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SUMMARY PROCEEDINGS OF A WORKSHOP ON CEREAL YIELD VARIABILITY

edited by
Peter B. R. Hazell

International Food Policy Research Institute (IFPRI)
Deutsche Stiftung für Internationale Entwicklung (DSE)

Summary Proceedings of a Workshop on Cereal Yield Variability

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Foreword

John W. Mellor and Erhard Krüsken

Many countries have achieved impressive rates of growth in national foodgrain production in recent years. Much of this growth can be attributed to new technologies and the increased use of modern inputs, such as fertilizers. At the same time, the variability of world foodgrain production around trend also increased as measured by the variance or the coefficient of variation of production. This increased variability is reflected in increased market and price instability, which poses difficult problems for farmers and poor consumers alike. It also increases the size of emergency food stocks that need to be carried by governments to ensure that consumption does not fall precipitously below trend.

Research by the International Food Policy Research Institute (IFPRI) on countries and crops shows that in most cases increases in yield variability and, more importantly, a loss in offsetting patterns of variation (increased correlations) in crop yields between regions are the predominant sources of the increase in production variability.

There has been a tendency by some researchers to attribute this increased yield variability to improved seed/fertilizer based technologies. Some researchers have also argued that plant breeders should focus less on maximizing average yields and more on reducing yield sensitivity to environmental stress. Such recommendations may prove costly for future growth in foodgrain production, and they cannot be warranted before more thorough and quantitative studies of the sources of increased variability have been undertaken.

In view of the importance of this issue to national breeding programs and to the international agricultural research centers, the Deutsche Stiftung für Internationale Entwicklung (DSE) and IFPRI convened an interdisciplinary workshop for an intensive four-day discussion of a broad range of issues associated with increasing yield variability. There were about 60 participants, comprising biologists, social scientists, and policy makers, and with particularly strong representation from the centers of the Consultative Group on International Agricultural Research (CGIAR).

Workshop participants discussed the relationship between changes in yield variability and yield correlations and such causal factors as changes in agricultural technology, weather, irrigation, input availability, and related variables. They also discussed the consequences of increasing yield variability, including its effect on different types of farmers and on poor urban and rural consumers.

Participants were asked to make specific recommendations for agricultural research policy in the fields of plant breeding, farming systems, and management of irrigation, fertilizers, and pesticides, and to address the need for changes in national and international agricultural policies.

This volume summarizes the workshop discussions and includes an assessment of findings prepared by a review panel chaired by Lloyd T. Evans. It also contains summaries and abstracts of thirty-five papers prepared specifically for the workshop. Selected papers from the workshop plus papers commissioned to fill important gaps will subsequently be published as a separate book by IFPRI and DSE. It is our hope that these proceedings will stimulate debate and further research on the important topic of yield variability and that it will lead to improved policies and agricultural research priorities for coping with yield risks in the future.

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Erhard Krüsken
(DSE)

Acknowledgments

The publication of these Proceedings marks the end of a three-year planning and organizational effort by me and Klaus Klennert. I am greatly indebted to Klaus for his dedicated support, and to all those who helped us in our planning task. We are especially grateful to Randolph Barker, G. Fischbeck, John W. Mellor, H. Schmutterer, Joachim von Braun, Ulrich von Poschinger-Camphausen, Winfried von Urff, Thomas S. Walker, Trevor Williams, and Donald Winkelmann, who served at various times on a planning advisory committee.

The success of the workshop owes much to the thorough administrative arrangements made by the staff of DSE's Food an Agriculture Development Center in Feldafing, where the meetings were held. Special thanks go to Erhard Krüsken, Klaus Klennert, and Mrs. Dörre for arranging the workshop, and to George Bauer and Uwe Krappitz who provided valuable assistance with visual aids.

Preparation for this volume is possible only because of the efforts of the many participants who wrote down their comments and reported on working group sessions. Lloyd T. Evans chaired a review panel and performed the miraculous task of synthesizing the findings and recommendations of the workshop in a cohesive statement. Finally, financial support provided by the Ministry for Economic Cooperation of the Federal Republic of Germany is gratefully acknowledged.

Peter B. R. Hazell

1

Yield Variability in Cereals: Concluding Assessment*

Lloyd T. Evans

My experience has been more with the instability of data than with data on instability. Variability in cereal yields and production constitutes an important problem in relation to world agriculture and food supplies, even if it turns out that there is no clear evidence that the relative variability has been changed by modern varieties and agronomic practices. Whatever the causes of the variability, research on them should lead to more effective national and international management.

Several earlier analyses of the problem (for example, Mehra 1981; Barker et al. 1981) suggest that some aspects of the new agricultural technology resulted in greater variability in yield, but Hazell's subsequent work (1982, 1985) shows that the increased variability in world cereal production is due not only to greater yield variability but also to a reduction in the offsetting patterns of variation in yields between crops and regions. It is timely, therefore, that IFPRI and DSE have provided this opportunity for a comprehensive consideration of the issues, and with a particular focus on cereal yields. Feast or famine in many parts of the world depends on cereal yields, and their variation has been the subject of a range of analyses (for example, Thompson 1969, 1975; Luttrell and Gilbert 1976; Stanhill 1976; Church and Austin 1983; Gales 1983).

The answer that emerges from this workshop is complex, varying by crop, by country, and by stage of technological change, but what is clear is that, whereas in many cases there has not been an increase in the coefficient of variation for production with the new technology, there has nevertheless been an increase in covariance across regions, countries, and crops. In fact some of the practices that decrease variance at the farm level may increase covariance at the regional level.

Hazell's analysis for this workshop suggests that the probability of a 5 percent shortfall in total cereal production may have doubled in recent years. Even though the effect of such shortfalls on per capita consumption may be buffered (Sahn and von Braun, Chapter 6), this increased probability constitutes a major problem in need of further research. At this stage of the analysis, however, the "green revolution" should not be blamed for the problem, a

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*The panel consisted of Jock R. Anderson, Nazmi Demir, Lloyd T. Evans (chairman), G. Fischbeck, Eduardo Venezian, and Donald Winkelmann.

conclusion supported by the fact that the coefficients of variation for world production of both wheat and rice, the flag bearers of the green revolution, have in fact decreased (Hazell, Chapter 2).

SOME METHODOLOGICAL PROBLEMS

Before we dissect the anatomy of cereal production and yield variability, some methodological problems should be mentioned.

In general, as production and yield levels rise, we should expect the absolute variance also to rise, more or less in proportion. For some issues, such as the management of surpluses and international trade and their effects on prices, it is the absolute variance that poses the problem and provides the relevant measure. But for comparisons between crops, varieties, countries, environments, and levels of input, it is the size of the variance relative to yield or production -- the coefficient of variation (cv) -- that is most useful. However, even the cv of the many cvs presented at the workshop would be high! The answers we get may also depend on how the variances are estimated, whether in relation to trends or expectations, whether by farmers or government, and whether detrended or pooled (Bindlish et al., Workshop Paper 3).

The point should also be made, as it was by Jock Anderson, that instability and risk are not the same thing, and that real risks may not be related directly to variance. A random variable of interest to a decision maker at the policy or farm level can increase in both variance and cv and yet be less risky than the previous situation. But the judgement of such changing riskiness depends on more comprehensive comparisons of distribution functions and on assumptions about utility preferences. The price of relevance may therefore be a more comprehensive estimation of the uncertainties involved.

There are also major problems estimating variances before and after the technological change or, more correctly, during the earlier and later phases of such change. Given the extent of climatic variability and its impact on cereal yields, consecutive periods of 10 to 15 years are barely enough to yield reliable evidence of trends. Yet longer posttechnology periods are often not available. The choice of boundary years can affect conclusions (compare Anderson and Findlay, Workshop Paper 1), and the basis and reliability of much of the statistical data can itself change in the course of the two periods.

But beyond these problems there is the need to supplement the statistical data with local knowledge and assessments -- to read the newspapers, as Randy Barker put it -- in order to know "when a new irrigation scheme came on stream; or what year the pumps failed; or when fertilizers were scarce; or when moth and rust corrupted; or when extensive marginal areas came in or out of production; or when crop locations changed."

With such complications in mind, there was no general agreement with the proposition that the cv of cereal production had been increased by the new technology (or the green revolution). Nor is there clear evidence that, in aggregate, variability in cereal consumption per capita had increased (Sahn and von Braun, Chapter 6).

CLIMATIC CHANGE

A major source of yield variance in all cases, but especially in cereals grown in more arid areas, is the variability in crop weather. Carter and Parry (Chapter 3) conclude, however, that there is no indication that recent changes in cereal yield variability can be ascribed to climatic change.

Interannual variations -- such as those associated with the El Niño/Southern Oscillation phenomenon or with the sub-Saharan droughts of 1972, 1977, and 1983/84 -- have certainly influenced global cereal production and variability. But for changes in variance and covariance in recent years it is necessary to look elsewhere for the causal factors, even though long-term climatic changes associated with rising atmospheric carbon dioxide levels are likely to have important implications for cereal production in the future.

THE INTERACTION OF GENETIC AND AGRONOMIC IMPROVEMENT

In the few cases in which the relative contributions of genetic and agronomic improvement to yield increase have been estimated, plant breeding and agronomy have contributed about equally overall, although the proportions differ with the stage of advance (Evans 1984).

Varietal improvement often acts as the catalyst beginning the process, the Trojan horse for the new technology, but both genetic and agronomic improvement are needed for sustained increases in yield.

SOME CHARACTERISTICS OF GENETIC IMPROVEMENT

Adaptability. Shortening the life cycle of cereal crops and reducing their sensitivity to seasonal signals, such as day length, allow crops to perform more evenly across a range of sites, latitudes, and climates, thereby increasing their adaptability. So too does wider tolerance of soil conditions.

Hardiness. Another important characteristic is the ability of cereal varieties to withstand drought, cold, heat, and other climatic insults, especially at the most sensitive stages of the life cycle. Such hardiness is sometimes highly specific, sometimes general. Specific resistance to extremes of heat or cold has been improved in many crops -- for example, rice and millet in Japan to cold -- and although the changes may seem small in a physiological sense, they may be of considerable significance in reducing downside variability. Hybrids may exhibit a more general hardiness in that, although they may be no more productive than inbreds under optimal conditions, they may perform substantially better than their parents at both high and low temperatures (McWilliam and Griffing 1965; McWilliam et al. 1969).

Reduced Vulnerability. The incorporation in cereal varieties of genetic resistance -- wide or narrow -- to the current biotypes of

pests and diseases is a major preoccupation of plant breeders and a major contribution toward yield stability. In general, reduced vulnerability has been easier to achieve than resistance to climatic stresses.

Responsiveness. Another desirable characteristic is the ability of a variety to give a return of greater yield or improved quality on favorable conditions or higher inputs.

Competitiveness. Competitiveness is desirable especially in marginal environments or where weed problems are serious.

All of these genetic improvements can influence the variability of yield (responsiveness especially on the upside, hardiness and reduced vulnerability on the downside). However, they are not always compatible with one another, and trade-offs between them must be decided by the plant breeder -- for example, between hardiness and responsiveness or, especially in the case of tall versus dwarf selections, between competitiveness and responsiveness.

STABILITY

Another characteristic more talked of than understood is stability. In the ecological literature, stability is a quite complex concept, implying not that the plant community is unmoving but rather that its response to change is muted by negative feedback reactions and that it tends to return to its former equilibrium after disturbance (Rindos 1984). The conventional wisdom is that complexity begets stability, but in fact complex communities such as rain forests can be quite fragile, while monocultures such as crops can be quite stable.

Plant breeders' usage of the term and their ways of estimating stability are so varied, it is difficult to know what they mean by it. In general, but by no means always, they mean stability of performance across years at a particular site, a matter of real concern to farmers and policy makers. All the characteristics mentioned previously, except responsiveness, contribute positively to such stability.

Stability came into fashion among plant breeders with the widespread use of the method of analysis used by Yates and Cochran (1938), Finlay and Wilkinson (1963), and Eberhart and Russell (1966). Their method is a convenient and seductive way of presenting multi-location, multivariety trial results of global plant breeding programs.

But this form of analysis can be misleading (especially when only the regressions and not the data points are presented); it can obscure valuable site-specific adaptation; it is too open to the selective presentation of data; it does not tell us how to deal with trade-offs among mean yield, regression slope, and the variance from that; and it tends to be rather unhelpful at the low mean-yield sites characteristic of on-farm conditions, especially in developing countries. The regression (or b value) is not a fixed varietal characteristic, as Peterson et al. (Workshop Paper 22) show for Kharkov wheat, where it has fallen progressively over the years

(presumably because it is estimated in relation to the average for all the varieties in the trial and because the responsiveness of the new entries has risen over the years).

It is clearly time to explore other forms of data assessment, such as multivariate and cluster analysis and stochastic dominance (compare Witcombe, Workshop Paper 35), which could overcome these failings. We hope the international agricultural research centers will give more attention to these in the future. In the meantime, however, there are three points to make in the context of the usual form of analysis.

Breeding for Responsiveness

Ignoring for the moment the problems of crossovers in varietal performance at the poorer sites and the need to minimize vulnerability to pests and diseases, the major element of yield improvement is increased responsiveness -- that is, the ability to reward favorable sites or years and high inputs with progressively higher yields per crop, or per day in the tropics.

Inevitably, such emphasis will accentuate the upside variability problems, but it would be unrealistic to expect plant breeders to place a moratorium on such improvements or to expect farmers not to take advantage of them. Indeed, improvements should be welcomed as enlarging the overall potential food supply, whatever management problems they may create.

Breeding for Marginal Conditions

There is less agreement about breeding for the most marginal, lowest yield sites. Varietal improvement under these conditions is difficult and will be slower, less certain, and more costly in terms of plant breeding effort. But it can be achieved, as examples for most cereals indicate. Improved tolerance to drought and heat stresses (U.S. maize hybrids), greater tolerance of adverse soil conditions (IRRI rice), more efficient performance in low-nutrient conditions (Mahsuri rice), greater resistance to Striga or downy mildew, and many other characteristics have already improved cereal performance under poor conditions. Even a small improvement may substantially affect adoption (finger millet in India).

Yet various factors tend to discourage plant breeding for poor environments. Gains are not spectacular and may be seen as having little effect on the variability of cereal production. Many farm conditions may be even poorer than the poorest experimental test sites, and their conditions may also be inherently more variable and diverse, leading to greater site specificity. Government policies for varietal testing and release may discourage such work, as may policies restricting the allocation of fertilizers to such areas.

We recommend, therefore, that the IARCs give more attention to this complex of problems and recognize that such work may require fuller analysis of on-farm constraints in these areas and that agronomic improvements may be a necessary prelude to genetic improvement.

Crossovers in Performance

For many CIMMYT wheat varieties (Pfeiffer and Braun, Workshop Paper 23) and U.S. maize hybrids (Duvick, Workshop Paper 5), superiority in favorable conditions appears to be associated with superiority (or at least not inferiority) at the poorest test sites. But there are also cases where a clear crossover in relative performance occurs, as may be seen in the original analysis of barley varieties by Finlay and Wilkinson (1963), which particularly reflects cultivar differences in length of life cycle vis-à-vis length of the growing season. Walker and Witcombe's data for pearl millet (Workshop Paper 35) provide another significant example, as does that extracted from CIMMYT yield trials by Laing and Fischer (1977). Thus it could be well worthwhile to select varieties that are superior only under poor conditions. Most plant breeders feel that such efforts would not make best use of their time, but more breeding work dedicated to such objectives could be justified.

GENETIC VULNERABILITY

The extent to which the genetic base of modern cereal varieties and hybrids influences the downside risks is difficult to assess. Outbreaks of pests and diseases have had an effect, sometimes disastrous, throughout recorded history. Problems still occur -- for example, with downy mildew on millet in India (compare Walker and Witcombe, Chapter 16) -- but major disasters, like the earlier stem rust epidemics in North American wheat crops, have been contained in recent years. Southern corn leaf blight on T-cytoplasm maize hybrids was pandemic in 1970, but within a year the genetic base was changed enough to deal with the pathogen. Other problems loom as possible threats, such as the lack of resistance in IR-36 rice to brown plant hopper biotype 2, and in some CIMMYT varieties to leaf rust, or the widespread cytoplasmic uniformity of IRRI rices (Coffman and Hargrove, Workshop Paper 5), but replacement varieties are already in reserve. Breeding for pest and disease resistance is now so sophisticated that rapid turnover of varieties in time substitutes for many traditional varieties used at one time.

However, the fact that several wheat and rice varieties, such as Bezostaia wheat in Eastern Europe and IR-36 rice in Asia, are grown on more than 10 million hectares inevitably means that their sudden failure would raise the covariance in yield, as could their similar response to weather conditions common to a large region. This element of covariance may, however, decline in the future as plant breeding -- whether public, private, or in the IARCs -- evolves toward greater emphasis on regional and local adaptation.

Three other points should be made. First, the breadth of the genetic base is not simply proportional to the number of varieties in present use: many varieties and hybrids may be closely related. On the other hand, modern varieties often bring together an extremely wide range of genotypes in their ancestry. Second, there is, by and large, no direct trade-off between comprehensive resistance to pests and diseases on the one hand and yield potential on the other, although there may be a trade-off between resistance to climatic

stress and yield potential. Yield advance may, however, be slower when selection for many pest and disease resistances has to be practiced. Third, in some crops (pearl millet, for example) genetic uniformity may be more limiting to the improvement of adaptability and hardiness than to the reduction of vulnerability.

AGRONOMIC INPUTS

Agronomic inputs are as significant as genotype to cereal production and stability, yet they received far less attention at the workshop, where breeders outnumbered agronomists.

In general, it seems likely that variability in yield is exacerbated during the early stages of more widespread and heavier use of a particular input, but then falls as its use becomes uniform and as its rate of application approaches the response asymptote. For example, variability of wheat crops in the Punjab fell as tube well irrigation became more extensive (Mehra 1981), but limited, uneven, and unreliable irrigation of dry season rice crops in the Philippines increased variability (Rosegrant, Workshop Paper 26).

With nitrogenous fertilizer application to wheat and barley, Hanus and Schoop (Workshop Paper 12) found that the yield variance changed little as yields rose in response to heavier applications, so that the cv fell markedly. However, at the heaviest application rates, the variance rose as diseases increased, and it was reduced only by the application of fungicides.

Such interactions between inputs on yield variability deserve more attention, because the development of modern agriculture has involved a sequence of inputs, each of which has successively rescued the yield response from the asymptote for earlier inputs, and the variances to each might interact in a complex way, as Austin and Arnold (Workshop Paper 2) indicate in their binomial model.

Conflicting forces may be at work as agriculture becomes more intensive. Variability tends to fall as agronomic control of the environment becomes more complete, as in the case of wheat in Western Europe and the Punjab. But selection for higher yield is dependent on enhanced agronomic support for the crop, and when this is unreliable the higher yielding varieties may be vulnerable to greater variation. In general, however, there may be considerable scope for the reduction of variability by more flexible, better informed, and more diversified and specific use of inputs.

DIFFERENCES AMONG CROPS

The considerable differences in variability among the major cereal crops, evident in Hazell's overview (Chapter 2), probably reflect differences in growing conditions rather than differences among species.

Intensive irrigation and deep bunding probably account for rice having the lowest cv of all cereals in both periods. Likewise, an increasing proportion of the world's wheat crop is grown under irrigation and with high inputs. At the other end of the scale are the millets, grown in marginal conditions and with low and variable

rainfall. Moreover, there is a tendency in many arid regions for maize to push sorghum and for sorghum to push millet toward the least favorable environments. Likewise, barley may be pushed by wheat into more marginal environments, as Fischbeck (Workshop Paper 7) shows, and this could account for the rise in its cv.

The rise in the variability of maize production is more puzzling. The closer synchronization of maize plantings across the U.S. corn belt, described by Duvick (Workshop Paper 6), may have contributed to the substantial rise in the cv of maize yields in the United States. But the cv of U.S. maize production has not increased, and the greater variability in world maize production in recent years appears to be associated with those countries where maize production is growing rapidly. Another factor contributing to greater variability in some crops may be growing them under both intensive, irrigated conditions and marginal, dry land conditions, the relative proportions of which may change from year to year (as with wheat in several countries).

FARMING SYSTEMS

Research in farming systems also merits more attention, for its holistic approach to the problem of production variability and for its potential in reducing downside variability and risk. Greater diversification of crops, varieties, and practices has been emphasized, but such practices as more flexible operations (like reduced tillage), better fertility maintenance, and better on-farm storage could also reduce variability. Research more clearly targeted on these objectives is needed, particularly in high-risk environments.

