	0.23	4.6
S. Korea	92	0.82	4.40	0.35	7.9
Taiwan	-	0.86	3.90	0.20	5.1

a/ based on exponential instead of linear trend.

sense those practices which demand more of the crop's environment will tend to make yields less stable while those practices which add to the environment's capacity to support a crop will add to stability. However, the issue is more complex. As in the case of irrigation initially stabilizing activities may encourage subsequent practices that introduce instability. For example, in the Pacific Northwest of the United States in the early 1940s a new method of handling soil was introduced. The result was a notable increase in wheat yields and an initial reduction in variability, but this made it possible to increase the level of fertilizer and other modern inputs. The recent introduction of modern varieties in many of the developing nations had also resulted in an increased use of fertilizer and modern inputs, and it is therefore important to examine the effect of this on yield stability.

A note of caution is warranted at this point concerning the use of the standard deviation to measure yield variability. Day (1965) and subsequently Roumasset (see Barker, Cordova, and Roumasset, 1976) using experiment station data demonstrated that field crop yield distributions are in general nonnormal and nonlognormal. The degree of skewness and kurtosis depends on the specific crop and the amount of fertilizer applied. However, there seems to be a tendency for the skewness to be more positive (median yield below mean yield) at low levels of fertilizer input and more negative (median yield above mean yield) at high levels of input. Thus, the increase in standard deviation due to the higher level of input may overstate the increase in risk involved. In this section we have included in our analysis the standard skewness coefficient, $\sqrt{\beta} = \mu_3/\mu_2^{3/2}$ where μ_2 and μ_3 are the second and third population moments about the mean.

In the Puebla Project in Mexico farmers were told that to obtain higher yields they should increase the number of plants per hectare (from roughly 30,000 to 50,000) and at the same time increase the application of fertilizer (from 30 kg N/ha to 120 kg N/ha and from essentially no P_2O_5 to 40 kg P_2O_5/ha). Data from experiments conducted in farmers fields between 1971 and 1974 show that this recommendation would increase the absolute variability in yields even though the coefficient of variation is lowered (Table 5). But as the

yield level increases with the application of technology, our results confirm the earlier findings of Day and Roumasset that the skewness changes from positive to negative (Fig. 2a and 2b). Not only are yields higher, but the probability of being below the average yield is much lower. This could place the farmer in a more favorable risk situation depending on costs. National food security models based on mean yields should tend to over-predict yields for countries or regions with low use of modern technology and under-predict yields for the very advanced regions.

In the case of rice, we examined the data from a survey of villages conducted in 1971-72 (International Rice Research Institute, 1975). Out of a total of thirty-six villages, twenty-nine were irrigated and grew two crops of rice, although there was considerable variability among villages in the quality of irrigation. The fifty-eight total observations were classified into "low" and "high" based on yield level, the standard deviation and coefficient of variation and skewness computed for each of the village observations and averaged for the two groups. The corresponding average NPK input was also calculated. The results are similar to those found for corn at Plan Puebla in Mexico. The standard deviation increased with high yields and input levels but the coefficient of variation declined. The degree of skewness is highly variable among villages, but those villages with low yield and low level of fertilizer input show a strong positive skewness in yield distribution while those villages with high yield and high level of fertilizer input have an almost normal yield distribution. The pattern of change is consistent with previous findings. In the high technology villages it is reasonable to expect that the level of technology is not as high as that recorded under experimental conditions. On average, skewness remains slightly positive although ten out of twenty-nine observations showed negative skewness.

We also examined the relative stability of yields between wet and dry season. The Indian government is now emphasizing in its development plans for the expansion of the dry season cropped area, not only to raise production, but also ostensibly to increase yield stability. Our results suggest that this strategy will not increase yield stability.3/

The difference in risk preference among farmers and among countries should be emphasized. If we conceptualize the curve depicting the trade off between high yield and low variance, the familiar E-V frontier, countries will almost certainly prefer to operate at different points on the frontier. Most important, of course, is the frequency and magnitude of severe crop losses.