COVARIANCE: THE TOGETHERNESS PROBLEM

Even if some doubt remains as to whether increased variance of cereal production and yield is significant, or is applicable only to certain countries and crops, or reflects only a transitional stage, there is clear agreement that increased covariances across crops, regions, and nations merit further analysis. However, there is no agreed notion of how this covariance should be apportioned among weather patterns, input supplies, varietal responses, agronomic practices, irrigation, and price signals.

The increasing synchronization of crop life cycles across countries and regions made possible by better weather forecasting, mechanization, inputs, and varietal homogeneity, as with maize in the United States (Duvick, Workshop Paper 6), may contribute to covariance. But whereas synchronization of the crops in a region may make them all susceptible to extremes of heat or cold or drought at particular stages, it may also spread the risk of losses from birds or rodents, as with rice crops in Asia. And even when irrigation, better information, or availability of inputs help to reduce variation at the farm level, they may increase covariance at the regional level.

Indeed, such covariation is surely to be expected more and more as agriculture becomes better informed, its infrastructure improves,

and it becomes more responsive to opportunities on a global scale. In that context, it seems more effective to focus attention on policies aimed at mitigating the adverse socioeconomic effects of covariation rather than expecting plant breeders and agronomists to solve the problem. While many other aspects of the variability problem merit further research, the highest priority should be given to socioeconomic policy research aimed at reducing the adverse effects of cereal production variability.

POLICY ASPECTS

As farmers become more responsive, as trade grows, and as the probability of shortfalls increase for some countries, variability will increase and policy problems will grow. There is no one optimal solution. Policies will vary with the magnitude of variability, the level of the economy, the extent of urbanization, the amount of poverty, the grain storage capacity, whether a country imports or exports cereals, and so on.

Evidence of changes in the variability of cereal production in the centrally planned economies, especially the U.S.S.R. but also countries such as Egypt and Syria, suggests that central planning does not overcome the problem. However, national policies to assure input supplies (such as improved varieties, fertilizers, and irrigation water), to distribute them more widely, and to stabilize prices should help reduce variability, as would policies encouraging regional and crop diversification. Hazell's (1982) analysis of the covariance problem in India suggests that it could be advantageous to distribute production among crops and states in a more risk-efficient way -- for example, through the distribution of public investment in irrigation or agricultural research -- but such an approach could be inconsistent with other public objectives.

In general, policies to ameliorate the effect of covariances rather than to reduce them seem likely to be more effective. Crop insurance is not effective, nor is consumption credit. But well-managed food-for-work schemes and flexible, well-targeted food subsidies can deal with downside variability in rural and urban areas, respectively. In this context, long-term research on household data, which could indicate how poor families are buffered against production variability, merits sustained support by the CGIAR.

IN SUMMARY

Although variability in cereal yield is largely weather driven, climatic change is not the likely cause of recent changes in variability. And although plant breeding and improved agronomy have probably enhanced upside variability in cereal yields, they may have decreased downside swings. Thus the major components of the problem are the stronger covariances across crops and regions. Genetic and agronomic improvement may have contributed to these, but the main factors are probably better information about weather, crop, and

market prospects, better infrastructure, and a more responsive agricultural sector.

Policies for diversification may reduce the supply side of the problem to some degree, but those to ameliorate the social effects of such variability are likely to be more effective and should be given priority in further research.

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Part I

Overview of Issues

13

2 Introduction

Peter B. R. Hazell

There are two levels of concern about possible increases in the variability of cereal production:

- increased risks for farmers, which may make new technologies less attractive for adoption;
- increased instability in national food production, which acts to destabilize domestic prices, national income, and the food consumption of the poor.

The purposes of the workshop are to establish whether there has been a significant increase in the variability of cereal production in recent years, and, if so, why this has occurred and what, if anything, should be done about it. This chapter has the more modest objective of organizing the major issues and questions in, one hopes, a systematic way. It also has a definitional content, seeking to clarify and relate some of the differing concepts of instability (or stability) that biological and social scientists use in thinking about these issues.

CONCEPTS OF YIELD VARIABILITY

In preparing this workshop, it became apparent early that plant breeders and economists work with very different concepts of yield variability, and this can all too easily lead to misunderstandings and unnecessary disagreements. These differences do not invalidate the approach of either discipline. Rather, they reflect differences in the clientele of breeders and economists and differences in the sources of variability in yield data measured at different levels of aggregation.

Breeders are primarily concerned with providing farmers with high-yielding varieties that also offer acceptable levels of risk. Thus breeders tend to focus on reducing downside yield risks and on selecting varieties that will perform well for farmers over time. Their analyses are based on yield data collected in experimental plots or in farmers' fields.

Economists are more concerned with national food problems, which can be brought on by both high and low yields. Low national yields may result in food shortages or high food prices for the poor, whereas high yields may result in unacceptably low prices for farmers and excessive government-owned food stocks. Both upside and downside risks are therefore important to economists, and they work with

regional or national yield data, which embody much more diverse sources in their variability.

This chapter develops the relationship between sources of variability and the level of aggregation at which yields are measured. It needs to be noted here, though, that there can also be important differences in the type of yield distributions observed at the farm and national levels. Experimental plot and farm yields are often skewed (Day 1965), whereas national yields tend to be more symmetric. This is to be expected, since the latter are a weighted sum of many individual farm yields, and many of these are only weakly correlated. In fact, to the extent that many farm yields are independently distributed, the central limit theorem suggests that national yields could be approximately normally distributed even if farm yields are highly skewed.

When yield distributions are symmetric, then measures of variability that focus only on downside risks give the same results as comparable measures that focus on upside risks. The variance or the coefficient of variation of yields are then satisfactory measures of variability for a wide range of purposes. However, if yield distributions are skewed, then other measures of variability, such as the semivariance, or the probability of yield falling below some specified level, may be more relevant.

VARIABILITY IN WORLD CEREAL PRODUCTION SINCE THE 1960s

Total cereal production for the world (excluding the People's Republic of China) grew at an average yearly rate of 2.7 percent between 1960/61 and 1982/83. The average yield during this period grew by 2.0 percent per year, and the total gross cropped area allocated to cereals grew by 0.7 percent per year.

This growth in aggregate production has been accompanied by a widening band of variability around the trend. An encouraging feature is that each trough in production has been consistently higher than all previous downturns. However, as growth in consumption has kept pace with the growth in production, a more realistic indicator of the trend in world food security is the probability with which aggregate production can fall 5 percent or more below trend. Hazell (1985) has calculated that this probability increased from 3.5 percent in the period 1960/61 to 1970/71 to 6.8 percent in the period 1971/72 to 1982/83.

Table 2.1 shows the changes in the mean and variability of world cereal production by crop between 1960/61 to 1970/71 and 1971/72 to 1982/83. The data were obtained from the U.S. Department of Agriculture and have been detrended through regression analysis (see Hazell 1985). The People's Republic of China is excluded from the analysis because of the poor quality of data available during the 1960s and because of the upheavals of the "Great Leap Forward" and the "Cultural Revolution." Given the importance of China in world cereal production, it would not make sense to measure change in production variability using a base period contaminated in this way. A separate analysis of China is provided by Stone and Zhong, Workshop Paper 28. Between the two periods, total world cereal production increased by 37 percent, or by 305 million tons. Increases in wheat and maize

Table 2.1--Changes in the mean and variability of world cereal production, 1960/61 to 1970/71 and 1971/72 to 1982/83

Cereal	Average Production			Coefficient of Variation of Production			F Ratio		
	1960/61 to 1970/71	1971/72 to 1982/83	Change	1960/61 to 1970/71	1971/72 to 1982/83	Change	Production	Area Sown	Yield
	(1,000 metric tons)			(percent)					
Wheat	253,454	352,982	39.3	5.46	4.83	-11.5	1.52	0.34**	1.64
Maize	210,074	317,303	51.0	3.29	4.41	34.0	4.08**	1.65	4.17**
Rice	119,971	155,031	29.2	3.97	3.80	-4.3	1.52	2.45*	0.88
Barley	95,283	150,997	58.5	4.81	7.50	55.9	6.18***	3.13**	3.28**
Millet	19,705	21,381	8.5	7.78	7.66	-1.5	1.14	2.22	0.69
Sorghum	40,159	53,386	32.9	4.75	5.70	20.0	2.55*	1.08	2.10
Oats	49,033	47,595	-2.9	11.30	5.35	-52.6	0.21***	0.07***	4.42**
Other	41,404	35,231	-14.9	4.57	9.33	104.2	2.95**	0.36*	3.61**
Total	829,087	1,133,908	36.8	2.76	3.36	21.7	2.78*	2.22	2.69*

Source: U.S. Department of Agriculture.

Note: Data do not include the People's Republic of China.

*statistically significant at the 10 percent level of confidence.
**statistically significant at the 5 percent level.
***statistically significant at the 1 percent level.

production accounted for one-third each of this total increase, while rice accounted for 12 percent of the total increase, barley for 18 percent, and sorghum and millet for the rest. The production of oats and "other" cereals (rye and mixed grains) declined modestly between the two periods.

The coefficient of variation of total world cereal production increased from 2.8 percent to 3.4 percent between the two periods, an increase of 22 percent. At the same time, the variance of total cereal production increased by 178 percent. The F ratio of 2.78 is significant at the 10 percent confidence level. Both area and yield variability also increased, although only the F ratio for yields is statistically significant at the 10 percent confidence level.

Table 2.1 also shows that, despite sizeable increases in world wheat and rice production, this growth was not accompanied by a significant increase in production variability. In fact, the coefficients of variation declined -- from 5.5 percent to 4.8 percent for wheat and from 4.0 percent to 3.8 percent for rice. The coefficient of variation of rice production would have declined even more in the second period had there not been a significant increase in area variability.

In contrast, the production variability of coarse grains--maize, barley, and other cereals (rye and mixed grains) -- increased significantly. Except for barley, yield variability was the primary source of this increase. The variability of oat production declined significantly, but this was because of a sharp decline in area variability. The variability of oat yields increased sharply.

Table 2.2 shows the changes in the mean and variability of total cereal production for the 34 most important cereal producing countries. There is little observable relationship between a country's performance in increasing cereal production and the changes in production variability. The correlation across countries between the percentage change in average production and the change in the coefficient of variation of production is -0.15. This coefficient is not significantly different from zero at the 10 percent confidence level.

Production variability has increased most in France, Brazil, Mexico, Turkey, Italy, Spain, and South Korea. Increases in yield variability were particularly large in the United States, France, Poland, Spain, and South Korea. Area variability increased most in Brazil, the Philippines, Italy, and Japan. There was a significant decline in production variability in Nigeria and Egypt, which originates from significant declines in both yields and area variability.

Table 2.3 shows the coefficients of variation of production by crop and country. Production is most variable in Australia and South Africa; the coefficients of variation for total cereals are about 20 percent, and they are even higher for individual crops. Production is also relatively unstable in Canada and the U.S.S.R. The least risky countries are those that predominantly grow rice, presumably because much of the crop is irrigated. These countries include Indonesia, Thailand, Bangladesh, and Japan.

Table 2.3 also shows that while coefficients of variation of wheat and rice production declined for many countries, as well as at the global level, there are some important exceptions. Wheat produc-

tion became considerably more variable in Mexico, Turkey, Bangladesh, Poland, Italy, Spain, and Czechoslovakia, and rice production became considerably more variable in the United States, France, Mexico, and South Korea. Similarly, there are many countries where the variability of coarse grains went down between the two periods, even though global variability increased.

Tables 2.4 and 2.5 show the coefficients of variation of yields and of areas sown, by crop and country. The patterns of yield variability closely parallel the patterns of variability in production. Yields are most variable in Australia and South Africa and least variable for rice growing countries in Asia. The coefficients of variation of areas sown are typically much smaller than the coefficients for yield variability -- by a factor of one-half. The coefficient of variation for the global area sown to cereals was 1.4 percent in the second period. This compares with a coefficient of variation for the average yield of 3.4 percent. Both coefficients increased between the two periods, but it does seem that increased yield variability must have been the most important source of the increase in production variability.

The importance of increased yield variability is confirmed by a statistical decomposition analysis of the increase in the variance of world cereal production between the 1960/61 to 1970/71 period and the 1971/72 to 1982/83 period (Hazell 1985). Of the total variance increase, 26.4 percent is due to increases in the variances of individual cereal yields within countries and a further 69.5 percent is due to increases in yield covariances (Table 2.6).

Within most crops, increased yield variances account for the lion's share of the contribution to the variance of total cereal production. For example, when summed over countries the increased production variances for wheat account for 7.61 percent of the increase in the variance of total cereal production. Of this, 5.27/7.61 = 69.3 percent is due to increased yield variances. Similarly, the yield variance shares for other crops are maize 124 percent, rice 36 percent, millet 57 percent, sorghum 77 percent, and total cereals 77 percent.

Changes in yield covariances are much more important than changes in yield variances for the variability of world cereal production. However, part of the increase in the yield covariances is itself a direct consequence of increased yield variances. Part of it may also be due to autonomous changes in yield correlations and to interactions between changes in yield variances and changes in yield correlations.

Using an additional decomposition analysis, I found that only 6 percent of the 69.5 percent increase in the variance of total cereal production arising from changes in yield covariances is directly attributable to changes in yield variances (Hazell 1985). Some 52 percent of the increase is attributable to changes in yield correlations alone, and the remaining 42 percent is due to interaction effects. Of the correlation increases, the predominant ones are between the yields of the same or different crops in different countries. Increases in the intercrop yield covariances within countries were nearly all attributable to increased yield variances.

Table 2.2--Changes in the mean and variability of total cereal production by major countries, 1960/61 to 1970/71 and 1971/72 to 1982/83

Country	Average Production			Coefficient of Variation of Production		
	1960/61 to 1970/71	1971/72 to 1982/83	Change	1960/61 to 1970/71	1971/72 to 1982/83	Change
	(1,000 metric tons)		(percent)	(percent)		
United States	181,982	265,022	45.6	6.83	6.64	-2.8
U.S.S.R	138,436	180,952	30.7	12.16	14.26	17.3
India	74,753	104,000	39.1	7.65	5.42	-29.2
Canada	29,991	40,033	33.5	17.07	10.66	-37.6
France	27,456	41,085	49.6	6.01	9.19	52.9
Indonesia	13,464	20,341	51.1	6.09	5.15	-15.4
Brazil	16,500	26,149	58.5	5.19	8.87	70.9
Argentina	17,186	23,764	38.3	11.80	14.04	19.0
Mexico	10,487	15,571	48.5	7.03	11.10	57.9
Turkey	12,932	18,363	42.0	7.06	9.71	37.5
Australia	12,618	17,445	38.2	19.54	23.15	18.5
Thailand	8,555	13,255	54.9	7.82	8.40	7.4
Germany, F.R.	16,030	22,211	38.6	9.13	5.96	-34.7
Bangladesh	10,544	12,861	22.0	7.21	5.03	-30.2
Poland	8,373	13,135	56.9	9.21	9.29	1.0
Romania	11,602	17,360	49.6	10.87	9.87	-9.2
United Kingdom	12,442	16,75	34.7	8.73	8.34	-4.5
Italy	14,219	16,680	17.3	3.44	5.68	65.1
Pakistan	7,668	13,179	71.9	10.23	3.15	-69.2
South Africa	7,499	11,999	60.0	20.37	19.69	-3.3
Yugoslavia	11,397	15,069	32.2	9.98	5.18	-48.1
Burma	4,933	6,537	32.6	9.88	7.68	-22.3
Japan	14,565	11,393	-21.8	6.01	9.31	54.9
Vietnam	6,011	7,326	21.9	8.99	5.59	-37.8
Hungary	7,342	12,115	65.0	10.08	6.05	-40.0
Spain	9,291	13,676	47.2	8.09	13.86	71.3
Philippines	4,295	7,005	63.1	5.51	5.43	-1.5
Nigeria	7,793	8,491	9.0	11.68	5.05	-56.7
Czechoslovakia	6,189	9,688	56.5	11.73	7.54	-35.7
Germany, D.R.	4,606	7,147	55.2	11.29	6.40	-43.3
Iran	4,955	6,508	31.3	8.29	9.24	11.4
Bulgaria	5,429	7,706	41.9	10.27	7.47	-27.3
South Korea	5,266	6,227	18.3	5.97	10.77	80.4
Egypt	5,789	7,109	22.8	4.95	2.67	-46.1
Rest of world (excluding China)	98,481	117,747	19.6	3.19	2.80	-12.2
Total world (excluding China)	829,087	1,133,908	36.8	2.76	3.36	21.7

Source: U.S. Department of Agriculture.

*statistically significant at the 10 percent level.
**statistically significant at the 5 percent level.
***statistically significant at the 1 percent level.

F Ratio			Probability of a 5% Shortfall Below Trend	
Production	Area Sown	Yield	1960/61 to 1970/71	1971/72 to 1982/83
1.97	1.24	8.23***	23.3	22.6
2.35*	1.28	1.69	34.1	36.3
0.97	0.65	0.92	25.8	17.9
0.69	0.22***	0.44*	38.6	31.9
5.26***	1.58	4.30**	20.3	29.5
1.62	0.74	2.89*	20.6	16.6
7.25***	4.30**	2.47*	16.9	28.8
2.72*	1.04	2.12	33.7	35.9
5.58***	3.99**	3.40**	23.9	32.6
3.80**	3.98**	3.45**	23.9	30.2
2.66*	1.65	1.67	39.7	41.3
2.76*	3.00**	2.01	26.1	27.4
0.82	3.24**	0.59	29.1	20.1
0.72	0.20***	1.05	24.5	16.1
2.52*	0.12***	4.00**	29.5	29.8
1.83	0.80	2.17	32.3	30.5
1.66	0.33**	1.77	28.4	27.4
3.72**	5.50***	0.66	7.4	18.9
0.28**	0.44*	0.27**	31.2	5.6
2.40*	2.63*	1.99	40.1	40.1
0.47	0.74	0.57	30.9	16.9
1.06	0.45	1.77	30.5	25.8
1.45	4.27**	1.58	20.3	29.5
0.58	1.26	0.41*	28.8	18.7
0.98	0.35**	1.39	39.9	20.3
6.37***	0.68	7.73***	26.2	35.9
2.56*	6.87***	0.77	18.1	16.1
0.22***	0.16***	0.14***	33.4	25.5
1.01	0.07***	1.62	33.4	25.5
0.78	1.18	0.65	33.0	21.8
2.15	1.00	3.88**	27.4	29.5
1.05	3.55**	0.72	31.2	25.1
4.62**	0.96	7.76***	20.1	32.3
0.44*	0.23**	0.37*	15.6	3.1
1.10	0.47	0.75	5.9	3.8
2.78*	2.22	2.69*	3.5	6.8

Table 2.3--Coefficients of variation of production by cereal crop and country, 1960/61 to 1970/71 and 1971/72 to 1982/83

Country	Wheat	Maize	Rice	Barley	Millet	Sorghum	Oats	Other Cereals	Total Cereals
					(percent)				
United States									
1960/61 to 1970/71	8.1	9.0	9.3	5.4	-	11.8	9.8	16.9	6.8
1971/72 to 1982/83	8.7	8.3	14.6	12.7	-	14.2	12.7	35.4	6.6
U.S.S.R.									
1960/61 to 1970/71	15.9	24.0	7.0	15.3	18.7	-	44.1	10.2	12.2
1971/72 to 1982/83	15.1	18.7	7.1	21.7	35.9	-	10.8	21.4	14.3
India									
1960/61 to 1970/71	17.2	10.4	8.9	15.7	14.9	10.0	-	-	7.6
1971/72 to 1982/83	8.6	8.9	9.4	14.7	13.7	11.4	-	-	5.4
Canada									
1960/61 to 1970/71	26.9	10.3	-	17.3	-	-	14.8	27.6	17.1
1971/72 to 1982/83	13.7	12.0	-	19.1	-	-	11.1	10.5	10.7
France									
1960/61 to 1970/71	12.9	22.4	11.3	9.7	-	16.4	7.2	16.1	6.0
1971/72 to 1982/83	9.3	21.6	28.6	8.4	-	9.6	10.8	13.6	9.2
Indonesia									
1960/61 to 1970/71	-	21.7	5.1	-	-	-	-	-	6.1
1971/72 to 1982/83	-	14.7	4.4	-	-	-	-	-	5.1
Brazil									
1960/61 to 1970/71	58.8	5.3	10.4	16.5	-	-	7.2	-	5.2
1971/72 to 1982/83	34.0	10.9	8.0	44.3	-	28.6	17.2	-	8.9

Argentina									
1960/61 to 1970/71	31.1	13.8	20.8	38.9	23.3	37.2	24.0	41.1	11.8
1971/72 to 1982/83	19.4	22.8	10.5	28.4	27.1	24.4	21.1	44.6	14.0
Mexico									
1960/61 to 1970/71	9.9	10.4	10.0	8.9	-	24.1	29.5	-	7.0
1971/72 to 1982/83	18.9	14.1	19.7	29.4	-	18.3	33.4	-	11.1
Turkey									
1960/61 to 1970/71	7.2	9.4	14.5	9.8	6.2	-	5.8	11.5	7.1
1971/72 to 1982/83	11.4	6.0	11.5	10.5	13.1	-	4.0	4.8	9.7
Australia									
1960/61 to 1970/71	25.0	13.3	8.4	30.1	22.7	57.8	25.0	25.6	19.5
1971/72 to 1982/83	26.7	22.3	9.6	27.5	28.4	24.1	30.3	43.6	23.2
Thailand									
1960/61 to 1970/71	-	5.2	8.9	-	-	-	-	-	7.8
1971/72 to 1982/83	-	19.3	6.9	-	-	26.2	-	-	8.4
Germany, F.R.									
1960/61 to 1970/71	10.3	39.1	-	9.7	-	-	9.1	10.1	9.1
1971/72 to 1982/83	5.5	19.3	-	5.0	-	-	12.6	7.1	6.0
Bangladesh									
1960/61 to 1970/71	17.1	-	6.7	24.6	14.0	-	-	-	7.2
1971/72 to 1982/83	29.7	-	5.3	7.9	9.8	-	-	-	5.0
Poland									
1960/61 to 1970/71	7.0	25.6	-	12.8	13.6	-	10.1	7.3	9.2
1971/72 to 1982/83	11.8	90.0	-	16.3	39.8	-	10.0	-	9.3
Romania									
1960/61 to 1970/71	19.7	10.5	21.4	13.1	-	-	31.5	26.9	10.9
1971/72 to 1982/83	12.1	12.7	19.5	15.7	-	-	22.0	6.7	9.9

(continued)

Table 2.3--(continued)

Country	Wheat	Maize	Rice	Barley	Millet	Sorghum	Oats	Other Cereals	Total Cereals
					(percent)				
United Kingdom									
1960/61 to 1970/71	13.8	-	-	14.0	-	-	13.3	40.0	8.7
1971/72 to 1982/83	12.4	-	-	7.3	-	-	10.6	24.4	8.3
Italy									
1960/61 to 1970/71	6.0	8.9	15.2	9.0	-	-	12.0	10.8	3.4
1971/72 to 1982/83	10.9	4.3	12.9	10.6	--	23.8	9.2	12.3	5.7
Pakistan									
1960/61 to 1970/71	13.4	9.5	13.1	10.7	11.8	6.5	-	-	10.2
1971/72 to 1982/83	4.8	4.0	5.6	15.4	10.3	10.1	-	-	3.2
South Africa									
1960/61 to 1970/71	22.2	25.3	-	29.2	-	46.0	23.2	-	20.4
1971/72 to 1982/83	14.9	24.3	-	34.6	-	34.4	15.7	-	19.7
Yugoslavia									
1960/61 to 1970/71	12.0	11.6	14.3	18.8	-	7.7	11.3	8.7	10.0
1971/72 to 1982/33	11.8	7.4	13.2	15.5	-	22.4	9.7	7.8	5.2
Burma									
1960/61 to 1970/71	61.3	25.7	9.9	-	16.9	-	-	-	9.9
1971/72 to 1982/83	22.5	8.0	8.4	-	8.8	-	-	-	7.7
Japan									
1960/61 to 1970/71	26.9	7.6	5.2	19.5	19.4	-	10.0	-	6.0
1971/72 to 1982/83	16.6	11.1	8.9	22.2	-	-	10.1	-	9.3

Vietnam									
1960/61 to 1970/71	-	-	8.9	-	-	-	-	-	9.0
1971/72 to 1982/83	-	30.8	6.2	-	-	-	-	-	5.6
Hungary									
1960/61 to 1970/71	14.8	10.4	-	14.7	-	-	26.4	15.3	10.1
1971/72 to 1982/83	13.8	10.0	-	10.6	-	-	25.3	13.7	6.1
Spain									
1960/61 to 1970/71	3.0	11.3	5.3	23.0	-	46.2	13.5	10.0	8.1
1971/72 to 1982/83	18.2	10.6	3.0	18.7	-	19.2	16.2	11.4	13.9
Philippines									
1960/61 to 1970/71	-	5.5	6.1	-	-	-	-	-	5.5
1971/72 to 1982/83	-	7.7	5.0	-	-	-	-	-	5.4
Nigeria									
1960/61 to 1970/71	-	11.0	8.4	-	15.5	12.3	-	-	11.7
1971/72 to 1982/83	-	6.2	10.1	-	7.4	6.0	-	-	5.0
Czechoslovakia									
1960/61 to 1970/71	9.7	12.4	-	14.5	-	-	15.8	10.6	11.7
1971/72 to 1982/83	14.0	17.3	-	9.5	-	-	15.6	11.4	7.5
Germany, D.R.									
1960/61 to 1970/71	15.7	-	-	14.6	-	-	13.2	20.3	11.3
1971/72 to 1982/83	5.9	-	-	9.8	-	-	18.9	37.1	6.4
Iran									
1960/61 to 1970/71	10.5	13.5	7.8	8.7	-	-	-	-	8.3
1971/72 to 1982/83	9.3	18.3	8.5	13.8	-	-	-	-	9.2
Bulgaria									
1960/61 to 1970/71	14.5	14.9	17.2	13.6	-	-	26.9	16.7	10.3
1971/72 to 1982/83	7.6	17.4	14.7	11.5	-	-	19.9	17.3	7.5

(continued)

Table 2.3--(continued)

Country	Wheat	Maize	Rice	Barley	Millet	Sorghum	Oats	Other Cereals	Total Cereals
					(percent)				
South Korea									
1960/61 to 1970/71	29.2	32.1	8.9	14.2	18.6	-	-	-	6.0
1971/72 to 1982/83	32.6	21.3	13.0	20.0	21.1	-	-	-	10.8
Egypt									
1960/61 to 1970/71	12.3	7.1	16.0	11.6	-	4.2	-	-	4.9
1971/72 to 1982/83	6.3	4.3	6.4	14.0	-	7.6	-	-	2.7
Rest of world (excluding China)									
1960/61 to 1970/71	7.9	4.0	3.0	7.1	4.4	9.6	5.7	6.9	3.2
1971/72 to 1982/83	7.9	3.6	4.5	5.1	7.6	5.7	7.5	7.1	2.8
Total World (excluding China)									
1960/61 to 1970/71	5.5	3.3	4.0	4.8	7.8	4.7	11.3	4.6	2.8
1971/72 to 1982/83	4.8	4.4	3.8	7.5	7.7	5.7	5.3	9.3	3.4

Source: U.S. Department of Agriculture.

Table 2.4--Coefficients of variation of yields by cereal crop and country, 1960/61 to 1970/71 and 1971/72 to 1982/83

Country	Wheat	Maize	Rice	Barley	Millet	Sorghum	Oats	Other Cereals	Total Cereals
					(percent)				
United States									
1960/61 to 1970/71	4.8	6.6	3.1	5.0	-	6.5	5.5	6.0	4.0
1971/72 to 1982/83	6.7	9.6	6.4	8.6	-	12.0	6.9	10.4	8.8
U.S.S.R.									
1960/61 to 1970/71	16.2	10.9	4.1	14.7	18.9	-	14.2	11.0	13.2
1971/72 to 1982/83	13.7	11.3	3.8	17.7	34.1	-	11.9	15.7	13.4
India									
1960/61 to 1970/71	10.6	8.4	8.0	8.9	13.7	8.3	-	-	6.2
1971/72 to 1982/83	5.9	7.8	7.9	9.0	10.8	10.4	-	-	4.6
Canada									
1960/61 to 1970/71	17.8	7.8	-	12.1	-	-	9.1	21.1	14.1
1971/72 to 1982/83	9.7	7.7	-	7.2	-	-	6.4	5.6	7.3
France									
1960/61 to 1970/71	7.9	19.3	11.7	8.6	-	13.1	5.0	6.9	5.6
1971/72 to 1982/83	8.6	10.5	19.1	8.5	-	10.7	10.8	12.1	8.2
Indonesia									
1960/61 to 1970/71	-	5.0	2.5	-	-	-	-	-	2.1
1971/72 to 1982/83	-	4.2	2.8	-	-	-	-	-	2.5
Brazil									
1960/61 to 1970/71	16.8	4.7	6.9	13.4	-	-	7.1	-	4.6
1971/72 to 1982/83	25.2	8.4	5.2	19.0	-	10.8	8.6	-	6.7

(continued)

Table 2.4--(continued)

Country	Wheat	Maize	Rice	Barley	Millet	Sorghum	Oats	Other Cereals	Total Cereals
					(percent)				
Argentina									
1960/61 to 1970/71	18.5	9.0	5.0	16.5	9.4	14.8	8.5	16.8	8.6
1971/72 to 1982/83	8.7	14.9	7.4	12.8	10.9	12.4	8.6	14.1	9.4
Mexico									
1960/61 to 1970/71	7.4	8.2	6.6	5.8	-	9.7	14.2	-	5.5
1971/72 to 1982/83	10.5	11.3	7.5	19.7	-	15.5	21.2	-	8.1
Turkey									
1960/61 to 1970/71	7.4	8.6	9.7	9.0	5.9	-	5.2	9.3	6.9
1971/72 to 1982/83	0.3	6.7	6.5	9.8	12.7	-	3.8	3.8	9.1
Australia									
1960/61 to 1970/71	15.8	9.9	10.2	15.6	17.0	19.2	18.7	15.4	15.2
1971/72 to 1982/83	21.6	8.7	10.9	19.8	16.1	12.4	13.2	16.5	18.5
Thailand									
1960/61 to 1970/71	-	11.0	7.2	-	-	-	-	-	6.4
1971/72 to 1982/83	-	17.4	6.7	-	-	37.3	-	-	8.1
Germany, F.R.									
1960/61 to 1970/71	9.1	7.7	-	10.6	-	-	6.5	9.2	8.8
1971/72 to 1982/83	5.7	8.8	-	4.2	-	-	9.0	5.2	5.2
Bangladesh									
1960/61 to 1970/71	15.2	-	4.2	9.4	6.0	-	-	-	4.3
1971/72 to 1982/83	8.6	-	4.0	5.8	7.1	-	-	-	3.9

Poland									
1960/61 to 1970/71	5.1	20.6	-	8.5	6.4	-	9.4	3.4	6.2
1971/72 to 1982/83	9.1	18.6	-	7.4	14.6	-	8.2	14.8	9.2
Romania									
1960/61 to 1970/71	16.9	9.1	15.6	10.0	-	-	13.6	11.9	8.7
1971/72 to 1982/83	10.5	9.8	17.7	10.3	-	-	14.6	3.9	8.0
United Kingdom									
1960/61 to 1970/71	7.8	-	-	5.9	-	-	3.4	3.2	6.1
1971/72 to 1982/83	7.5	-	-	6.1	-	-	7.5	9.1	6.6
Italy									
1960/61 to 1970/71	6.5	8.5	9.8	6.7	-	-	10.8	4.1	3.9
1971/72 to 1982/83	5.1	2.8	12.7	7.1	-	9.6	8.6	4.7	2.3
Pakistan									
1960/61 to 1970/71	9.8	8.2	11.9	7.6	5.9	7.0	-	-	8.6
1971/72 to 1982/83	4.1	3.1	3.9	3.6	4.8	5.4	-	-	3.0
South Africa									
1960/61 to 1970/71	17.6	24.1	-	24.8	-	22.9	24.7	-	19.8
1971/72 to 1982/83	11.9	21.9	-	22.8	-	26.9	16.1	-	18.2
Yugoslavia									
1960/61 to 1970/71	11.8	11.1	10.7	10.7	-	8.1	7.9	5.8	9.4
1971/72 to 1982/83	9.1	5.8	11.4	9.2	-	10.5	6.9	7.1	4.7
Burma									
1960/61 to 1970/71	24.9	32.5	6.6	-	34.9	-	-	-	6.4
1971/72 to 1982/83	8.3	10.0	7.5	-	47.5	-	-	-	6.6
Japan									
1960/61 to 1970/71	19.6	6.3	4.0	17.7	9.1	-	8.2	-	5.4
1971/72 to 1982/83	10.5	5.7	5.7	8.4	-	-	6.8	-	5.8

(continued)

Table 2.4--(continued)

Country	Wheat	Maize	Rice	Barley	Millet	Sorghum	Oats	Other Cereals	Total Cereals
					(percent)				
Vietnam									
1960/61 to 1970/71	-	-	8.0	-	-	-	-	-	8.2
1971/72 to 1982/83	-	6.5	5.6	-	-	-	-	-	5.0
Hungary									
1960/61 to 1970/71	12.5	8.4	-	11.0	-	-	17.1	7.6	7.2
1971/72 to 1982/83	10.6	6.7	-	11.0	-	-	19.1	16.7	4.8
Spain									
1960/61 to 1970/71	10.6	18.9	4.3	10.2	-	22.2	11.6	8.6	6.9
1971/72 to 1982/83	15.0	6.2	3.8	16.8	-	11.4	15.5	11.0	13.2
Philippines									
1960/61 to 1970/71	-	4.3	7.8	-	-	-	-	-	5.9
1971/72 to 1982/83	-	3.5	4.8	-	-	-	-	-	4.0
Nigeria									
1960/61 to 1970/71	-	14.8	8.5	-	17.5	8.7	-	-	9.3
1971/72 to 1982/83	-	3.5	4.0	-	5.9	4.3	-	-	3.8
Czechoslovakia									
1960/61 to 1970/71	7.7	14.6	-	12.1	-	-	9.6	6.3	8.4
1971/72 to 1982/83	9.1	19.2	-	7.6	-	-	12.8	9.4	7.3
Germany, D.R.									
1960/61 to 1970/71	9.5	-	-	15.0	-	-	8.6	9.4	10.5
1971/72 to 1982/83	6.0	-	-	7.8	-	-	13.6	13.4	6.5

Iran										
1960/61 to 1970/71		5.5	9.0	9.9	4.4	-	-	-	-	3.6
1971/72 to 1982/83		5.4	14.6	9.2	13.1	-	-	-	-	6.1
Bulgaria										
1960/61 to 1970/71		15.2	13.5	15.1	12.1	-	-	24.1	11.3	10.3
1971/72 to 1982/83		6.4	11.1	14.8	7.5	-	-	10.7	10.5	5.7
South Korea										
1960/61 to 1970/71		8.0	12.1	8.0	14.2	12.1	-	-	-	5.6
1971/72 to 1982/83		15.6	17.5	12.6	15.8	13.2	-	-	-	11.0
Egypt										
1960/61 to 1970/71		10.2	14.0	5.8	20.6	-	1.8	-	-	4.5
1971/72 to 1982/83		4.3	3.5	3.8	5.3	-	4.6	-	-	2.3
Rest of world (excluding China)										
1960/61 to 1970/71		6.3	4.2	3.2	4.5	4.4	3.4	4.7	5.1	3.2
1971/72 to 1982/83		4.8	3.4	1.0	6.8	6.2	3.2	5.5	6.1	2.5
Total world (excluding China)										
1960/61 to 1970/71	5.0	3.0	3.3	4.3	7.3	4.0	3.0	5.5	2.6	
1971/72 to 1982/83		4.9	4.6	2.6	6.4	5.8	4.6	5.6	8.0	3.4

Table 2.5--Coefficients of variation of area sown by cereal crop and courtry, 1960/61 to 1970/71 and 1971/72 to 1982/83

Country	Wheat	Maize	Rice	Barley	Millet	Sorghum	Oats	Other Cereals	Total Cereals
					(percent)				
United States									
1960/61 to 1970/71	9.8	8.1	8.8	6.4	-	11.0	7.4	14.1	5.3
1971/72 to 1982/83	10.6	4.2	11.5	10.6	-	7.0	8.0	25.8	5.3
U.S.S.R.									
1960/61 to 1970/71	4.4	23.7	4.9	12.8	9.0	-	34.4	9.9	2.7
1971/72 to 1982/83	3.7	14.9	5.7	7.5	-	-	5.3	12.7	3.0
India									
1960/61 to 1970/71	8.7	4.5	1.5	8.6	2.7	4.2	-	-	1.8
1971/72 to 1982/83	4.0	2.3	1.9	10.7	4.1	2.7	-	-	1.4
Canada									
1960/61 to 1970/71	20.5	6.7	-	12.7	-	-	7.4	16.1	10.8
1971/72 to 1982/83	6.1	7.3	-	15.5	-	-	7.9	7.1	4.9
France									
1960/61 to 1970/71	6.4	11.6	3.5	4.5	-	21.1	4.4	13.3	1.1
1971/72 to 1982/83	3.4	18.6	20.6	3.2	-	14.6	3.5	5.8	1.3
Indonesia									
1960/61 to 1970/71	-	17.4	3.7	-	-	-	-	-	5.8
1971/72 to 1982/83	-	13.7	2.3	-	-	-	-	-	4.6
Brazil									
1971/72 to 1982/83	57.4	1.9	6.0	13.9	-	-	8.4	-	3.0
1971/72 to 1982/83	28.3	4.7	7.5	32.6	-	26.0	14.9	-	4.3

Argentina									
1960/61 to 1970/71	19.7	7.0	17.0	28.3	18.9	31.4	19.3	30.2	9.6
1971/72 to 1982/83	15.0	15.4	7.3	16.4	17.6	16.9	16.9	33.3	9.5
Mexico									
1960/61 to 1970/71	5.1	4.6	6.6	6.7	-	22.8	24.5	-	2.7
1971/72 to 1982/83	10.6	3.9	15.5	15.4	-	14.3	38.1	-	4.6
Turkey									
1960/61 to 1970/71	0.7	2.1	22.9	1.3	4.4	-	4.5	4.7	0.7
1971/72 to 1982/83	1.4	1.5	12.4	4.0	11.8	-	1.9	3.4	1.3
Australia									
1960/61 to 1970/71	17.3	8.3	7.1	23.0	27.5	36.7	8.9	16.4	9.9
1971/72 to 1982/83	10.8	22.7	10.1	19.0	32.7	24.6	22.6	35.0	9.9
Thailand									
1960/61 to 1970/71	-	9.9	4.2	-	-	-	-	-	3.9
1971/72 to 1982/83	-	6.5	5.5	-	-	16.3	-	-	4.8
Germany, F.R.									
1960/61 to 1970/71	3.7	35.3	-	2.8	-	-	3.8	2.2	1.1
1971/72 to 1982/83	2.0	14.7	-	2.5	-	-	5.8	4.2	1.9
Bangladesh									
1960/61 to 1970/71	13.8	-	3.7	21.1	10.8	-	-	-	4.2
1971/72 to 1982/83	29.1	-	1.9	9.2	6.9	-	-	-	1.7
Poland									
1960/61 to 1970/71	4.6	16.0	-	9.9	11.7	-	6.5	7.8	6.3
1971/72 to 1982/83	5.1	83.2	-	12.8	32.8	-	6.0	4.6	1.9
Romania									
1960/61 to 1970/71	6.1	3.4	26.1	8.0	-	-	25.8	20.3	3.2
1971/72 to 1982/83	2.5	4.4	11.4	10.8	-	-	20.6	6.2	3.1

(continued)

Table 2.5--(continued)

Country	Wheat	Maize	Rice	Barley	Millet	Sorghum	Oats	Other Cereals	Total Cereals
					(percent)				
United Kingdom									
1960/61 to 1970/71	8.8	-	-	11.3	-	-	13.1	41.7	5.0
1971/72 to 1982/83	7.4	-	-	2.8	-	-	6.4	22.7	2.6
Italy									
1960/61 to 1970/71	2.5	3.3	11.0	3.4	-	-	5.9	10.8	1.7
1971/72 to 1982/83	7.2	2.8	3.1	6.1	-	19.4	2.6	12.5	4.8
Pakistan									
1960/61 to 1970/71	5.7	5.7	3.5	6.1	9.7	8.7	-	-	3.6
1971/72 to 1982/83	2.6	4.3	6.4	15.8	11.6	8.3	-	-	2.1
South Africa									
1960/61 to 1970/71	14.6	3.8	-	10.8	-	31.5	9.9	-	2.7
1971/72 to 1982/83	7.7	5.7	-	20.6	-	19.1	10.7	-	4.2
Yugoslavia									
1960/61 to 1970/71	6.8	2.2	18.2	9.1	-	10.1	4.0	4.6	1.5
1971/72 to 1982/83	5.2	2.8	5.2	8.7	-	18.6	4.4	5.3	1.5
Burma									
1960/61 to 1970/71	47.7	37.5	4.8	-	22.4	-	-	-	5.3
1971/72 to 1982/83	20.7	4.0	3.7	-	32.5	-	-	-	3.5
Japan									
1960/61 to 1970/71	18.6	8.5	2.6	6.2	14.9	-	9.6	-	2.5
1971/72 to 1982/83	12.2	12.4	6.2	16.2	-	-	11.8	-	7.7