Higher levels of yield and fertilizer input enhance the potential loss due to insect and disease damage. This problem seems to be particularly acute in the tropics and in monoculture areas. In the rice farming survey referred to earlier (Table 6) farmers considered diseases, insects, and pests to be the

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3/ D. Gale Johnson called to our attention that this statement is predicated on the assumption that wet and dry season yields are correlated. In years of heavy flood, low wet season yields are offset by higher than normal dry season yields. But the most serious cause of yield loss is due to drought and under these circumstances wet and dry season yields are highly correlated.

TABLE 5

Corn yield and variability of yield at high and low input levels, 41 experimental observations in farmers fields, Plan Puebla, 1971-74.

Input Land	N (kg/ha)	P (kg/ha)	Density (plants/ha)	Mean Yield (t/ha)	Standard Deviation (t/ha)	Coefficient of Variation (%)	Skewness $\sqrt{b_1}$
Low	0-50	0-25	20-35,000	1.68	.92	54.8	.76
High	90-150	30-70	40-55,000	3.17	1.17	36.9	-.71

FIGURE 2a. DISTRIBUTION OF YIELDS AT HIGH LEVEL OF TECHNOLOGY, 41 EXPERIMENTAL OBSERVATIONS ON FARMERS FIELDS, PLAN PUEBLA, 1971-74