Vietnam									
1960/61 to 1970/71	-	-	3.4	-	-	-	-	-	3.7
1971/72 to 1982/83	-	33.3	3.0	-	-	-	-	-	3.5
Hungary									
1960/61 to 1970/71	6.0	6.1	-	12.4	-	-	14.4	10.5	3.6
1971/72 to 1982/83	4.7	6.0	-	6.4	-	-	21.6	6.7	2.3
Spain									
1960/61 to 1970/71	4.2	8.3	3.4	20.1	-	38.9	3.4	5.1	2.0
1971/72 to 1982/83	8.7	5.4	2.5	5.0	-	19.2	3.8	2.8	1.6
Philippines									
1960/61 to 1970/71	-	3.5	2.7	-	-	-	-	-	2.2
1971/72 to 1982/83	-	7.3	3.0	-	-	-	-	-	4.7
Nigeria									
1960/61 to 1970/71	-	15.5	8.3	-	5.6	8.0	-	-	4.8
1971/72 to 1982/83	-	4.0	11.2	-	2.3	2.2	-	-	1.7
Czechoslovakia									
1960/61 to 1970/71	4.3	13.5	-	3.6	-	-	8.7	9.5	4.0
1971/72 to 1982/83	6.2	10.9	-	7.1	-	-	13.9	5.7	1.0
Germany, D.R.									
1960/61 to 1970/71	8.4	-	-	10.3	-	-	7.5	18.0	4.1
1971/72 to 1982/83	3.8	-	-	9.4	-	-	12.2	31.5	3.7
Iran									
1960/61 to 1970/71	5.9	6.7	8.0	6.1	-	-	-	-	5.5
1971/72 to 1982/83	6.0	11.9	3.5	2.2	-	-	-	-	4.8
Bulgaria									
1960/61 to 1970/71	3.2	6.0	7.3	4.1	-	-	6.4	8.1	2.0
1971/72 to 1982/83	2.8	10.6	7.7	10.9	-	-	13.7	19.3	4.1

(continued)

Table 2.5--(continued)

Country	Wheat	Maize	Rice	Barley	Millet	Sorghum	Oats	Other Cereals	Total Cereals
					(percent)				
South Korea									
1960/61 to 1970/71	26.2	28.6	2.9	3.6	15.5	-	-	-	3.4
1971/72 to 1982/83	25.0	8.2	0.9	11.9	20.8	-	-	-	4.0
Egypt									
1960/61 to 1970/71	6.2	8.5	12.9	21.9	-	3.4	-	-	5.9
1971/72 to 1982/83	4.8	5.1	3.4	13.8	-	5.0	-	-	2.7
Rest of world (excluding China)									
1960/61 to 1970/71	3.5	6.5	2.2	4.1	2.5	8.9	2.2	3.3	2.1
1971/72 to 1982/83	4.5	2.7	4.3	5.3	3.4	3.5	4.8	3.5	1.4
Total world (excluding China)									
1960/61 to 1970/71	3.4	1.4	1.3	3.5	1.5	2.2	10.1	5.4	1.0
1971/72 to 1982/83	1.9	1.6	1.8	4.7	2.1	2.2	3.0	5.1	1.4

Table 2.6--Components of change in the variance of world cereal production, 1960/61 to 1970/71 and 1971/72 to 1982/83

Variance Component	Source of Change							
	Change in Mean Yields	Change in Mean Areas	Change in Yield Variances & Covariances	Change in Area Variances & Covariances	Change in Area-Yield Covariances	Change in Interaction Terms	Change in Residual	Row Sums
	(percent)							
Crop variances								
Wheat	2.06	-2.38	5.27	-0.57	3.57	-0.49	0.15	7.61
Maize	6.67	1.94	17.16	-6.15	-5.01	-1.54	0.73	13.80
Rice	0.11	0.25	0.45	0.12	0.16	0.13	0.05	1.26
Barley	0.43	2.30	1.87	0.86	1.37	4.67	0.96	12.46
Millet	0.01	-0.01	0.04	0.01	0.06	-0.02	0.00	0.07
Sorghum	0.19	0.07	0.57	-0.23	0.12	0.07	-0.05	0.74
Oats	0.83	0.27	0.11	-1.25	-0.54	-1.06	-0.19	-1.85
Other	0.14	-0.15	0.94	-0.14	0.29	-0.77	0.06	0.36
Sum of crop variances within countries	10.44	2.28	26.40	-7.36	0.01	0.99	1.70	34.45
Intercrop covariances within countries	0.97	4.48	36.68	-0.94	-9.38	1.89	1.65	35.35
Intercountry covariances within crops	0.09	1.61	11.49	-3.61	-4.40	-0.98	0.49	4.70
Covariances between different crops in different countries	2.75	0.85	21.36	19.13	-28.51	6.43	3.55	25.50
Sum of variances and covariances	14.24	9.22	95.93	7.22	-42.28	8.33	7.40	100.00

Note: Data do not include People's Republic of China.

CHANGE IN YIELD VARIABILITY AND YIELD CORRELATION

The previous analysis shows that world cereal production has become less stable since the 1960s, primarily because of increases in yield variances and yield correlations.

It is also clear that there is no general uniformity to the patterns of change. The coefficients of variation of wheat and rice yields declined at the global level (Table 2.4), but the coefficients of variation increased for coarse grain yields. There are also important differences among countries, many of which defy the global patterns of change in the variability of individual cereal yields. While these contrasting changes complicate the task of the workshop, they also may be invaluable in identifying the causal factors at work. We have as much to learn from cases where yield variability went down as we do from cases where it went up.

I turn now to formulating hypotheses about the possible causes of change in yield variability and yield correlations. This may be viewed as an attempt to provide a checklist for the workshop discussions. The presentation is also organized to show the relationship between the sources of change in yield variability and yield correlations and the level of aggregation at which yields are measured.

Sources of Change: Experimental Plot Data

The least number of possible sources of change in yield variability, both within and between plots, arise in experimental plot data, because the experimenter has considerable control over the inputs (treatments) used and the period and location (environment) in which the experiment is conducted.

If y_i denotes the yield of the ith genotype, then a useful yield model is as follows:

$$y_i = f_i\ (X,\ E,\ u), \qquad (2.1)$$

where

- X = a vector of controlled inputs, for example, fertilizers;
- E = a vector of environmental variables like weather, altitude, and soil type (some of these variables are stochastic, in which case the experimenter can control only for the average values of such variables);
- u = a stochastic residual over which the experimenter has no control; and
- f_i = any relevant functional form.

Variability in y_i is then due to variability in E and u, but it will also be conditioned by the choice of genotype (i), the input levels (X), and the mean values of E. This conditioning is especially important if, as is usually the case, the genotype interacts with X and E.

Common breeding techniques involve measuring the yields of selected genotypes at different locations (E) with varying levels of treatments (X) at each location. Composite measures of stability are then calculated across X and E, and these provide a basis for comparing the stability of different genotypes (see, for example, Eberhart and Russell 1966; Finlay and Wilkinson 1963).

When controlled in this way, the only systematic source of difference in the variability of different genotypes is their

inherent biological stability. Much of the available evidence supports the argument that breeders have been successful in recent years in reducing plot yield variability across locations. However, we should probably expect their success to have been greatest where the relevant range of environments (E) is narrow, for example, for irrigated paddy rather than upland rice.

Two consequences of this approach to breeding must be mentioned. First, because most stability tests on specific genotypes are carried out for only one or two years, there is a strong presumption that stability across different locations is a good proxy for stability over time at specific locations. The evidence for this is not very encouraging (Watson and Anderson 1977; Evenson et al. 1978).

Second, by screening for genotypes that perform well in many locations at the same time, breeders may inadvertently be increasing yield correlations between locations, hence between farms or regions. This need not be a problem for farmers, but it may add to the variability of national yields.

Sources of Change: Farm Field Data

Once the experimenter is replaced by a business oriented decision maker, there are additional sources of yield variability beyond those operating at the experimental plot. This is especially true of time-series yield data.

The application of inputs (X) is no longer controlled, since the farmer will adjust the levels used each year in response to price changes and the availability of supplies. This behavioral component to farm yields could lead to changes in yield variability over time if price variability changes or if input supplies become more stable or more erratic.

The variability of farm-gate prices has increased significantly in many countries since the early 1970s, and this may be an important source of the increased yield variability. The effect may have been amplified by the coterminous and widespread adoption of high-yielding varieties, which in developing countries also increased farmers' dependence on modern inputs. There is also some evidence that input supplies have become more erratic in some developing countries. For example, electricity supplies for irrigation pumps in India became more erratic at the same time that farmers became more dependent on pumping to achieve higher yields with HYVs.

Farmers also change and improve their cultural practices over time, often in conjunction with the adoption of improved genotypes, and this may lead to changes in yield variability. For example, increased planting densities and greater monocropping may lead to significant increases in yield variability. On the other hand, improvements in weed and pest control practices or increases in irrigation may reduce yield variability.

Time series yield data from farmers' fields may also be affected by changes in weather patterns, and particularly if yield variability within relatively short time periods is compared. Changes in genotypes and cultural practices may also interact with changes in weather, with quite complex consequences for changing patterns of yield variability.

Sources of Change: National Data

At the national level of aggregation, changes in yield covariances between farms (and between regions) also become important sources of change in yield variability. In fact they are often the dominant source of change.

Suppose n farmers grow the same crop, then a simple measure[1] of their aggregate yield is

$$Y = 1/n \sum_{j=1}^{n} y_j. \tag{2.2}$$

The variance of aggregate yield over time is then

$$V(Y) = 1/n^2 \left[\sum_j V(y_j) + \sum_{i \neq j} \sum_j \text{Cov}(y_i, y_j)\right]. \tag{2.3}$$

That is, V(Y) is the sum of individual farm yield variances, $\sum_j V(y_j)$, plus the sum of all the yield covariances between farms, $\sum_{i \neq j} \sum_j \text{Cov}(y_i, y_j)$.

Since there are n farms, then there are n yield variances and $(n^2 - n)$ yield covariances in equation (2.3). For example, if n = 1,000 then there are 1,000 variances and 999 thousand covariances. It is not therefore surprising that changes in interfarm yield covariances are usually the dominant source of change in V(Y).

By definition, a yield covariance can be written as

$$\text{Cov}(y_i, y_j) = \rho_{ij} \left[V(y_i)\, V(y_j)\right]^{\frac{1}{2}}, \tag{2.4}$$

where ρ_{ij} is the correlation coefficient. Part of the change in yield covariances over time is therefore directly attributable to changes in the variances of farm yields. But part may also be due to autonomous shifts in the correlations.

Hazell (1984) provides evidence of sharp increases in interstate correlations for U.S. maize yields since the mid-1960s. Walker (Workshop Paper 30) shows even stronger trends in interdistrict yield correlations for sorghum and pearl millet in India.

Interregional (or interfarm) yield correlations may have increased over time for a number of reasons:

- Weather patterns may have become more covariate across regions.
- More erratic supplies of farm inputs affect many farmers simultaneously, and this may lead to more synchronized patterns of variability in yields. A good example is the increased irregularity of electricity supplies for irrigation pumping in India. Large regions are affected at the same time, and this may lead to a common decline in farm yields, particularly in drought years.

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[1]This measure does not weight for differences in farm production.

- An increase in price variability at the same time that new genotypes are adopted has increased farmers' dependence on modern inputs. A common response to the same price signals will lead farmers to adjust their use of fertilizers and other yield affecting inputs in the same direction.
- A narrow range of genotypes, which have a common susceptibility to the same kinds of pest and weather stresses, have been widely adopted. Dalrymple (1976) and Hargrove, Coffman, and Cabanilla (1979) provide evidence of the narrowing of the genetic base for wheat and rice.
- Genotypes that have been screened for stability at a wide range of locations have been widely adopted.
- There has been a move toward more uniform cultural practices, which increases the exposure of larger areas of a crop to the same risks -- for example, practices that lead to a narrower range of planting dates.
- Irrigated area has been increased. Although irrigation may be effective in reducing yield variability within fields, it may, by reducing some climatic influences on yields, lead to more synchronized patterns of variability across locations.

Expansion of cereal production into more marginal lands has been an important source of increase in the variability of national yields in some countries, for example, Australia and Brazil. Changes in the size distribution of farms, such as those incurred through land reforms or other structural and institutional changes, can also be important.

CONSEQUENCES OF INCREASED INSTABILITY IN CEREAL YIELDS

Consequences for Farmers

Increased yield risks associated with improved varieties or new technologies may hinder their widespread adoption by farmers, thereby limiting growth in national food supplies. There is plenty of empirical evidence to show that most farmers, and particularly small-scale farmers in developing countries, act in risk-averse ways when making resource allocation decisions that affect their income (see, for example, Binswanger 1980; Dillon and Scandizzo 1978). However, studies of the relationship between yield risks and the adoption of specific varieties or technologies show mixed results. For example, Roumasset (1976, 1979), O'Mara (1971), and Gladwin (1977) found that risk aversion was not a significant impediment to the adoption of the improved technologies they studied. Walker (1981) in his study of the adoption of maize hybrids in El Salvador also found that the risk attitudes of adopters and nonadopters were about the same. In contrast, Binswanger (1980), Moscardi (1976), Moscardi and de Janvry (1977), and Scandizzo (1974) found that risk can be an impediment to adoption.

These differences may be due to the different technologies and farming systems studied (for example, irrigated versus rainfed agriculture). There are still too few studies using comparable methodologies to permit useful cross-study analyses. But the conflicting results may also reflect the complexity of the relation-

ship between yield risks and the variability of farm or family income. Since it is presumably the stability of income (or family consumption) that concerns farmers most, increased yield risks should be a problem only if they lead to greater instability in income.

Yield risks are only one of many risks that affect a farmer's income, and some of these risks may act to offset each other. Within a crop, higher yield risks may be partly offset by negatively correlated fluctuations in prices, and the return from the crop may be much more stable than the variability of prices and yields alone would suggest. When more than one crop is grown, there is also scope for low or even negative correlations among the returns of the different crops, with a resultant stabilizing effect on aggregate income. Work at ICRISAT (for example, Walker and Jodha 1986)[2] has shown that even small-scale farmers in dryland India can be surprisingly efficient in reducing income risks through a variety of cultural practices (intercropping, spatial diversification, staggered planting dates, and so on), through off-farm employment, through the use of credit, and by participating in land leasing arrangements, which effectively share some of the yield risks with landlords. Within this rather complex framework, few generalities about the relationship between yield risks for individual cereals and the stability of family income seem likely to emerge.

Consequences for Poor Consumers and the National Economy

Yield variability is important at the more macrolevel if it translates into instability in the supplies of important food or export crops. We have already seen that much of the increase in production variability since the 1960s is attributable to increases in yield variances and covariances. This is true for many individual countries as well as at a global level. Of course, this link between yield and production variability will not always be true, and much depends on how the variability of the sown area behaves.

In principle, one would expect high production years for major cereals to be good for poor consumers. They should gain from more plentiful food supplies, from lower prices, and perhaps from increased agricultural employment. The opposite might be expected in low production years. But as in the case of farm incomes, things can be more complex than this. Since consumers typically purchase a number of different food crops, shortages or high prices for one may simply be offset by substituting other foods whose supplies are more plentiful or whose prices are lower. There is a surprising lack of evidence on the relationship between the variability of individual food supplies and the instability of the incomes and nutritional intake of the poor. Sahn and von Braun (Chapter 6) have mustered most of this evidence in their background paper for the workshop.

Production variability can lead to increased price variability in domestic markets and hence indirectly increase the price risks confronting farmers. Whether this will worsen their income insta-

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[2]This previously published paper was circulated to workshop participants.

bility depends on how individual farm yields are correlated with market prices. If this relationship is negative, then price and yield risks will tend to offset each other, and income will remain relatively stable. The opposite will happen for farmers whose yields are positively correlated with market prices. At the national level there is likely to be a negative relationship between aggregate yield and market prices, simply because domestic demand is downward sloping. But this relationship may be weakened, or even reversed, if the market is dominated by import or export prices.

In poor agrarian countries, variability in the yields of important food or export crops can have serious destabilizing consequences for national income, employment, and the balance of payments. Even in as rich a country as the United States, it is quite surprising how much of the nonfarm economy and the banking system is adversely affected by fluctuations in cereal prices and yields.

CONTAINING INCREASING YIELD VARIABILITY

Assuming that increasing yield variability is a problem, either because of increasing variability at the farm level or because of increasing interfarm (and interregional) yield correlations, what can be done about it?

There are basically two approaches. One is to directly attack the cause of increasing yield variability. The other is to accept increasing yield variability as a necessary consequence of improvements in average production and to attempt to parry, or offset, its effects through appropriate interventions. Obviously, the relative costs and benefits of the two approaches need to be considered, particularly if a direct attack on the problem involves substantial trade-offs with growth in aggregate production.

Direct Approaches

Any direct approach must obviously be tied to proper identification of the causes of increased yield variability. If the problem lies with genotypes that are inherently too risky, then appropriate changes in plant breeding priorities may be in order. However, if the problem is due primarily to economic factors, such as increased price variability, more erratic input supplies, crop expansion into more marginal areas, or land reforms and other institutional and policy changes, then these factors need to be attacked in the policy arena.

Most likely, improved technologies have aggravated the instability induced by changes in the economic environment. They may have directly increased interfarm and interregional yield correlations, because of the way improved genotypes are selected and because they increase yield response to (covariate) economic factors. They may also have indirectly increased yield variability in farmers' fields by permitting a greater range of yield response to input use.

Perhaps breeders can tackle some of these problems directly, by giving more thought to yield correlations between locations, by

maintaining a more diverse range of genotypes in farmers' fields, and by focusing more on instability over time rather than across locations. Yield stability might also be improved through better management of fertilizers and pesticides, through improved cultural practices, and through increased or better managed irrigation. All these options need to be explored.

Indirect Approaches

If greater yield variability proves to be a barrier to the adoption of necessary yield increasing technologies, then crop insurance programs may be appropriate. Unfortunately, past experience with crop insurance is not encouraging, and the costs of publicly provided insurance have usually far exceeded their benefits (Hazell, Pomareda, and Valdés 1986). Nor should the efficiency with which farmers and traditional village institutions cope with risks be neglected. Walker and Jodha (1986) have provided a very interesting paper on these issues. They point out that crop insurance might simply provide a more costly substitute to existing private risk sharing arrangements. Improvements to financial institutions might be a viable approach, particularly an expansion of medium-term consumer credit so that farmers could borrow money in bad years and pay it back in good years.

At the national level, increased instability in prices and food consumption can be contained through buffer stocks. However, IFPRI's work shows that in most cases it is more cost effective for governments to use world markets to stabilize domestic consumption, using the International Monetary Fund's food facility as a source of funding for food imports when appropriate (Valdés 1981). Interventions can also be targeted, such as food subsidies for the poor, relief employment, and food-for-work schemes. The efficiency of these and other interventions are discussed more fully by Sahn and von Braun (Chapter 6).

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3 Climatic Changes and Yield Variability

Timothy R. Carter and Martin L. Parry

Increases in cereal yield variability have been recorded in certain regions during recent decades. This chapter is intended to assess the extent to which changes in climate may have contributed to this increased variability. In attempting to examine this issue, several difficulties are encountered. There are problems in matching the scales of analysis (both spatial and temporal), problems in isolating the significant climatic variables that affect crop yield variability, and problems with the inadequacies of the data themselves.

Three means by which climate can influence crop yield variability can be identified: through changes in mean climate, changes in climatic variability, and changes in cultivated area. We examine the evidence for these changes by reviewing some of the recent literature. We conclude that there is no indication, in general, that climatic changes are behind recent increases in cereal yield variability, although the role of climate may have been significant in a few regions (for example, in India, in sub-Saharan Africa, and, very recently, in Japan). The 1960s stand out in many regions as a period of generally low climatic variability compared with adjacent periods. However, the examples here are drawn from a rather ad hoc collection of sources, which together provide very little convincing evidence upon which to base any concrete judgement. Further work would require a more focused approach to the issue, using refined analytical methods.

ANALYZING CLIMATE EFFECTS

Temporal Variations in Climate and Crop Yield

At any location, measures of weather and climate (such as air temperature, solar radiation, and precipitation) can be observed or derived over time scales ranging from microseconds to millennia. The detection of variations in climate therefore depends critically on the time frame of reference. Furthermore, the temporal resolution of climatic data is of great importance in establishing causal relationships between climate and crop yields, for yields too can be analyzed over a variety of time scales. The range extends from measurements of the physiological development of crop plants at short intervals throughout the growing season to harvested yield averaged over decades or longer periods.

It does not follow, however, that in this investigation, which concentrates on fluctuations in average annual crop yields, the climatological analysis necessarily should focus on fluctuations in average annual climate. It is clear that the yield in a single year is not simply a function of an average annual climate, but rather the integrated effect of weather variations on the crop and its environment both before and during the growing season. Thus it is necessary to conduct our analyses at several temporal scales of resolution, although, in practice, considerations of data handling, quality, length of record, and spatial coverage sometimes restrict our options.

Spatial Variations in Climate and Crop Yields

Crop yield is an average quality taken to represent a particular area. On the basis of the size of area used to calculate yields, it is possible to identify three spatial scales that are of interest in this study. This enables us to discuss how we can select appropriate climatic data to match the spatial scale of the yield data.

First, it is important to recognize that a value of regional crop yield is simply an average that obscures any intraregional variations. As yields are commonly measured only over standard regions (such as counties, districts, or provinces), it is often difficult to obtain subregional scale data. However, when this is possible, it is then necessary (for the purpose of climatological analysis) to obtain data for locations that are representative of each of the subregions. For example, Huff and Neill (1982), using district data for five Midwestern states in the United States, demonstrate that the pattern of variability of July rainfall (the most important climatic factor influencing yields) matches closely the pattern of maize yield variability.

Second, one of the explanations cited for increased variability in national crop yield is that the cultivation techniques and crop hybrids used have become more spatially homogeneous. It is argued that with this decrease in regional diversity, countries may be more vulnerable to simultaneous interregional variations in crop yield over large geographical areas (for example, see Hazell 1984; Duvick, Workshop Paper 6). In testing this hypothesis, the effects of climate need also to be incorporated. Therefore, it is again necessary to establish a representative data set of regionally averaged climate from each of the regions for which yields are to be compared.

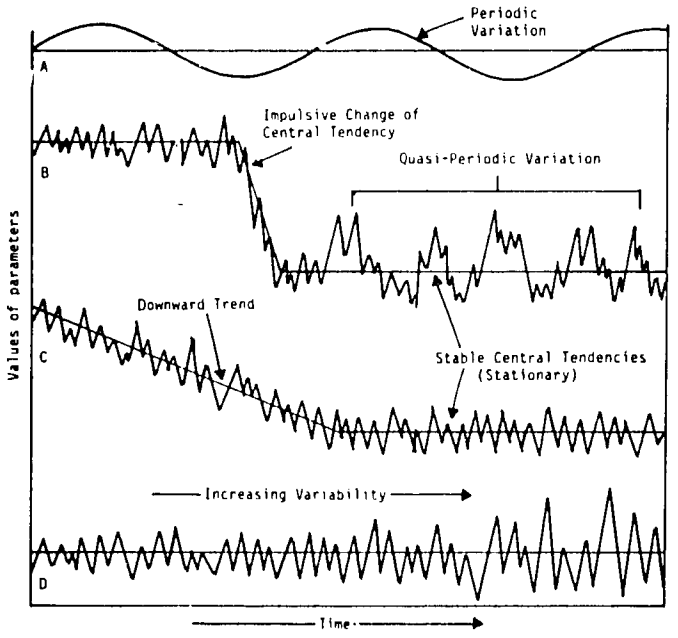
The third scale of analysis considers yield variations at remote locations. The significant crop failures in the Soviet Union in the 1970s and those that are causing devastating impacts in the semiarid zone of Africa to this day have, for different reasons, awakened public awareness of the importance and the effects of regional climatic variations. Over the same period, climatic research has progressed to the stage where scientists are beginning to identify global-scale "teleconnections" between climatic events occurring at geographically remote locations. The implications of this research are exciting, if only because they suggest causal mechanisms that may help explain coincident variations in crop yield variability in

regions spatially distant but that together may play a key role in determining world food trade, prices, and security. These issues are developed further below.

The Orthodox Classification of Climatic Changes

Four types of climatic change are illustrated in Figure 3.1. In the context of this paper, we can regard the high-frequency fluctuations depicted here as interannual variations that might be associated with year-to-year fluctuations in crop yield. While not dismissing the possibility of periodic or quasi-periodic variations in climate, such as are depicted by lines A and B in Figure 3.1, the time frame of this study (essentially the last few decades) precludes some of the long-period cycles, which might well resemble a trend such as that shown by line C in Figure 3.1. The more interesting climatic variations, from the point of view of crop yield, relate to shifts in central tendency -- either impulsive, step-like changes (line B), or gradual trends (line C) -- and to changes in interannual variability around the average (line D), or, indeed, to a combination of these.

Figure 3.1. Types of climatic change



Source: Based on Hare 1985.

ISOLATING THE SIGNIFICANT VARIABLES

For a cereal crop, the relative importance of temperature, light, water, and nutrients varies throughout the crop's development. During each phase of growth, the crop can be thought of as exhibiting an optimum tolerance range in response to its environment. If the weather conditions remain within these tolerance ranges during the growth of the crop, then these factors should not, by themselves, impose limitations upon crop yields (although other constraints may, of course, intervene).

However, the direct effect of climate as a constraint on yields assumes an importance with the occurrence of anomalous weather events that fall outside the tolerance range of the crop. These may be of very short duration (such as night frosts during the flowering phase, and strong wind, heavy rainfall, or hail before harvest), or occur over an extended period (such as serious soil moisture deficits brought on by anomalously low rainfall amounts, or periods of high rainfall where waterlogging may occur, causing leaching of important nutrients from the soil or rotting of the crop).

Thus if we are to test whether climate has contributed at all to increased crop yield variability, a standard climatological analysis of variability (for example, examining the interannual variance of air temperature averaged on an annual, seasonal, or monthly basis for successive decades) may not be wholly appropriate. Instead, we should first identify the critical tolerance ranges of a crop during each phase of growth, thus enabling us to evaluate the frequency of damaging weather events that lie outside these limits. Nonetheless, this information on its own serves little purpose unless the weather anomalies can be converted into a measure of effect on crop yield. For this reason, the use of mathematical models that stimulate crop responses to climate is of particular value.

The Use of Models

Models, by incorporating various physiological characteristics of a crop (including tolerance ranges, growth phases, and responses to environmental conditions) as well as crop management considerations (for example, sowing date, fertilizer applications, and weed control), can be used to test the sensitivity of crop growth and yield to any prescribed weather conditions (defined as model input variables).

For example, a simulation model has been developed by Horie (forthcoming) to study the sensitivity of Japanese rice yield to climatic variations. Irrigated rice in northern Japan is particularly susceptible to cold summer damage, which can cause grain sterility and hence reduced yields. Model runs can help to determine the nature and timing of the critical weather events (for example, July-August temperatures and, less importantly, June-September radiation). Thus, Horie was able to conduct a sensitivity study to ascertain the tolerance range of crop yield to these critical anomalies.

Of course, in conducting experiments of this kind, it is assumed that a model has been satisfactorily verified against actual condi-

tions. If this condition is fulfilled, then models may be quite effective tools for identifying those particular climatic anomalies to which a crop is more sensitive, while at the same time holding other factors (such as crop variety, fertilizer application, and sowing density) constant. Inevitably these factors are also likely to change through time, so it is clear that, in order to conduct a rigorous study of the impact of climate on crop yield variability over several decades, all of these adjustments need to be considered and modeled. This task is feasible in theory but only realizable in a few selected cases, where models and data are available.

Climatic Change as a Change in Risk

It is possible, as noted, to evaluate the frequency of damaging weather events that lie beyond the tolerance ranges of a crop. Given long-period data sets, such frequencies can be converted to measures of probability, forming the basis for assessments of the risk of climate impact. In areas where a single weather variable is the dominant yield-determining factor (such as precipitation in most dry regions and temperature in high latitude or high altitude locations), and in the absence of a detailed model, it is often instructive to compute indices of risk of climate-induced crop failure and to analyze how these risk levels may change between periods. (For example, see the analysis of failures in oats harvests over three centuries in southern Scotland by Parry and Carter 1985). As an important corollary to such studies of risk, if it is assumed that interannual climatic variability remains unchanged, any impacts from long-term changes in the mean climate are likely to be felt through changes in the risk of short-term events (Parry and Carter 1985; Mearns et al. 1984).

Mapping Spatial Shifts of Crop Suitability

The type of crop cultivated in a particular area is a function of many physical, economic, social, and political factors, but the preference for one crop rather than another usually bears some relation to its suitability for the prevailing climatic conditions of that region. While boundaries between crop types are difficult to discern on the ground, since they are really transition zones of comparative advantage, they can often be located approximately or the basis of climatic criteria related to crop tolerance ranges. However, we know that climate is not static, and secular changes either in the mean or the coefficient of variation will affect the location of the mapped isopleths. The risk of yield shortfalls will shift, and the hypothetical cultivation limits (however defined) will either contract across formerly cultivated land or extend into new territory. Such shifts have been illustrated by Newman (1980), who simulated the effect on the location of the U.S. corn belt of hypothetical changes in mean annual air temperatures of ±1° centigrade relative to the 1969-78 normal temperatures.

CLASSIFYING THE PATHWAYS OF CLIMATE EFFECTS

The effect of climate on crop yield variability may be transmitted via a number of different routeways.

Changes in Mean Climate

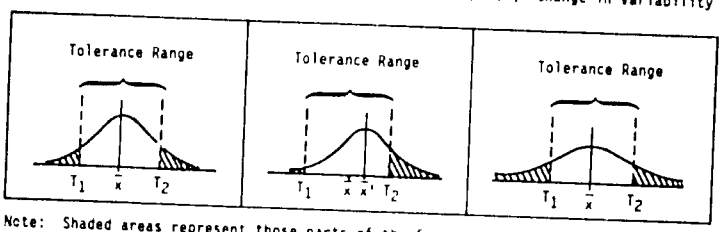
Using the concept of a crop tolerance range, we can illustrate (Figure 3.2a) how an existing crop is likely to be relatively well matched to the prevailing climate.[1] In this example the probability of critical climatic events (falling outside the tolerance range) is quite low (shaded regions) implying a correspondingly high chance of a successful crop yield. Figure 3.2b shows how a change in mean climate, with no attendant change in variability (see also line B in Figure 3.1), causes the whole distribution to shift relative to the normal situation. Moreover, if this occurred as an abrupt perturbation, we could expect there to be no initial change in locally grown crop variety, so the tolerance limits remain fixed.

Thus the shift in mean climate would, ceteris paribus, have a destabilizing effect on yields, with an increase in probability of upper-tail (or lower-tail for a shift in the other direction) anomalies disproportionately greater than the decrease in probability of lower-tail or upper-tail anomalies. However, if the transition to this changed climatic condition is gradual, it is likely that farmers would respond by planting a better adapted variety or a completely new crop, in order to maintain yield stability.

Changes in Climatic Variability

Figure 3.2c depicts the equivalent situation to that in Figure 3.2b, but here it is the variance of the climate that changes (in

Figure 3.2. Change in climate relative to normal



Note: Shaded areas represent those parts of the frequency distribution of a climatic parameter lying outside the tolerance range (T_1 - T_2) of a particular crop.

[1]Although the frequency distributions of some climatic variables such as rainfall or windspeed are often nonnormal, Figure 3.2a suffices for illustrative purposes.

this example, symmetrically) about a fixed mean (for example, see line D in Figure 3.1). Naturally our expectation would be of increased (or decreased) yield variability in response to equivalent changes in climatic variability. Note, however, that in these examples, if the normal range of climatic fluctuations had been well within the tolerance range (as might be the case in the core of a large grain growing region, for example) then the changes in climate represented in Figure 3.2b and 3.2c may have only a minor effect.

Changes in Cultivated Area

In a large region, the relationship between the size of cultivated area and the regional climate can certainly influence crop yield. In an earlier section we considered the effect of climatic changes on spatial boundaries of cultivation. Toward the limits of tolerance in a region, we would expect a crop to be more sensitive to climate and thus to exhibit higher variability of yields. However, if the cropped area is adjusted, this could affect regional yields either by expanding cultivation into more marginal land or by contracting into the more suitable, low-risk areas.

Aggregating these effects, we can construct a 4 x 3 matrix of climatic versus area effects on crop yield variability, showing qualitatively our intuitive expectations of the outcomes as an increase, as a decrease, or as no appreciable change (Table 3.1).

EVIDENCE FOR CHANGES IN MEAN CLIMATE

Long-term climatic data series for surface conditions (most appropriate for agricultural applications) are available from hundreds of meteorological stations over the globe, but their coverage is extremely variable both in space and time, making it very

Table 3.1--Response of crop yield variability to changes in regional climate and cultivated area

Climate	Cultivated Area: Current Area	Cultivated Area: Expanded Area	Cultivated Area: Contracted Area
Present climate	-	↑	↓
Change in mean climate	↑	↑↑	↑
Increase in climatic variablity	↑	↑↑	-
Decrease in climatic variability	↑	-	↓↓

Note: ↑ increase, ↓ decrease, - little change.

difficult to evaluate unbiased averages over large areas. The usual procedure is to use statistical methods to interpolate the station-point values to a grid network and from this to compute mean values. The two variables that have received the most attention are surface air temperature and precipitation. Variations in these are considered separately below and at two spatial scales: the global and zonal scale and the regional scale.

Global Temperature Variations

The majority of the long-period mean annual temperature series have been constructed for the Northern Hemisphere, extending over about a century of observations, by, for example, Jones et al. (1982, in press) and Vinnikov et al. (1980) on mainly land stations; and Folland et al. (1984) using marine data. All point to a mean hemispheric warming of around a half degree centigrade from about 1880 until the mid-1980s, punctuated by a cooling phase in the period 1940-65.

Records for the Southern Hemisphere are rather sparse, but some attempts have been made to produce temperature series. For example, Hansen et al. (1981) computed trends for the southern latitudes as part of a global analysis of surface temperatures. While the pattern of change is different from that in the Northern Hemisphere, a similar long-term warming tendency is evident.

Several workers have suggested that these trends provide evidence of a carbon dioxide induced climatic warming, which, when combined with estimates of the effects of volcanic aerosol loading and variations in solar activity, can explain a large percentage of the observed temperature variations (see Hansen et al. 1981, and Gilliland 1982). However, such claims should be treated with caution until robust statistical procedures have been developed and applied to test the significance of model fits (Weller et al. 1983).

This comment underlines the need for continued monitoring of surface temperature and further investigations into the causes of observed changes. For example, the important role of the oceans in regulating the climate cannot be ignored (see also Hansen et al. 1985), nor the observed increases of other (that is, non-CO_2) "greenhouse" gas concentrations in the atmosphere.

Trends in temperature have also been identified on a seasonal basis. Using the Gruza and Ran'kova (1980) Northern Hemisphere data set for January and July, Angell and Gruza (1984) report that the warming up to 1940 and the subsequent cooling until about 1965 show up strongly in the January data but hardly at all in the July data, implying that the hemispheric trends are dominated by winter conditions.

Finally, there is a striking contrast between temperature series from different latitudinal zones in the increase in interannual variability toward higher latitudes. This has been illustrated by Angell and Gruza (1984) for five latitudinal zones, and by Kelly et al. (1982), who remark that the range of variations in the data for the Arctic zones (65-85°N in their analysis) is three times greater than the range for the Northern Hemisphere average.

Global Precipitation Changes

Long-period records of precipitation, like temperature, are quite abundant for land stations, particularly in the Northern Hemisphere. However, in contrast to temperature, it is much more difficult to evaluate average precipitation amounts over large areas. There are several reasons for this.

First, precipitation amounts can be highly variable over space, especially in dry regions subject to localized and infrequent convective rainfall, which can distort both individual station records and area averages, so that special procedures are necessary to produce large-area averages that are at all representative. A second problem concerns the large areas, particularly over the oceans, where data are extremely scant. Third, the effect of orography on precipitation is more difficult to quantify than on temperature, and further complicates the compilation of area averages. Finally, precipitation trends at the global and hemispheric scale have received little attention from atmospheric scientists, who have focused on testing their hypotheses about global temperature changes.

The evidence that is available suggests that in most latitude bands in the Northern Hemisphere there has been an increase in January precipitation between 1945 and 1960 and a decrease thereafter to 1975 (Angell and Gruza 1984). In the July records, there are differences between zones, although a similar trend to that in January is strongly evident in the low latitudes. Over the continents, there is evidence of a long-term increase in January precipitation in northern Asia and in Eurasia, but in July this trend is not apparent, although there is an interesting "out-of-phase" relationship between long-term variations in July precipitation in America and those in northern Asia (Angell and Gruza 1984).

Lamb (1977) has expressed 1960-69 annual precipitation over the globe as a percentage of 1931-60 averages. An equivalent comparison of the 1970-79 pattern relative to the 1931-60 averages has also been conducted for the Northern Hemisphere (Lamb 1981), and while there are some differences between the patterns depicted, there are also noteworthy similarities. Both show significant negative departures over subtropical Africa, northern India, China, and much of the U.S. Great Plains. Positive anomalies are evident in both periods between northern European U.S.S.R. and eastern Europe, the southern United States, and western Scandinavia.

Regional Temperature Variations

It can be misleading to associate large-scale climatic change with changes in regional agricultural production. For instance, during the hemispheric "cooling" period (1940-65) some areas actually recorded a warming trend including the Ukraine, a major grain growing region. Other areas, for example, northern U.S.S.R., Alaska, and northwestern Canada, recorded significant cooling (Jones and Kelly 1983). The recent "warming" (1965-80), in contrast, has been strongest (>0.5°C) over northern Scandinavia, most of the U.S.S.R., Alaska, northwestern Canada, the southwestern United States, and

northern Africa, with cooling occurring over the Canadian Arctic islands and northeast Greenland.

Interpretation of regional temperature changes is further complicated by the differences in seasonal temperature trends. Small changes in annual mean temperature often mask large trends in the seasonal data. Of course the relevance of such trends for crop production depends upon the magnitude of changes and the particular seasons in which changes occur. For example, in northern Japan, rice is grown toward the limits of its tolerance to cool temperatures, so the recent warming trend (since about 1955), which is apparent in summer but does not show up in either the winter or annual records (Yoshino forthcoming), may help to explain the rather stable rice yields about an increasing trend during the period 1957-79 (Uchijima and Seino, forthcoming). However, four consecutive years (1980-83) of damage from cool summers have reemphasized that rice production in Japan is still vulnerable to the effects of climate. Thus although increasing temperatures would probably favor more stable rice production, there still remain cooler episodes embedded within the trend that can be damaging.

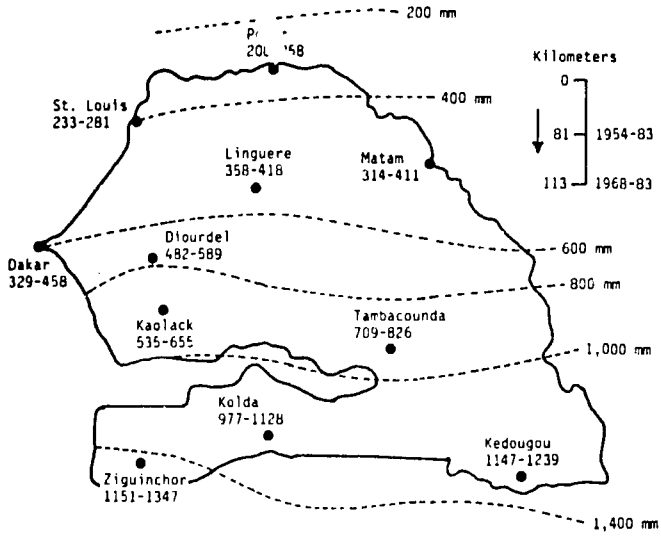
In the Southern Hemisphere, the rise in annual mean maximum temperatures in much of Australia was recorded between 1946 and 1975, with the greatest increase occurring in inland southeastern Australia (Coughlan 1979; Paltridge and Woodruff 1981). While there are considerable variations between regions, and while it is difficult to state unequivocally that a general warming has occurred in Australia (Hobbs forthcoming), there are also clear indications of warming in New Zealand from the 1860s until the present (Salinger 1979), leading some to suggest a possible causal link to CO_2 induced climatic change (for example, Pittock 1983). Trends toward increased precipitation since 1946 (discussed below) would also be consistent with the current estimates from the general circulation model of CO_2 related climatic change in this region.