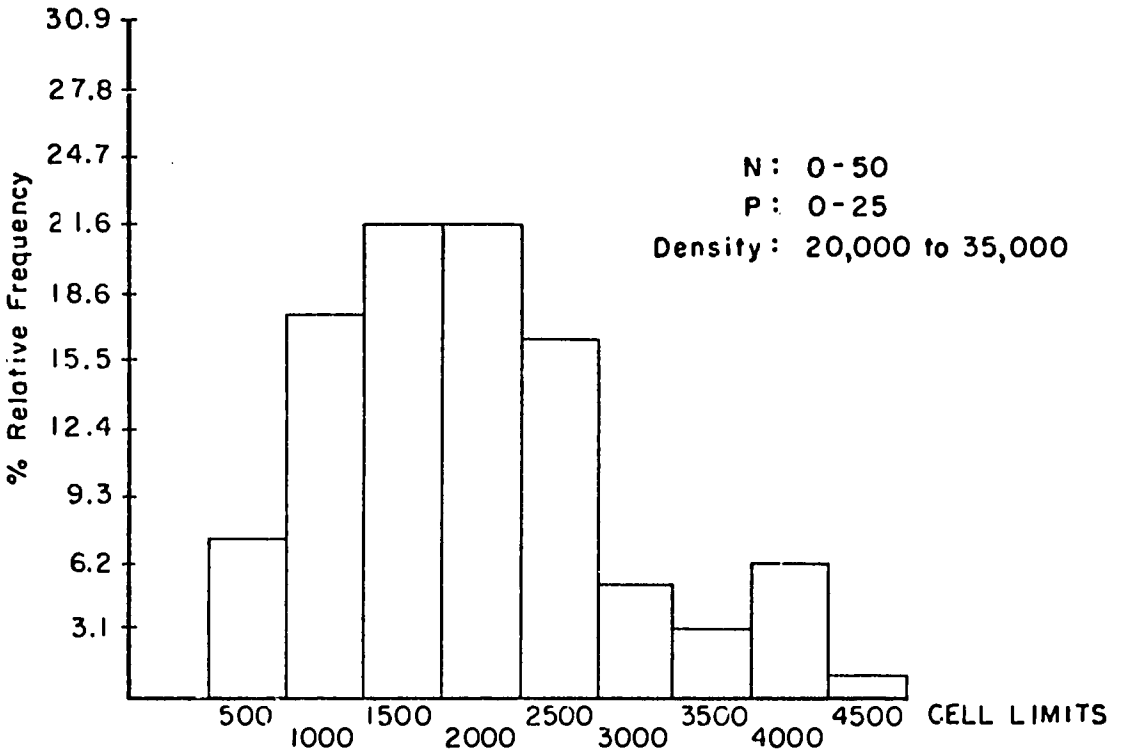
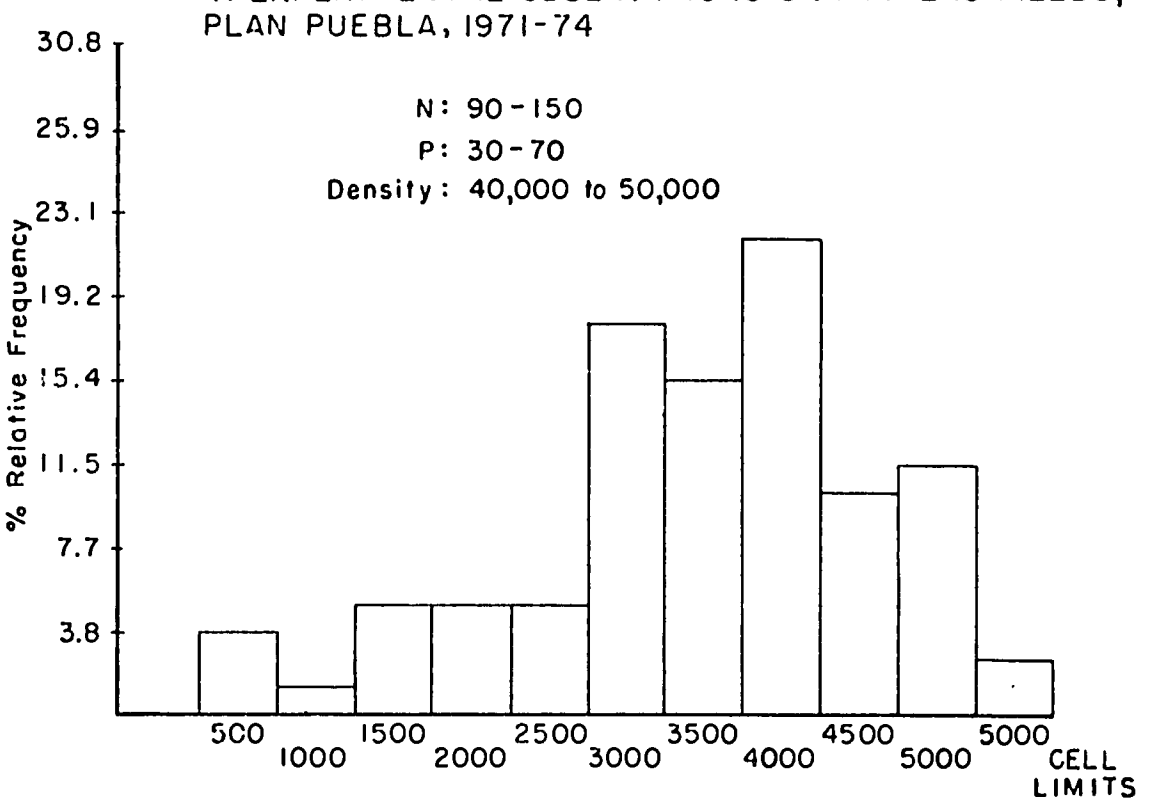


FIGURE 2b. DISTRIBUTION OF YIELDS AT HIGH LEVEL OF TECHNOLOGY, 41 EXPERIMENTAL OBSERVATIONS ON FARMERS FIELDS, PLAN PUEBLA, 1971-74



most important constraint to higher yield (International Rice Research Institute, 1975, p. 23). There have been several serious incidents of loss due to insect and disease damage following the introduction of modern varieties. For example, in Central Luzon, Philippines yields in 1971-72 declined by about thirty percent from the previous two year average due principally to tungro virus damage. In Indonesia rice crop loss due to brown planthopper in 1976 was estimated to exceed one million metric tons or four percent of the total crop.

TABLE 6

Rice yield and variability of yield at high and low yield levels and for wet and dry season observations, survey data average of 29 Asian villages, 1971-72.

	NPK (kg/ha)	Mean Yield (t/ha)	Standard Deviation (t/ha)	Coefficient of Variation (%)	Skewness $\sqrt{b_1}$
	Yield Level[a/]				
Low	45	2.14	0.99	46.3	0.95
High	148	4.89	1.33	27.2	0.22
	Season				
Wet	87	3.36	1.13	35.7	0.79
Dry	111	3.67	1.19	32.4	0.38

a/ 58 observations for wet and dry season were divided at the median based on yield.

Use of insecticides has increased rapidly with the introduction of modern varieties, but for rice there is little evidence to suggest that the farmers' levels and methods of application have been very effective. The higher recommended level of insecticides may be more effective in controlling insects, but the additional costs frequently outweigh the additional benefits (International Rice Research Institute, 1977, p. 78). With respect to disease, benefit-cost ratios for chemical control tend to be even less favorable. Attempts to reduce yield variability due to insects and diseases must depend fairly heavily on the ability of plant breeders to develop and disseminate resistant varieties.4/

4/ N. Borlaug emphasized the complexity of the problem of integrated pest management, siting some cases where chemical control has been highly effective. Monoculture rice presents one of the most difficult situations with respect to insect and disease control.

VI. PLANT BREEDING

Plant breeders have long been concerned with problems of yield stability. Breeding for resistance to wheat rust was an initial focus of the Rockefeller Foundation wheat program initiated in Mexico in the 1930s since it was recognized that this was an essential first step in raising yields in many areas. The same can be said of downy mildew in corn and of rice blast disease, both of which have received the attention of breeders and pathologists over a considerable period of time. Attention was focused on high yield with the initial success of the fertilizer responsive wheat and rice varieties, but the introduction of the new varieties brought new problems for the breeder with respect to crop protection. As already noted in the previous section, the increased input of fertilizer and more vigorous plant growth seems to have increased the incidence of severe insect and disease attack. But of equal concern is the problem of yield stability in the less favorable environments where the new varieties have made little headway. For example, in a recent survey of the predominantly rainfed rice growing areas of Eastern India, a joint Indian Council of Agricultural Research - International Rice Research Institute team recommended as follows (see Swaminathan, 1977, p. 12):

> Since the performance and profit of existing high-yielding varieties with costly inputs are uncertain, scientists should develop a technology which combines good yield with reliability and security of profit to farmers. In other words, we need a <u>high yielding and high stability technology</u>, if small and marginal farmers are to be helped to take such a technology.

Developing varieties with greater yield stability involves a two step process. The first step is to identify and incorporate genes into the plant which will give greater resistance to insects and diseases or tolerance to adverse environments. The second step is to screen new lines and varieties to test their relative stability. With respect to this latter process, Evenson et. al. (1978, p. 4) observe that there is considerable confusion in the recent literature with the concepts of stability and adaptability. <u>Stability</u>, as we have used it in this paper, refers to the performance of a genotype with respect to changing environmental factors over time within a given location. <u>Adaptability</u> refers to the performance of a genotype with respect to environmental factors that change across locations.

There has been a presumption in much of the literature that adaptability and stability are highly correlated, but Evenson et. al. (1978, pp. 12-17) present evidence to suggest that this might not be the case. This evidence is important for crop improvement strategies. The breeder can achieve greater stability usually by sacrificing other traits. Thus, in breeding for stability it becomes important to specify the environment and to identify the trade offs between stability and other traits in order to establish priorities in the breeding objectives. In the remainder of this section we will describe some of the lines of investigation being explored which offer promise for improving yield stability in the coming decade.

Three diseases are important to maize in various parts of the developing world -- streak virus in Africa, downy mildew in Southeast Asia, and stunt in tropical South America. Progress is being made in developing more resisting varieties for these areas. Beyond that, careful attention is being given to breeding strategies aimed at varieties with a greater capacity to accommodate moisture stress. The efforts here, for the most part, are multi-national, involving several national programs and some international efforts.

Wheat has its ever-present problem with rusts as mutating pathogens insure that first one variety then another falls to this set of diseases. Several strategies are being followed to gain an advantage over the pathogens. The first involves classical breeding techniques and seeks to develop ever wider resistance to the disease through the incorporation of many different sources of resistance accompanied by multi-location testing.