Regional Precipitation Changes

The most distinctive and disturbing precipitation trends of this century have occurred in the semiarid sub-Saharan zones of Africa over the last 20 years. Even accounting for differences in the various data sets, all the rainfall series that have been compiled indicate a similar downward trend in annual rainfall since the 1950s (Farmer and Wigley 1985). A comparison of these records indicates how the drying trend intensified after the 1960s, with three waves of particularly dry conditions peaking in 1972, in 1977, and in 1983 through 1984 (the two driest years this century).

One effect of the sub-Saharan drought has been to produce a marked spatial shift of the rainfall regime. This is demonstrated in Figure 3.3, which shows how the isohyets of mean annual rainfall in Senegal calculated for the 16-year period 1968-83 are displaced by about 113 kilometers south of the isohyets based on long-term mean rainfall calculated for 1954-83. The agricultural implications of such a shift (paralleled across most of the sub-Saharan zone) include reduced rainfall amounts, a shortened growing season, and a lower probability of sufficient rainfall for crop production (that is, increased risk of crop failure; Todorov 1985).

Figure 3.3. Isohyets of mean annual rainfall in Senegal

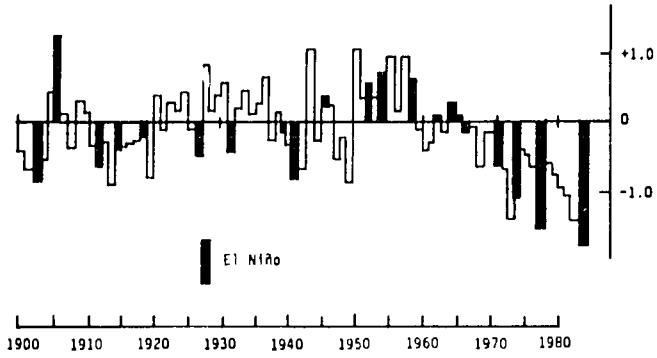


Source: Based on Todorov 1985.

Despite the many hypotheses put forward to explain the sub-Saharan drought, the causes are not known. Changes in surface albedo and soil moisture (characteristics often strongly correlated, which may be brought on by overgrazing or by drought itself), by affecting the surface radiation balance, can induce increased subsidence. These effects have a physical basis and can be replicated using computer models. However, in the sub-Saharan regions, the available evidence does not provide any convincing proof that these are major controlling mechanisms (see Rasool 1984).

The majority (over 70 percent) of precipitation in the Sahelian zone of the sub-Sahara originates from squall lines (World Climate Data Program 1985), which are associated with convergence in the lower troposphere between two upper-level easterly air flows, the tropical easterly jet to the south and the African easterly jet to the north. A weakening of these large-scale features can seriously disrupt the circulation patterns, resulting in enhanced upper-air convergence and subsidence, with consequent rainfall reductions at the surface. Weakening such as this occurred in 1982 and 1983 and may be related to the El Niño/Southern Oscillation (ENSO) phenomenon (see Figure 3.4; also see appendix to this chapter). However, while perhaps responsible for periodic enhancement of drought intensity, the ENSO-related events cannot explain the progressive drying trend in this region. It has been speculated that in many years, although the squall lines have been present (controlled as they are by large-scale effects), they have produced less rainfall because each system contains less water vapor (a possible result of deforestation, poor vegetation cover, and dry soils; Kandel, personal communication).

Figure 3.4. Rainfall in the Sahel and the occurrence of the El Nino/Southern oscillation phenomenon, 1900-83



Source: Based on World Climate Data Program 1985.

Finally, the severity of the present conditions relative to earlier recorded droughts has prompted some to speculate on the possible role of atmospheric carbon dioxide and trace gas concentrations in influencing the climate of the region (for example, Farmer and Wigley 1985). However, temperature and precipitation records offer few clues about any global trends during the past 30 years that might be associated with the changes in the sub-Saharan zone.

Evidence for long-term changes in annual precipitation can also be discerned from the instrumental records of rainfall in Australia. Much of eastern Australia was wetter in the latter part of the nineteenth century than in the first half of the twentieth century, and this may account for the failure of denser settlement in much of northeastern South Australia, particularly in the 1890s (Hobbs forthcoming). After 1945/46, an increase in annual rainfall amounts (concentrated in the spring, summer, and autumn months) of about 10 to 20 percent was observed over the major wheat growing area of southeast Australia (for example, Pittock 1983). Along with the temperature increases in some regions (see above), a spatial shift in the pattern of climate occurred, which might well have affected grain yield stability in the wheat belt.

EVIDENCE FOR CHANGES IN CLIMATIC VARIABILITY

Changes in Temperature Variability

There is no clear evidence of a link between trends in interannual variability and trends in mean hemispheric temperature over the last century (van Loon and Williams 1978). More specifically, in recent years (1961-78) there has been no significant increase in annual temperature variability in Europe relative to the 1931-60

period (Schuurmans 1984), although there is some evidence of a negative correlation between period mean winter air temperature and interannual variability (Schuurmans and Coops 1983).

In the United States Midwest a tendency toward decreased interannual mean monthly temperature variability between the 1930s and the 1970s was observed, mainly during the winter months (Chico and Sellers 1979). In common with a tendency in the Northern Hemisphere as a whole, however, this does not appear to be related to trends in mean temperature (van Loon and Williams 1978).

Temperature variability can also be viewed in terms of shorter time-scale fluctuations and changes in the range of temperature extremes. For example, over much of the United States and Canada, a significant decrease (most apparent in the summer and autumn) in the mean diurnal temperature range (that is, the difference between daily maximum and minimum temperatures) has been observed during the period 1941-80 (Karl et al. 1984). These results can be considered alongside a recorded increase of about 1° centigrade in mean spring and summer temperatures and a decrease of 20 to 40 percent in spring and summer precipitation in the central and northern United States Great Plains over a similar period (Karl and Riebsame 1984). Combining all of these results, it is pertinent to ask two questions:

- What has been the impact on crop production, if any, of these apparent tendencies during the growing season in the Great Plains toward increased mean temperatures, decreased diurnal temperature range, and decreased mean precipitation?
- Furthermore, if (as conjectured by Karl and Riebsame) these trends could serve as a partial analog of a future CO_2 enriched climate, what might the impacts of continued changes be on the level and stability of crop production?

As partial response to the first question, there is little doubt that benign weather conditions contributed to very favorable and stable crop yields in the Great Plains during the period 1956-73 (Thompson 1975). However, recent events such as the 1984 drought serve as reminders of the potential effects of the climate on crop yields, especially if such events are likely to become more frequent through trends such as those implied above.

Changes in Precipitation Variability

In general, for any latitude zone, interannual precipitation variability tends to be highest where the mean annual rainfall is lowest. This relationship implies that, in the absence of irrigation, where crops are grown in dry regions, not only are average water resources restricted, but they are also highly variable. The coefficient of variation of annual precipitation trends in semiarid areas such as the Sahel zone of Africa, northwestern and central India, northeastern Brazil, and much of Australia usually exceeds 25 percent and often approaches 40 percent at desert margins (Lockwood forthcoming). In some regions positive annual anomalies may imply torrential rain and flooding, but in all regions, large negative departures indicate drought, and this generally implies crop failure. It has been suggested that no regular secular pattern in the interannual variability of precipitation can be detected for semiarid

regions, except perhaps a very weak two-to-three-year rhythm in some areas, and a 10-, 20-, or 30-year recurrence interval in others (Rasool 1984). We examine this assertion further below.

Whereas meteorologists look to the global temperature record for indications of global-scale climatic change, they use regional precipitation patterns to provide clues about the mechanisms underlying short-term climatic variability. Several global teleconnections have been noted. For example, there is a strong tendency for the El Niño phenomenon to occur simultaneously during -- or within one year of -- drought in northeast Brazil (Hastenrath 1984), and ENSO events seem also to be associated with some of the severest droughts in Australia (including five out of the six that have occurred since 1950; Hobbs forthcoming). Similarly, there appears to be a strong negative correlation between the occurrences and intensity of El Niño and the Indian summer monsoon rainfall (Rasmusson and Wallace 1983). Moreover, there appears to be a significant positive correlation between the strength of the Indian monsoon and the strength of the zonal circumpolar westerlies over Eurasia, implying that when the Indian monsoon is drier than usual there is a tendency toward blocking and meridional flow in the middle latitudes (Raman and Maliekal 1985). This relationship supports an independent observation of increased irregularity of the Indian monsoon in the 1960s and 1970s relative to the period 1925-60, coincident with a general decline from about 1950 to 1980 in the number of days with surface westerly winds over the British Isles, a good indicator of the strength of the zonal circulation (Lamb 1981).

A century-long rainfall series for southeastern Africa reveals that 22 of the 28 ENSO events during the past 110 years were accompanied by below-normal rainfall (1875-1977 mean). There are indications that the periodic intensification of the sub-Saharan drought mentioned above was related to the occurrence of ENSO (Figure 3.4), and ENSO episodes have also been correlated with above-average winter temperatures in southwestern Canada and the northwestern United States, and with abnormally wet winters in the Gulf States and northern Mexico (Rasmusson and Wallace 1983). However, as these authors point out, there are many regions where there is no evidence for systematic patterns of anomalies during ENSO events (for example, in Eurasia and over much of North America), although several of these areas have recorded unusual weather during an individual episode, such as the 1982-83 ENSO.

Further work in Brazil (Molion and Nobre forthcoming) and in Australia (Nicholls and Woodcock 1981; Hobbs forthcoming) explores the possibility of exploiting the teleconnections between measurable atmospheric and oceanic effects to allow prediction of droughts several months in advance of their occurrence. Results seem encouraging but verification is difficult.

More important for the purposes of this investigation is the identification of any trends toward increased or decreased variability of precipitation over the last few decades. The recent increased irregularity of the Indian monsoon and the sub-Saharan drying trend have already been noted, but in other regions there is little evidence of significant changes in variability. However, the global teleconnections do show us that simultaneous anomalies of climate are, in many regions, linked in some way to the ENSO phenome-

non and are not simply coincidental. Furthermore, the ENSO events, when they occur, are often associated with some of the severest climatic anomalies. It may be that, while the episodes themselves are probably no more frequent than previously, the world food system is more sensitive to the distinctive global anomalies that they induce.

One characteristic of many precipitation series that hampers the interpretation of relationships between yield variability and climate is the clustering of years with anomalously low rainfall. One good example of this is the record of drought in the United States Great Plains where the 1930s and 1950s show up as periods of persistent drought conditions (Warrick 1980). Similar traits of drought clustering are also evident in the Soviet Union (Rauner 1985).

The probability of simultaneous drought has also been investigated. For example, estimates show that droughts are likely to occur simultaneously in both the U.S.S.R. (Asian and European) and United States grain growing regions in about 1 year in 20 or 25 (Rauner 1980). Drought is a major cause of wheat yield variability in each of these regions, and it is interesting to match this probability (4-5 percent) with the probability of significant wheat yield shortfalls (10 percent or more below mean trend yield) occurring simultaneously in both countries, estimated at about 7-8 percent (Sakamoto et al. 1980). The implications for world food security of such events could be far reaching, particularly if their likelihood increases as a result of climatic change.

EVIDENCE FOR CHANGES IN CULTIVATED AREA

It is extremely difficult to judge the extent to which changes in cropped area have influenced regional crop yield variability. For instance, of the 800 thousand hectares of paddy rice taken out of cultivation in Japan from 1970-84, about 20 percent was withdrawn in Hokkaido, the northernmost and most unstable production area (Yoshino forthcoming). This contraction into more favorable areas (a policy for reducing total production) may have contributed to a subsequent increase in mean yields and to a stabilizing of total production, although other factors, including improved technology and management and the weather itself, are also important and may tend to mask any trends.

In the United States, each year a certain percentage of the planted area is not harvested, particularly in regions that are climatically marginal for crop growth. In the Great Plains, unfavorable weather conditions are of major significance in influencing the farmers' decisions to abandon spring and winter wheat crops (Michaels 1985), actions that may have contributed to a stabilization of harvested yields in this region.

In the U.S.S.R., the expansion in the 1950s of grain cultivation to drought-prone regions in the new lands of Kazakhstan and western Siberia, though adding a highly variable component to total U.S.S.R. grain production, may well have helped, paradoxically, to stabilize national yields, for good yields in these regions tend to offset poor yields in the traditional grain growing regions (Sakamoto et al. 1980). Note that the assessment of crop yield in the U.S.S.R., since it is based on planted area and not harvested area as in the United

States (Tarrant, Workshop Paper 29), may exaggerate the variability of crop yields relative to that in the United States, although other differences in yield measurement may negate this disparity.

CONCLUSIONS

It is extremely difficult to evaluate the role of climate in influencing changes in grain yield variability. There are problems of

- separating out the role of climate from a host of other factors that together determine crop yields and yield variability;
- identifying the climatic variables that are significant in influencing crop yields and matching their spatial and temporal scales of measurement to those of the crop;
- detecting possible trends in the climatic data that may have affected crop yield variability; and
- explaining the connection between remote variations in climate and how these may affect regional grain yield variability and the stability of world grain production and trade.

Summary of Results

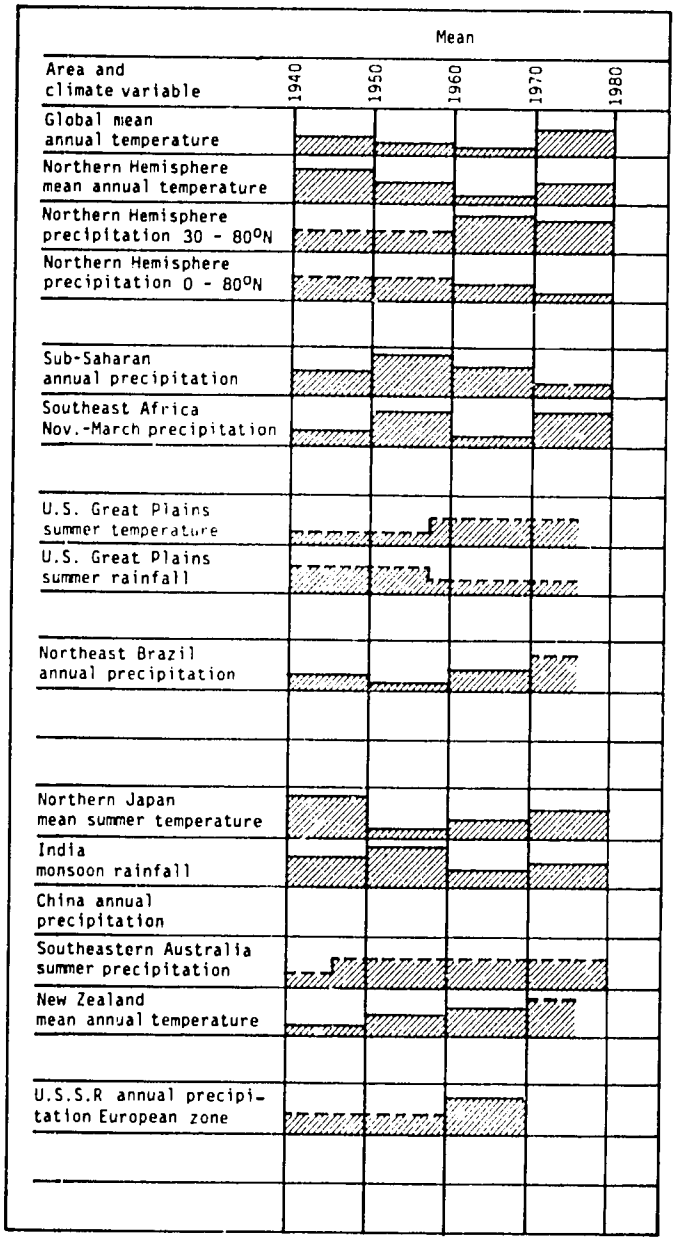
We have attempted to synthesize some of the available knowledge on how climate can influence crop yield variability. Three categories of change were identified as potential influences on crop yield variability: (a) changes in mean climate; (b) changes in climatic variability; and (c) changes in cultivated area. Evidence for changes of each of these types (and at a variety of spatial scales) have been identified. A summary of the first two types of direct climatic changes for 1940-80 are presented in Figures 3.5 and 3.6. These are not intended as exhaustive lists; the trends (if any) are depicted on a decade-to-decade basis and are meant to provide an impression of the appropriate relative magnitude of any changes.

From the material assembled in Figures 3.5 and 3.6 and throughout the chapter, we conclude that there is no indication, in general, that climatic changes are behind recent increases in cereal yield variability, although the role of climate may have been significant in a few regions (for example, in India, in sub-Saharan Africa, and, very recently, in Japan). The 1960s stand out in many regions as a period of generally low climatic variability compared with adjacent periods. At a global scale there is widespread evidence for a recent warming trend from about 1965 to the present. Trends in precipitation are more difficult to discern, but there appear to be strong global teleconnections between certain regional precipitation anomaly patterns and the El Niño/Southern Oscillation phenomenon.

Further Work

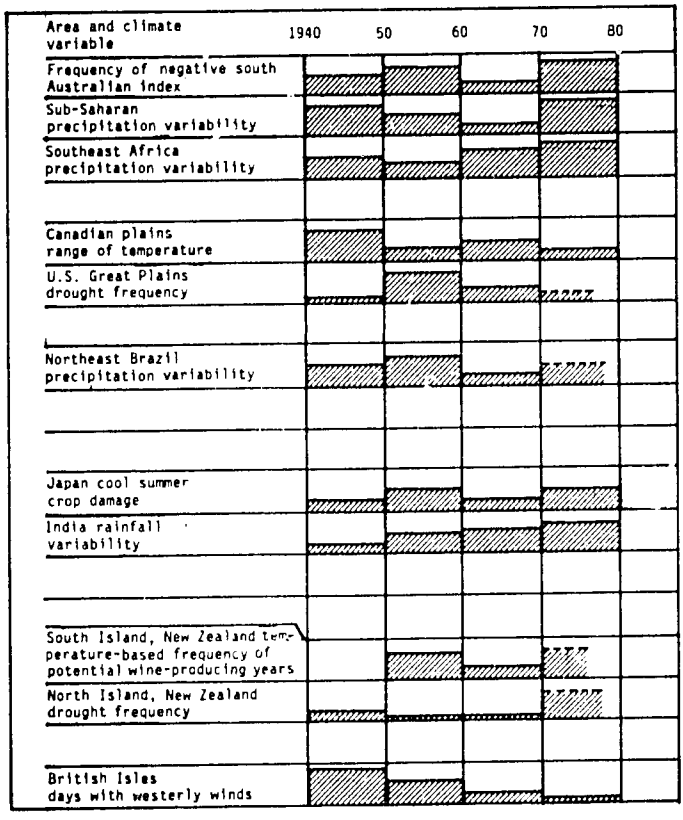
The examples presented here have been drawn from a variety of sources, but together they still provide very little convincing evidence upon which to base any concrete judgements. If more comprehensive and definitive results are to be obtained, there is need

Figure 3.5. Change in mean climate by continent and hemisphere, 1940-80



Note: Assessments are approximately on a decadal basis except where a dashed line is used. Height of bars depicts relative change and is not to scale.

Figure 3.6. Change in climate variability by region, 1940-80



Note: Assessments are approximately on a decadal basis except where a dashed line is used. Height of bars depicts relative change and is not to scale.

- to evaluate the critical tolerance ranges of crops with respect to climate, estimating these according to the crop varieties grown in a particular regional environment during the investigation period;
- to conduct direct analyses of climatological data using methods that will produce information pertinent for studies of crop yield variability; for example, studies of trends in maximum and minimum temperatures and evaluations of frequencies of climatic events that are damaging to crops;
- to use appropriate and validated crop-climate models that can simulate, by holding other factors constant, the sensitivity of crop yields to climate over several decades, allowing the user to identify any climatic variables that may be responsible for changes in modeled crop yield variability; and
- to monitor changes in cultivated area and abandonment trends (seasonal or longer) of planted cropland, so that these can be incorporated into any assessment of crop yield variability.