But new avenues are being explored which offer great promise of reducing the impact of the rusts. The first of these, an old idea recently reintroduced, is the development of multi-lines. Each multi-line variety combines several lines of wheat which have many virtually identical characteristics -- e.g. maturity, height, grain type -- but different sources of resistance to rust. The idea is that with several such "iso-genic" lines a newly emerged family of rust might find one, perhaps even two, of the lines a propitious place for multiplication but it is unlikely that all of the lines will succumb to any given set of mutants. Moreover, the different lines tend to buffer one another from the spread of rust's spores. One investigation shows that as many as one line in three can be susceptible to a particular family of rust and yields suffer only slightly as the resistant lines buffer the susceptible ones from the encroachment of the disease. Several countries are pursuing the multi-line idea. India's wheat improvement program announced the release of three such varieties in 1978.

A second approach to the problem of disease in small grain is exemplified by what is called "slow rusting." Here, the breeder seeks to develop varieties which, when attacked by a family of rust to which they are not resistant, succumb to the rust very slowly, so slowly that the plant's capacity to produce grain is little impaired. This contrasts with the classical strategy of seeking complete resistance.

Spring wheat scientists (and most of the developing world's wheat is spring wheat) hope to find varieties which show greater capacity to accommodate moisture stress. Their hope is based on the early results of crossing spring wheats with winter wheats. Some of these crosses already examined show remarkable hardiness, supporting the belief that this breeding strategy can be exploited for a variety of characteristics not usually found in spring wheat.

In rice the most serious problems of recent concern have been tungro virus, transmitted by the green leafhopper and brown planthopper burn. Attempts to control these two pests illustrate the complexity of the problem. Following the serious outbreak of tungro virus in the Philippines efforts to control the disease through plant breeding were intensified. Varieties were developed with resistance to both the insect and disease and a good deal of success has been achieved in forecasting tungro virus outbreaks.

Basically the same strategy was followed in the effort to control the brown planthopper. A 1973 issue of the IRRI Reporter announced that "IR26 is resistant to brown planthopper" (International Rice Research Institute, 1973). Shortly thereafter it was discovered that the brown planthopper had developed several biotypes. The strategy that succeeded in the case of the green planthopper and tungro virus proved ineffective in the case of the brown planthopper. The biotypes of the brown planthopper vary not only in their ability to attack different varieties but in their susceptibility to control by pesticides.

Control methods other than host plant resistance are now being sought including the use of the pesticides and biological control. There is talk of a new breeding strategy including the development of moderately resistant varieties or the development of varieties similar to the multi-lines being developed to combat wheat rust. The objective would not be to eliminate the brown planthopper but to control against epidemic outbreaks. However, achievement of this goal will still be sometime in the future, and for the present varieties continue to be developed with resistance to the various biotypes of brown planthopper.

To add to these problems, a new rice disease, ragged stunt, was discovered in 1977 in both Indonesia and the Philippines and has subsequently been found to be present in several other rice growing areas. Breeding for insect and disease resistance is clearly a never ending task and one of the important "maintance" research costs essential for maintaining yield potential and stability over time. There seems little likelihood through this route that we will achieve any significant increase in stability, although we have yet to witness the impact of multi-line breeding.

Rice breeding for adverse environmental conditions includes the attempt to develop varieties that are drought resistant, flood tolerant, tolerant to adverse soil conditions, and tolerant to low temperatures. The research involves screening of a large volume of materials and making crosses to incorporate these characteristics with other desirable traits such as high yield potential. Perhaps the most important achievement in this area to date has been the development of varieties with short growth durations (90 to 100 days from transplanting to harvest) which in many areas will allow the rice variety to escape drought. There is already evidence that this can lead to a significant increase in yields in the rainfed rice growing areas (Barker and Herdt, 1978). Research of this nature will increase the stability of the rice plant in those areas now regarded as marginal. However, the consequence may be to permit greater crop intensification on existing land, or to allow the spread of the rice crops to areas now thought to be submarginal, resulting in low yields. Therefore, it is difficult to predict the effect of such research on yield stability.

The final decision as to the degree of uncertainty or yield stability that is permissable rests with the farmer who must choose the cropping mix and bear the risk. Much has been written to suggest that small and marginal farmers in the developing countries are risk averse, but the evidence on this point is far from clear. For example, the government of India has been attempting, without visible success, to convince farmers in Eastern India to switch from rice to millets in the drought prone upland areas. For any given crop there must be some limit to the degree of instability that farmers in a

given location are willing to tolerate. This probably is higher for preferred staples such as rice, wheat, and corn than for other crops.

VII. POLICY IMPLICATIONS

Economists have frequently been able to measure the impact of various policies on the adoption of new technology and growth in food production. However, our understanding of the impact of technological change on yield variability and hence on policies that might lead to greater yield stability is much less clear. There seems to be an implicit assumption in some circles that the adoption of modern technology will lead to greater yield stability. We have found no evidence to support this contention. On the contrary, our results show a tendency for the absolute variability to increase even though relative variability may in some cases remain unchanged or even decline. These results confirm the earlier findings of Mann (1977) for wheat in Turkey.

The belief that variability will decline is perhaps related to the fact that several components of the modern technology are ostensibly yield stabilizing. For example, plant and land ameliorating activities, including breeding for insect and disease resistance and tolerance to adverse environments, and irrigation expansion, taken independently should be yield stabilizing. But these changes have the effect of raising the marginal productivity of recurrent inputs such as fertilizer. Hence, stabilizing technology is almost invariably accompanied by destabilizing technology and on balance absolute variability in yield tends to increase.

However, there is consistant evidence to show that as new technology is introduced the skewness in yield distribution shifts from strongly positive toward negative, perhaps creating a more favorable risk environment. It would be useful to improve our understanding of the nature of the yield distribution around the trend. Does the distribution change with an increase in the level of technology, and if so, how? It almost goes without saying that a country would accept instability on the high side if they didn't have to worry about instability on the low. The use of modern inputs to raise yield levels will intensify in the developing countries in the years ahead. The fact that yield variability is likely to increase should not act as a deterent to the use of modern inputs, but does suggest the need for precautionary measures to insure food security. In order to minimize the inherent instability associated with new technology, it will be necessary to increase the investment in maintenance research. This is to say, unless the new multi-line strategy of breeding proves highly effective, we will need to intensify our efforts to develop insect and disease resistant varieties in order to realize the yield potential of the new varieties. Because of the sharply rising costs of irrigation development, it also will pay to increase the level of research investment in activities designed to develop varieties tolerant to adverse enviroments.

In addition to the measures outlined above, there are other policies and programs, such as the development of transportation, storage facilities, and buffer stocks, which can reduce the problems resulting from yield variability. These are the subjects of other papers at this conference. However, it is important to recognize that the introduction of new technology in the absence of appropriate policies and programs can aggravate the food security problem. The recent fertilizer crisis is an excellent example. Anticipating a severe shortage, many developing countries imported large quantities of fertilizer in 1974 driving fertilizer prices to unrealistically high levels. The direct cost to these governments for fertilizer imports as well as the indirect cost in terms of higher fertilizer prices and lower farm production has been very substantial.5/

In summary, we believe that crop losses of the magnitude experienced during the unfavorable weather years of 1965 and 1972 can occur again. In fact, according to some weather experts, increased sun spot activity will lead to greater instability in weather conditions in the decade ahead. Advances in the use of modern technology not withstanding, year-to-year variability in grain yields could increase, and planning for food security could be even more difficult in the future than it has been in the past.

5/ In this same context, D.A. Khan; in his discussion of our paper, points to the adverse effect on yields of the inadequate fertilizer procurement and distribution program in Pakistan.

Appendix Table 1. Comparison of standard error of regression and coefficient of variation fitting a linear trend and then yield lagged one year as dependent variables, selected locations in Asia, 1955-77.