APPENDIX: THE EL NIÑO AND THE SOUTHERN OSCILLATION (ENSO)

El Niño, or the Christ child (so called because it generally develops soon after Christmas), is a southward flowing ocean current, which brings warm waters to the normally cool coast of Ecuador and Peru. In recent years, this local oceanic phenomenon has been linked to a global atmospheric phenomenon known as the Southern Oscillation (SO). The SO is related to the observation that high atmospheric pressure over the Pacific Ocean is usually associated with low pressure over the Indian Ocean. This normal condition is linked, in turn, to average tropical atmospheric circulation patterns, which are characterized by three major convective rain generating areas of rising motion over southeast Asia and the western Pacific, tropical South America (Amazonia), and Africa (the Congo). Rainfall varies in the opposite direction to pressure, so that during a reversal (oscillation) of the pressure field, a high-pressure anomaly develops over the Indian Ocean (with low-rainfall anomalies over Australia and south and southeast Asia), and pressure becomes anomalously low over the equatorial central and eastern Pacific (giving above-average rainfall in these regions). The effect may be transmitted to other regions by shifting the location of the equatorial "Walker" circulation cells.

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4 Genetic Aspects of Yield Variability

John H. Holden

BREEDING FOR YIELD STABILITY

A characteristic feature of breeding programs in developed countries has been the high priority accorded to selection for yield under high-input systems. Crop varieties produced in this way have been described as high-response varieties, and it has been a feature of many of them that they have been particularly liable to show variations in yield response to variations in the environment. Year-to-year variations in soil nitrogen and soil moisture seem particularly important environmental components of yield stability.

The awareness of genotypic variation in yield stability of crop varieties comes from two principal sources, namely agricultural experience and experimental evidence. Finlay and Wilkinson (1963) developed a method for detecting and measuring differences between genotypes in sensitivity to the environment. In the barley varieties they analyzed, they found that high yielders were often unstable in their expression of this character (high genotype x environment [G x E] interaction) and that, conversely, low yielders were usually more stable in yield; that is, they were less responsive to environmental change (low G x E interaction). A third type of variety was shown to occur having intermediate sensitivity and yield across a range of environments.

Since the 1960s breeders have given increasing attention to the development of varieties with high and consistent performance. Breeders have two routes to this goal: (a) purposive breeding from parents selected for their ability to give stable progeny, and (b) selection among advanced lines of progenies not specifically bred for stability, to estimate G x E interactions (in multisite trials) and to detect those with the more stable yields. Both methods have been used and there are now numerous reports in the literature of the production of varieties with both improved yield and stability. There are a number of studies of cereals: for maize -- Cross (1977), Fakorede and Mock (1978), Francis and Kannenberg (1978), Lee et al. (1983), Subandi (1979), Toderkan (1980), Toit et al. (1979); for rice -- Kim et al. (1983), Mahadevappa et al. (1979), Mohanty and Roy (1974); Morais et al. (1981), Shankare Gowda et al. (1973), Vergara (1976); for wheat -- Gupta et al. (1977), Heiner (1976), Jatasra and Paroda (1980), Saulescu et al. (1980); for sorghum -- Rao and Rao (1978); for barley -- Centro Internacional de Mejoramiento de Maíz y Trigo (1977); for oats -- Reinbergs (1977).

Thus the breeding of varieties having both enhanced yield and stability is becoming commonplace and is probably feasible in all crops. However, the priority accorded to yield stability among the other selection criteria in a breeding program, will depend on the agricultural system for which the variety is intended. In advanced systems, where the major variables of the crop environment are largely controlled by the farmer through irrigation, fertilizers, fungicides, and insecticides, stability achieved by genetic means can be less important, and yield is frequently an overriding breeding objective.

PHENOTYPIC ASPECTS OF STABILITY

Numerous attempts have been made to analyze and explain stability in terms of physiological, anatomical-morphological, or developmental features of the plant. Various mechanisms have been invoked, such as higher and more efficient uptakes of major and trace elements present at low levels in the soil (Mahadevappa et al. 1979) or of soil moisture under conditions of water stress. In the case of some maize hybrids, yield stability was attributed to their possession of a short grain filling period, thereby reducing the time during which grain development was susceptible to environmental stress (Francis and Kannenberg 1978).

This diversity of interpretations of stability at the functional level is a reflection of the fact that yield -- of seed, fruit, root, or leaf -- is the result of the interaction of the diverse physiological activities of the plant and that each of these can act as a limiting factor on yield when stressed by a particular component of the environment. Identifying the critical development features or phases and breeding and selecting for desired expressions of these characteristics can more effectively lead to genotypes that are insensitive to environment than simply screening the final selections from a breeding program for stability of performance in multisite trials. But whatever the level of precision adopted in a breeding program, the point to note is that variation in yield can be reduced by genetic means.

BUFFERING IN POPULATIONS

The genotypically and phenotypically heterogeneous cereal landraces presented a degree of diversity to the environment such as the ensuing range of interactions served to buffer the response of the population as a whole and probably conferred a degree of yield stability from site to site and year to year.

One of the principal aims of plant breeding since the mid-nineteenth century has been to reduce the variability in crops, both inbreeders and outbreeders, and to increase the proportion of individuals with the desired phenotypes. In this, breeders have been very successful, raising both uniformity and yield and, in many cases, crop quality, also. However, in the absence of conscious or effective selection for yield stability, environmental sensitivity seems to have been an undesirable consequence of these breeding aims.

There has been a long history of experimentation in cereals with mixtures of pure lines to test the hypothesis that different components of the mixture could exploit different niches or strata of the crop environment and so raise yield levels above those of the components grown as pure stands. The aims of this work have usually been to raise yield levels per se rather than to improve yield stability, and while some experiments failed to demonstrate any advantage in either character (Lang et al. 1975), the general trend seems to be toward positive but small advantages in yield for the mixtures (Simmonds 1979). Recently, to profit from the buffering due to heterogeneity, attempts have been made to construct mixtures from high-yielding lines in order to improve yield stability.

An example of the successful use of population diversity to increase yield stability concerns resistance to wind dispersed fungal diseases. Two types of mixture have been proposed: (a) multiline varieties constructed from a mixture of isogenic or near isogenic lines and differing in alleles at a major gene locus, for example, resistance to stem rust in wheat (Borlaug 1959); and (b) mixtures of established varieties that differ in their resistance to physiologic races of the pathogen (Wolfe 1977). Both methods have been shown to delay the rate of development of an epidemic compared to that in crops consisting of monocultures of the components of the mixtures, to raise yields above the mean of the components grown singly, to reduce variation in yield, and to slow the rate of adaptation of the fungal population to the host resistance.

Despite the clear evidence from experiment of the benefits of heterogeneity, it seems that the magnitude of these benefits has been insufficient to offset the disadvantages to the management or marketing of the crop, for mixtures have not found a significant place in modern agriculture.

BUFFERING IN INDIVIDUALS

Heterozygotes

Since heterozygosity of individuals is usually associated with heterogeneity of populations in outbreeding species, both could contribute to buffering, and experiments to demonstrate the significance of heterozygosity must take this into account.

A comparison of six characters in maize inbreds and hybrids showed that the inbreds had larger coefficients of variability and were therefore less stable in phenotype (Shank and Adams 1960). This type of result is usually attributed to the allelic diversity of the hybrids, permitting greater flexibility of response to environmental change and thereby providing greater possibility of maintaining stability of phenotypic expression.

Homozygotes

With regard to homozygotes, however, Shank and Adams's experiment in maize also showed that the inbreds differed among themselves in their stability, and therefore it is necessary to recognize that attributes of genotypes other than heterozygosity are important when

considering breeding for stability in inbreeding crops. This view is supported, of course, by much practical experience in wheat, oats, barley, and rice, which demonstrates unequivocally that some pure lines are more stable than others and that breeding and selection for this character is a perfectly feasible objective.

IMPLICATIONS FOR GENETIC RESOURCES

Three kinds of genetic diversity influencing sensitivity to environmental variation have been identified: in populations, in heterozygotes, and between homozygotes. It is clear that each is capable of being manipulated and exploited to produce varieties of more stable yield. Since modern varieties are the result of a long process of reduction of genetic diversity, the question may be asked whether there is evidence that this progressive narrowing of the genetic base of our crop plants -- desirable as it may be from many points of view -- will seriously interfere with the selection of more stable varieties of inbreeders and outbreeders. The answer appears to be no, in that successes have been recorded in many crops where the attempt has been made to improve stability. For this reason breeders may be expected to continue to work with their adapted gene pools, so long as they can provide genetic gains in yield and stability, rather than risk disrupting adapted gene complexes by wide outcrossing.

In the special cases of disease and drought stresses, which for many crops are the principal causes of yield variation, there is clearly a need for new sources of variation from outside the gene pool of advanced cultivars. In these cases, breeders will continue to explore the wider gene pool of the crop and its wild and weedy ancestors for exploitable variation. It is in this area that we can expect crop genetic resources to continue to contribute to both the raising and stabilization of crop yields.

In conclusion, it should be said that while breeding has a significant contribution to make in the stabilization of crop yields, there are limits to what can be achieved in this way. The probability of breeding varieties capable of giving high and stable yields under widely fluctuating environments is low. It has to be remembered that breeders rarely, if ever, select for one character in isolation and usually try to hold simultaneously the desirable expressions of several others. For example, it rapidly becomes impossible to retain palatability and digestibility in forages or grain quality in cereals when selecting for resistance to increasingly low soil water.

Breeding, therefore, has a part to play in stabilizing yields, but its contribution relative to complementary approaches will depend on the crop, the nature of the environmental variables (drought, diseases, or pests), and the agricultural system under which the crop is grown.

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5 Yield Variability and the Transition of the New Technology

H. K. Jain, M. Dagg, and T. A. Taylor

The new agricultural technology based on improved varieties and the increased use of modern inputs has proved to be highly rewarding. It has led to significant increases in production growth rates in many developing countries. Tsutsui and Singh (1985) show that the growth rate of cereal production and yield has been higher in the Asia-Pacific region than in the rest of the world in recent years. They especially draw attention to increased production of wheat, rice, and coarse grains in these countries.

The effect of the new technology in many of these countries can also be seen in other ways. Thus Bangladesh, which faced a desperate food situation at the time of its independence in the early 1970s, has recorded a major advance in the production of both wheat and rice and could be well on its way to food self-sufficiency. Indonesia has more than doubled its rice production in the last ten years. Thailand has emerged as a major exporter of food, including not only its traditional export, rice, but also maize, soybeans, and cassava. Similarly, many Latin American countries have recorded major gains in their food production. Africa as a continent remains an exception, although some African countries (for example, Zimbabwe) have made effective use of the new technology to increase their production of maize and other crops.

Gains in food production should obviously contribute to an increasing sense of food security and stability. There is, however, no consensus on food stability even if it is generally accepted that the overall food situation in many of these countries has improved. Some social scientists have pointed out that food stability may, in fact, have declined in the sense that there is greater variability in the production and yield of some of the major food crops since the introduction of the new high-yield technology.

Many of these authors specifically refer to the situation in India. The link between agricultural growth and variability of agricultural output first received attention from Indian scientists like Sen (1967) and Rao (1975). Rao drew attention to the fact that

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since variability in yields tends to be far greater than that in area, productivity based growth has contributed to greater variability, as suggested also by Barker et al. (1981). Summarizing the observations of these and other authors, Hazell (1984) has posed the question whether the yields of crops grown with the new technologies may be more sensitive to weather and disease. Further, because they require more input, their yields may be more sensitive to year-to-year variability in input use arising from frequent price changes or from supply restrictions.

The concept of food security incorporates in it elements of stability, so that a country's agriculture may become a dependable source of food supplies year after year. In traditional agriculture this has seldom been possible. It would appear from the studies mentioned above that the new agricultural technology developed in recent years may also create instability. Obviously, this raises some basic issues, and it is useful at this stage to review some of the data that have led to these conclusions.

FOODGRAIN PRODUCTION IN INDIA

Soon after gaining political independence in the 1950s, India organized programs of agricultural development based essentially on crop varieties that do not require intensive use of inputs like chemical fertilizers. In the 1960s India made important policy decisions to transform its traditional agriculture. A major instrument of the new policy was the high-yielding varieties program, a program that has continued to grow and that now covers many crops and areas. India thus provides two fairly well-defined periods, one associated with traditional technology and one associated with modern technology.

Previous Studies

A number of authors have examined the effect of the new technology in terms of gains in production and yield and expansion of area (for example, Jain and Singh 1985). Some of them have also studied its effect on the stability of production and productivity. The first comprehensive analysis of this kind was carried out by Mehra (1981), who analyzed data for two periods: 1949/50 to 1964/65 and 1967/68 to 1977/78. Thus Mehra had 16 years of crop production data for the traditional period and 11 years for the modern period (the agricultural year in India extends from June to May). She excluded from her analysis the two crop years of 1965/66 and 1966/67 on the grounds that these were extreme drought years and could create possible distortions.

Mehra's main finding is that both the standard deviation and the coefficient of variation increased for production and yield for most of the foodgrains in the second period as measured by deviations from trend. She further observed that the difference in the variability of foodgrain and nonfoodgrain crops widened during the second period, indicating that foodgrains fluctuated more in recent years.

These studies have been extended more recently by Hazell (1984), who reached essentially similar conclusions. Hazell concludes that the coefficient of variation of production increased during the second period for all cereal crops except minor millet. Thus crops like rice, wheat, grain sorghum, maize, pearl millet, and barley showed increased yield variability during the second period, which saw the advent of the new technology.

Extending the Variability Analysis

India's high-yielding varieties program has come a long way since 1977/78, the last year encompassed in the two studies discussed above. It is now possible to analyze data over a longer span of 35 years, ending with the crop season 1983/84. The 35-year span has been divided into two periods: a period of 18 years (1949/50 to 1966/67) before the high-yield period, and a period of 17 years (1967/68 to 1983/84) of high yield. The longer time span should make for greater reliability in the analysis of the data.

More important, it is no longer necessary to leave out any of the crop years. Droughts are an integral part of Indian agriculture and its most important source of instability. Mehra and Hazell were probably justified in leaving out the two drought years of 1965/66 and 1966/67 from their pre-high-yield period considering the fact that the high-yield period was only 11 years. However, Indian agriculture since the early 1970s has encountered several serious droughts, including those of 1972/73 (characterized as very poor for agricultural production), 1973/74 (poor), 1974/75 (very poor), 1976/77 (poor), 1979/80 (very poor), and the next three years (all poor) (see Fertilizer Association of India 1984). Besides, the high-yield period saw the destabilizing effect of the oil crises of 1973 and 1979. Considering these factors, it seems more justified not to leave out any of the years from the two periods. It may well be that, on balance, more adverse conditions have been encountered during the second period than the first, but this must be ignored for the purpose of the present analysis until a more satisfactory quantitative measure of such adversity can be devised.

Table 5.1 summarizes the results of this analysis on India's important cereal crops: rice, wheat, maize, sorghum, and pearl millet. These five cereal crops have received the largest attention in terms of genetic improvement and form the main component of the high-yielding varieties program. Year-to-year variability in production, yield, and area was computed for each of the two periods in the form of standard deviations and coefficients of variation (cv) calculated around linear trend lines, which were estimated separately for each of the two periods.

The analysis shows that while the standard deviation of total cereal production increased between the two periods, relative variability, as measured by the cv, declined by nearly 17 percent. Rice and wheat, the two most important foodgrains of India, and grain sorghum also show a decline in their cvs between the two periods. However, maize and pearl millet show greater cvs in the second period. Yield variability follows a similar pattern, and total cereals, rice, wheat, and sorghum all show smaller cvs for yield during the second period.

Table 5.1--Production and yield of cereals in India, 1949/50 to 1966/67 and 1967/68 to 1983/84

Crop	Production			Yield per hectare			Area		
	1949/50 to 1966/67	1967/68 to 1983/84	Percent Change	1949/50 to 1966/67	1967/68 to 1983/84	Percent Change	1949/50 to 1966/67	1967/68 to 1983/84	Percent Change
	(10^3 tons)			(kilograms per hectare)			(10^3 hectares)		
Mean									
Total cereals	60,080.72	103,353.18	72.02	677.61	1,008.06	48.77	88,123.61	102,257.88	16.04
Rice	29,287.72	45,833.29	56.49	882.11	1,181.00	33.88	32,987.67	38,680.76	17.26
Wheat	9,321.22	29,105.47	212.25	768.00	1,424.59	85.49	11,987.72	20,061.71	67.35
Maize	3,502.33	6,335.35	80.89	837.22	1,085.59	29.67	4,095.89	5,831.71	42.38
Sorghum	8,092.28	10,131.47	25.20	462.06	607.88	31.56	17,422.56	16,728.06	-3.99
Pearl millet	3,545.56	5,403.00	52.39	319.17	456.12	42.91	11,047.72	11,803.88	6.84
Standard deviation									
Total cereals	5,062.79	7,241.26	43.03	44.70	57.12	27.79	2,088.88	1,687.45	-19.22
Rice	3,101.60	4,156.81	34.02	82.19	86.18	4.85	679.35	836.35	23.11
Wheat	872.53	2,434.70	179.04	55.90	84.76	51.63	745.94	785.15	5.26
Maize	255.91	715.19	179.47	57.58	115.55	100.68	121.76	136.21	11.87
Sorghum	978.92	1,165.69	19.08	46.50	59.09	27.08	634.75	759.29	19.62
Pearl millet	475.04	1,371.86	188.18	32.54	96.08	195.27	694.60	731.69	5.34
Coefficient of variation (%)									
Total cereals	8.43	7.01	-16.84	6.06	5.67	-14.09	2.37	1.65	-30.38
Rice	10.59	9.06	-14.35	9.32	7.30	-21.67	2.06	2.16	4.85
Wheat	9.36	8.37	-10.58	7.28	5.95	-18.27	6.22	3.91	-37.14
Maize	7.31	11.29	54.45	6.88	10.64	54.65	2.97	2.34	21.21
Sorghum	12.10	11.51	-4.88	10.06	9.72	-3.38	3.64	4.54	24.73
Pearl millet	13.43	25.39	89.05	10.20	21.06	106.47	6.29	6.20	-1.43

When contrasted with the results of earlier studies, the analysis suggests that the introduction of the new agricultural technology in India is now reaching a stage where the increased production of some cereals is combined with greater relative stability of production. There are exceptions, and these deserve some consideration. Pearl millet, for example, seems more variable in its production following the advent of the high-yielding varieties. This has a relatively simple explanation. Pearl millet in India provides a classic example of the genetic vulnerability brought about by increased genetic uniformity. The successful high-yielding varieties program in this crop was based on four single-cross hybrids, all of which had a common cytoplasmic male sterile parent (developed at Tifton, Georgia). This parental line was responsible for the vulnerability of all four hybrids to downy mildew, which resulted in a sharp decline in production and yield in the early 1970s. It is only in the past five years or so that the genetic diversity of the male sterile lines has been sufficiently increased to increase the production of pearl millet.

Maize, which also shows an increase in its cv between the two periods, presents a different situation. It is one of the most demanding crops in terms of its need for agronomic management and its sensitivity to climatic conditions. For this reason, maize is now being shifted from the kharif (rainy season) to the rabi (winter season), to which it appears to be better adapted. As a native of Central America, maize has never been at home in India during the highly volatile monsoon season.

THE TRANSITION FROM TRADITIONAL TO MODERN AGRICULTURE

Most developed countries practicing modern agriculture do not experience the kind of instability in their agricultural production so common in developing countries in transition from traditional to modern farming systems. In a changing agriculture, many factors can be sources of variability in the early transition years. Some of these factors are considered here.

Agronomic Sensitivity

The new agricultural technology is based on genotype-environmental interactions. The agronomic environment based on the use of costly inputs like chemical fertilizer is particularly important for the expression of the full genetic potential of the new crop varieties. The introduction of this kind of technology in a developing country, with its diverse groups of farmers and socioeconomic milieu, is a completely different process from its gradual evolution in the developed countries. In the latter countries, the improved agricultural technology evolved over a longer time and in association with the development of an industrial and service infrastructure, creating in its wake a wide variety of modern farm inputs and vast purchasing power.

Obviously, new technology in a developing country is adopted at different times by farmers, and there is a time lag before it permeates large sections of the farming community. Enlightened

governments in developing countries could help to bridge this time gap by creating institutional mechanisms to help the small and the resource-poor farmers. This is now happening in many developing countries. Even so, one must expect that the first effect of the introduction of a high-yield technology in a traditional society will be considerable variability in crop production and yields.

Response to Environment

The climatic factor in tropical and subtropical environments is potentially an important source of variability for the new production technology. With their high-yield potentials, the new varieties obviously have more to lose in stress environments, such as those resulting from failure of rains. It is important, however, to recognize the number of counteracting conditions.