	N	R^2	Mean	Standard Error of Regression	Coefficient of Variation
Bangladesh (1955-77)					
Trend	23	.56	1.637	.1055	.0644
Lag yld.	22	.36	1.656	.1081	.0653
Burma (1955-77)					
Trend	23	.46	1.602	.1118	.0698
Lag yld.	22	.20	1.611	.1327	.0824
India					
All India (1955-77)					
Trend	23	.61	1.549	.1089	.0703
Lag yld.	22	.30	1.557	.1456	.0935
Andra Pradesh (1960-76)					
Trend	17	.65	2.102	.1370	.0652
Lag yld.	16	.39	2.115	.1800	.0851
Bihar (1960-76)					
Trend	17	.03	1.258	.2178	.1731
Lag yld.	16	0	1.257	.2292	.1824
Orissa (1960-76)					
Trend	17	.08	1.345	.1574	.1170
Lag yld.	16	.04	1.338	.1644	.1229
Tamil Nadu (1960-76)					
Trend	17	.68	2.558	.2175	.0850
Lag yld.	16	.48	2.578	.2787	.1081
(1960-68)					
Trend	9	.26	2.264	.0446	.0197
Lag yld.	8	.04	2.269	.0522	.0230
(1968-76)					
Trend-T	9	.48	2.822	.2524	.0894
Lag yld.	8	.01	2.888	.3009	.1042

Appendix Table 1. (con't)

	N	R^2	Mean	Standard Error of Regression	Coefficient of Variation
Uttar Pradesh (1960-76)					
Trend	17	.25	1.128	.1558	.1382
Lag yld.	16	.24	1.129	.1630	.1444
West Bengal (1960-76)					
Trend	17	.15	1.744	.1380	.0791
Lag yld.	16	.11	1.743	.1466	.0841
Indonesia (1955-77)					
Trend	23	.87	2.065	.1520	.0736
Lag yld.	22	.94	2.083	.1039	.0499
(1955-67)					
Trend	13	.69	1.736	.0302	.0174
Lag yld.	12	.65	1.741	.0318	.0182
(1967-77)					
Trend-T	11	.89	2.428	.1037	.0427
Lag yld.	10	.84	2.494	.0873	.0350
Malaysia (1955-77)					
Trend	23	.85	2.569	.1291	.0503
Lag yld.	22	.75	2.598	.1532	.0590
Nepal (1955-77)					
Trend	23	.52	1.884	.1034	.0549
Lag yld.	22	.29	1.887	.1273	.0674
Pakistan (1955-77)					
Trend	23	.86	1.753	.1782	.1017
Lag yld.	22	.93	1.773	.1254	.0707
(1955-66)					
Trend	12	.70	1.352	.0486	.0360
Lag yld.	11	.50	1.356	.0648	.0478
(1966-77)					
Trend	12	.85	2.129	.1234	.0580
Lag yld.	11	.77	2.190	.1182	.0539
Philippines (1955-77)					
Trend	23	.83	1.401	.1055	.0753
Lag yld.	22	.79	1.410	.1192	.0845
(1955-68)					
Trend	14	.66	1.224	.0594	.0486
Lag yld.	13	.56	1.227	.0711	.0579

Appendix Table 1. (con't)

	N	R^2	Mean	Standard Error of Regression	Coefficient of Variation
Philippines (con't)					
(1968-77)					
Trend-T	10	.39	1.642	.1451	.0884
Lag yld.	9	.18	1.676	.1423	.0849
Sri Lanka					
(1955-77)					
Trend	23	.85	1.878	.1535	.0817
Lag yld.	22	.87	1.898	.1458	.0768
(1955-66)					
Trend	12	.47	1.541	.0861	.0559
Lag yld.	11	.45	1.551	.0876	.0565
(1966-77)					
Trend-T	12	.85	2.188	.1104	.0504
Lag yld.	11	.58	2.245	.1324	.0590
Thailand					
(1955-77)					
Trend	23	.16	1.803	.1294	.0718
Lag yld.	22	.69	1.810	.1002	.0554

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