First, the high-yielding varieties have been generally recommended for irrigated conditions and for those rainfed lands where the moisture stress is not too great. Agricultural scientists have yet to evolve a highly effective production technology for the drier environments. Second, the high-yielding varieties, even under nonirrigated conditions, usually receive better agronomic management than the traditional varieties. A common recommendation is that farmers apply some chemical fertilizers even under rainfed conditions. The response to fertilizer application in these lands, which are not only thirsty but hungry, is often very marked. Third, evidence suggests that some high-yielding varieties are better buffered against climatic variability than others. Some CIMMYT wheat varieties have been successfully grown in many countries under diverse conditions. Similarly, some IRRI rice varieties have been grown in large areas of Southeast Asia, South Asia, and other parts of the world. These varieties were bred for wide adaptation through photoinsensitivity, but they also seem to have an improved buffering mechanism. Some sorghum hybrids developed in the Indian program give high yields in years of both normal and poor rainfall. These varieties appear to show homeostatic properties, which may be a function of their heterozygosity.

Disease and Pest Epidemics

Some of the early high-yielding varieties of wheat and rice carrying the Norin 10 and the De-Gee-Woo Gen dwarfing genes, respectively, were found to be highly susceptible to diseases or pests. Their replacements, developed at the international agricultural research centers and in some of the national programs, generally show a greater degree of genetic resistance against pests and pathogens. However, these high-yielding varieties continue to be a potential source of production instability. A more basic approach to the problem is needed.

The broad adaptation characteristics of some of the high-yielding varieties of wheat and rice developed in recent years have served a most important purpose. It has been relatively easy to organize seed multiplication and to bring very large areas in many countries under the high-yielding varieties program. At the same time, it would be a mistake to believe that future agriculture in the

developing or even the developed countries could be organized around a few broadly adapted varieties of this kind. They bring about too much genetic uniformity, which is not good for production stability.

There is a time and place for such varieties; basically they help to buy time for solutions of a more lasting nature. These solutions must be found in diversifying the genetic base of crop varieties rather than in narrowing it, as has happened in the past 15 to 20 years. Already, in the last 15 years there have been several serious pest and disease epidemics, all of which can be traced to the genetic uniformity brought about by the high-yielding varieties. In Southeast Asia and South Asia in the 1970s, brown planthoppers attacked many of the dwarf rice varieties developed by the International Rice Research Institute. Sources of resistance to various biotypes of brown planthopper were discovered in some of the existing landraces and traditional varieties grown in countries like India. In 1970, southern corn lead blight broke out in the United States, appearing first in Florida and subsequently covering most of the corn belt in the north, with serious side effects on yields. The epidemic was related to a common genetic base in the male sterile parent of many of the recommended hybrids, which became a source of susceptibility to Helminthosporium maydis. The third example is the downy mildew disease epidemic, which attacked the newly released hybrids of pearl millet in many parts of India in the early 1970s.

The answer to the emerging problem of genetic uniformity lies in erecting genetic barriers against the spread of disease and pests. These barriers must be built around a large number of genetically diverse varieties, strategically placed in different regions of a country. Jain (1985) describes this approach as the development of a multilineal complex of varieties, deriving their resistance from different sources, and each recommended for a different and limited area. He refers to more than 30 wheat varieties recommended in recent years for different parts of India by the scientists of the Indian Wheat Program. The more important question, of course, is how does a country build up a complex of genetically diverse varieties of this kind. The present nature of the relationships between the international agricultural research centers and national agricultural programs obviously does not favor such diversification. The pattern that has emerged in the last 15 years is of the international centers making many crosses and distributing the resulting segregating material or advanced breeding lines to a number of national programs for local selections.

It is relevant to ask whether the development and distribution of germplasm evolved by the international centers will remain valid. With the ongoing efforts to strengthen research at the country level, national breeders should increasingly be able to make crosses of their own. Then, if national programs undertake their own hybridization (using parental germplasm available locally and from the international centers and other national programs), a wider gene pool will be created for evolving new varieties. Solutions of this kind must receive attention as the CGIAR System acquires maturity and new relationships are established between the centers and the national programs. Centers like IRRI are beginning to move in this direction.

The problem of genetic diversification for the stability of future agriculture is so fundamental that it must receive urgent

attention both in the national and international programs. Hazell (1984) refers to a very definite shift toward more highly correlated yields of important cereal crops among states within India and among states in the United States, drawing attention to the widespread cultivation of new varieties with a common genetic base. While we may take some comfort from the fact that the new agricultural technology has spread so widely, be it maize hybrids in the United States or wheat and rice varieties in India, there is no getting away from the fact of a vastly reduced genetic base for our future agriculture. The problem is made worse by the patenting of new crop varieties evolved mostly by private breeders in the western countries. The commercial incentive is to evolve those varieties whose seeds can be sold most widely. The legislation on the rights of private breeders, whose seeds have been introduced into many developed countries, has serious implications for world agriculture. This legislation has not received the attention it deserves.

THE TRANSITION TOWARD GREATER STABILITY

The stability of agricultural production as a general proposition appeals to most people. However, it can hardly be a major objective in an agriculture in an accelerated state of transition from traditional to modern. In the developed countries, this transition occurred as a long-term, evolutionary process, and its effects on production were less disruptive than in the developing countries. Many of the latter that are now rapidly trying to catch up with the agriculture of the developed countries are obviously passing through a phase of greater disruption, which produces considerable variability in its wake. The variability is the greater because massive investments in modern farm inputs, which the new technology requires, cannot be mobilized quickly -- these countries simply do not have the short-term economic capacity to provide them. For this reason, many developing countries have organized phased programs of production, defining annual targets on the basis of planned coverage with the high-yielding varieties. It is clear that agriculture in many of these countries will continue to be in a state of flux, as the high-yielding varieties program is extended to larger areas and to new groups of farmers.

It does not follow that the new technology [illegible] always be a source of instability. As developing countries continue to improve their management support for agriculture by creating new institutional mechanisms and infrastructure, the sources of variability considered above will be reduced. In some countries, this has already begun to happen. The results from the Indian analysis presented here indicate that 17 years after the advent of the high-yielding varieties program a measure of stability is beginning to emerge.

The coefficient of variation of production has declined for most crops in the United States in recent years (Hazell 1984). This observed decline is consistent with the proposition that, as a country's agriculture becomes more fully modernized, the sources of variability decline. But the contradictory behavior of maize in the United States remains of interest. A possible explanation is that

the improved maize technology in the United States has continued to make rapid strides since the development of the first double-cross hybrids in the early 1940s. The average yield of maize in Iowa increased by as much as 20 quintals (2 metric tons) per hectare since the release of the first hybrids (Duvick 1977). More generally, in North America maize yields have doubled during the 38-year period from 1941 to 1979 (Stoskopf 1981, p. 40). Much of this gain in yield has come through continued selection for a higher harvest index. Also, while genes played a key role in improving the harvest index of wheat and rice, progress in maize has extended over a longer period, with continued selection based on polygenic variability.

Technological innovations that have a major effect on production obviously become an important source of variability. They should, however, lead to a new equilibrium in which a higher level of production is combined with greater relative stability. The time needed to achieve this new equilibrium is a function of the adoption rate of the new technology by the farming community. In the developed countries the transition is typically quite rapid. In the developing countries it extends over a longer period, largely as a function both of slow adoption of the recommended agronomic management practices and of relatively ineffective price supports. Farmers will not invest in a technology that is cost intensive unless they have some assurance of remunerative prices for their produce.

NEW TECHNOLOGY FOR STRESS ENVIRONMENTS

It is clear that improved varieties alone cannot solve the problems of stress environments, where the heritability of quantitative traits, such as yield, is low. Real stability in the agriculture of developing countries will come only when scientists begin to address the problems of moisture stress, fertility stress, and stress arising from pests and pathogens. Perhaps the time has come for the national programs as well as the international centers to shift from a purely genetic approach to one that includes research on soils, water management, and other factors of production. Crop environment can be enhanced through improved moisture conservation practices, better soil health, and improved pest control measures. The next 20 years should see agricultural scientists evolving such research priorities.

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6 Yield Variability and Income, Consumption, and Food Security

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Variability in world foodgrain production has increased. In particular, there is evidence of an increase in interregional and intercrop production variations during the past two decades (Chapter 2). This chapter discusses the effects of increased production variability (IPV) on food security at the national and household levels. More specifically, three questions are addressed here:

- To what extent does IPV result in increased variability in food consumption?
- Which low-income groups are adversely affected by IPV, and how?
- What policy measures could cope with the adverse effects of IPV, in particular for the poor?

This chapter is concerned specifically with fluctuations in production and the resulting transitory changes in prices and incomes. This focus does not suggest that chronic undernutrition related to persistent deficiency in food consumption is a less heinous problem. Indeed, increasing food availability, along with increasing demand for labor and wages, are corollaries to any agricultural development strategy (Mellor 1976).

In answering the questions posed above, our point of departure is that malnutrition is closely linked with poverty, and that poverty, to some extent, is episodic in nature. Households that fall within the category of extreme poverty one year may well fall outside it the next year (Srinivasan 1985; Scott 1980), and villages affected by natural or man-caused disasters in one agricultural cycle may rebound in the following harvest cycle. By the same token, regions and countries that might dramatically reduce hunger and poverty at one time can quickly revert to deficiencies in basic needs. As stated by Mellor and Desai (1985), "the temporal variations in poverty include ... substantial intermediate-term undulations that can cause the number of people in absolute poverty to vary by 50 percent or more."

The causes of these fluctuations in measured poverty differ from one country to another and from one circumstance to another. The proportion of the poor in a population is a function of many complex relationships among exogenous events (like price shocks, deteriorating terms of trade), domestic policy changes (like increased price of tradeables vis-à-vis nontradeables due to a devaluation), stochastic weather-induced events (like a drought), existing technology, and the country's resource endowment. Our primary concern is with weather-induced fluctuations in yields, and thus, in cereal production.

We begin by examining the effects of instability on market aggregates. Thereafter, these effects are linked with the food economy of households. Our hypothesis is as follows: a variety of factors may increase output fluctuations, which translate into greater variability in income or prices of food and nonfood commodities; and income-price variability results in greater fluctuations in food consumption, representing nutritional risk to the household.

MARKET-LEVEL EFFECTS OF IPV

The process by which IPV affects commodity prices is of particular importance. Figure 6.1 traces the global and national market effects and indicates links between production variability and prices.

In the context of the whole world food economy, changes in levels of food production translate into price changes. Therefore an increase in production variability must be of concern, whether it be in developed or developing countries (Mellor and Johnston 1984). Given the high share of grain trade in developed countries, fluctuations in export supply or import demand will also exert substantial effects on world prices, and therefore on food security in developing countries. Variations in trade volumes and stocks and the extent to which exporters and importers responded to world-market price fluctuations in adjusting the volumes of trade were major determinants of the high variability in world prices experienced during the past two decades (Siamwalla and Valdés 1980). In fact Table 6.1 exemplifies how short-run price variability in the world grain markets occurs despite small global production fluctuations.

Figure 6.1. Effects of market-level instability on consumption

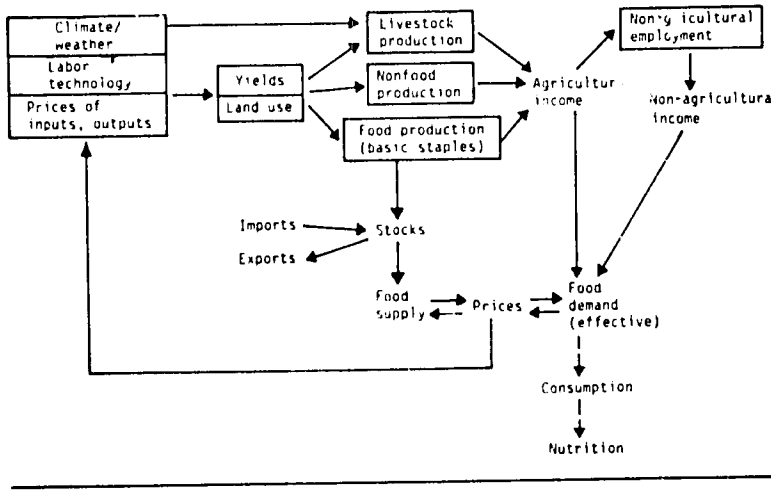

Table 6.1--World cereal production, trade, and price of wheat during the "food crises"

Year	Cereal Production (million tons)	Cereal Trade (million tons)	Wheat Price (US$/ton)
1970/71	1,104	110	74
1971/72	1,194	110	70
1972/73	1,161	134	100
1973/74	1,266	142	203
1974/75	1,213	136	204
1975/76	1,239	152	187

Source: U.S. Department of Agriculture, 1982.

As more countries exploit trade opportunities to stabilize domestic prices, further volatility in international grain markets may result (Koester 1984; Johnson 1975). As Johnson remarks, "There has been little recognition of the extent to which one nation or region achieves stability at the expense of instability to others" (p. 823). The fact that governments are interested in domestic stability and are far less concerned with price stability abroad reduces the likelihood that sovereign nations will work together to stabilize global supply and prices. At the individual country level, the effects of IPV on domestic prices and supply can be examined in the context of two distinct international grain trade regimes.

The first case is the open economy that participates actively in grain markets. Domestic prices will not be affected directly by IPV at the national level unless other factors, like foreign exchange constraints, limit participation in grain markets. Instead, the effects of IPV will be felt in the coffers of the treasury, which must have foreign exchange to purchase commodities on international markets. It is not simply the domestic IPV that will cause the foreign exchange bill to fluctuate, because the variability in world prices will have the same effect even if domestic supply and demand remain constant. However, the work by Valdés and Konandreas (1981) indicates that variability in the import bill is primarily due to volume rather than price. This poses a special problem among the poorer countries, where foreign exchange is clearly a constraint to food imports.

While foreign exchange constraints may partially explain fluctuations in imports and supply, most countries choose not to adhere to free-trade principles for a variety of reasons. Thus fluctuations in prices become part of a complex web of not only international prices but also domestic food production, demand, and price policy. Government decisions regarding imports and storage further compound the problem of predicting price movements in the face of greater instability.

The second case is the closed economy trade regime. Many landlocked African countries resemble the closed economy case that does not participate extensively in grain trade because of prohibi-

tive transport costs. Here, IPV will more likely result in increased variability in domestic supplies and prices. However, two qualifications must be considered when trade opportunities are not exploited. First, price responsiveness of stockholders will help determine the extent of this effect on availability and prices. Second, the relationship between the cereal sector and the rest of the farm production system, especially livestock and nonfood crops, will help determine the effect on prices (Figure 6.1). More likely, the intrasectoral changes in production will become more dynamic with increased market integration. For example, farmers at the margin may shift from subsistence crops to food or nonfood cash crops. This intrasectoral substitution will tend to smooth out price peaks and troughs in a closed economy, although cycles may develop.

Third, as Figure 6.1 indicates, the extent of IPV is also influenced by the linkage of production with agricultural and nonagricultural labor demand. For example, if lower yields imply lower wages and fewer hours worked, decreased income will reduce demand and tend to dampen price fluctuations, which may occur in the closed economy due to a decline in supply. Just the opposite will occur in the case of higher yields. Thus, although IPV may have an effect on consumption, it may be moderated by fluctuations in earnings from agricultural labor. This is especially true for the poor, whose expenditures are extremely elastic. Similarly, increased fluctuations in agricultural income may result in increased fluctuations in demand for nonagricultural products. In turn, variations in nonagricultural income will play an important role in determining price movements of agricultural goods, especially staple food crops.

Analysis of Market Aggregates

In a given year, the following staple food balance must hold in a country:

$$\begin{aligned}\text{Food Consumption} = {} & \text{Production} + \text{Imports} - \text{Exports} \\ & + \text{Stock Changes} - \text{Feed} - \text{Waste} \\ & - \text{Seed} - \text{Processing}.\end{aligned} \tag{6.1}$$

As intimated in the previous discussion, mitigating the effects of IPV on food consumption can be achieved through policies that adjust any of the components on the right side of the equation (6.1). Thus IPV may in principal be balanced by trade policies, stockholding policies, and adjustments in the use of staple food for feed and processing.

The relationship between production variability and its effect on consumption were analyzed for 16 countries using FAO Food Balance Sheet data. Table 6.2 shows the coefficient of variations around the

Table 6.2--Coefficients of variation for per capita cereal production and consumption and per capita total food consumption, 16 countries

Country	1966-80			1966-74			1972-80		
	Cereal Production	Cereal Consumption	Total Food Consumption	Cereal Production	Cereal Consumption	Total Food Consumption	Cereal Production	Cereal Consumption	Total Food Consumption
Bangladesh	7.8	5.8	5.9	9.4	5.6	5.8	5.0	4.8	4.4
India	7.5	5.7	5.3	7.9	6.1	5.7	6.3	5.5	5.1
Pakistan	11.3	7.7	6.6	12.6	7.8	6.6	5.4	3.2	2.7
Sri Lanka	15.2	4.9	3.9	11.9	3.5	3.1	16.6	5.5	4.0
Burma	9.3	5.7	5.3	5.9	4.9	4.7	11.5	5.2	4.7
Indonesia	10.6	10.3	7.7	10.1	8.9	6.8	7.5	6.2	5.1
Philippines	11.7	7.8	10.3	8.8	6.9	5.7	10.5	5.2	9.2
Thailand	7.8	4.8	4.2	7.8	1.2	1.0	8.9	6.3	5.6
Vietnam	6.9	7.0	3.1	6.1	3.1	2.7	7.2	7.8	2.9
Iran	8.2	12.2	11.9	8.1	7.4	7.3	7.7	7.0	6.8
Turkey	11.3	1.2	1.5	10.1	1.2	1.1	12.6	1.4	1.6
Egypt	5.0	5.7	5.3	2.9	3.1	3.0	4.7	5.9	5.4
Nigeria	9.8	3.2	2.3	11.1	3.2	2.4	5.9	3.3	0.4
Mexico	6.5	1.4	0.9	4.9	1.6	0.9	7.8	0.7	0.7
Brazil	9.8	7.2	3.2	6.1	3.2	3.0	10.3	7.3	1.4
Argentina	11.4	2.7	3.8	10.2	3.4	3.4	12.2	2.5	2.4

long-term trend for cereal production per capita (in calorie equivalents).[1] The most telling feature of these data is that the level of variability in cereal production is generally greater than consumption variability, either when measured in terms of total calories or calories from cereals. In fact, the average of the coefficient of variation in cereal production in the 16 countries was 9.4, nearly twice the coefficient of variation in total food consumption, 5.1, during the period 1966-80. Whether it be through trade policies, domestic stocking behavior, or other means captured in the identity above, the aggregate level of variability in production does not translate fully into consumption variability.

These data have also been disaggregated according to two overlapping time periods (so as to avoid the bias of the oil shock and world food shortage in 1972-74) to determine how the variability in cereals production and consumption changed over time. No overt trend from one time period to another emerges at a first glance at the coefficients of variation presented in Table 6.2, although 9 out of the 16 countries registered a decline in cv for total food consumption. However, some patterns are noteworthy: Of the 10 countries that show increased variability in cereals production from the first to the second period, 7 also experienced higher variability in total food consumption. Only the three middle-income countries in this group -- Mexico, Brazil, Argentina -- managed to achieve decreased variability in consumption with increased variability in cereals production. In the remaining 6 countries, both cereals production and total food consumption variability, measured in cv, decreased. In a number of countries (Sri Lanka, Thailand, Vietnam, Turkey, and Egypt) there is concurrently increased variability in cereals production with increased variability in cereals and total food consumption. It should be stressed that the changes in cv indicate tendencies, only, since statistical significance has not been tested.

In order to better understand the relationship between production and food consumption variability, simple correlation coefficients were calculated (see Table 6.3). With the exception of Argentina and Egypt, the correlations between cereal production and total food consumption are positive, although not as high as reported in a similar analysis by Valdés and Konandreas (1981).[2]

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[1]A similar analysis was done by Valdés and Konandreas (1981) for staple food consumption and production. The differences herein are that the data are in per capita terms, cover a more recent time period, examine a different set of countries, and employ a different source of data.

[2]For some countries, lagged production is correlated with consumption. If the lagged variable had a higher correlation, it is reported. The justification is that the timing of the harvest varies dramatically from one country to the next. So a late harvest in one year can have implications in consumption during the following calendar year.

Table 6.3--Correlations for per capita cereal production and consumption and per capita total food consumption, 16 countries

Country	1966-80			1966-74			1972-80		
	Cereal Production to Cereal Consumption	Cereal Production to Total Food Consumption	Cereal Production to Non-Cereal Consumption	Cereal Production to Cereal Consumption	Cereal Production to Total Food Consumption	Cereal Production to Non-Cereal Consumption	Cereal Production to Cereal Consumption	Cereal Production to Total Food Consumption	Cereal Production to Non-Cereal Consumption
Bangladesh	0.76*	0.75*	0.58*	0.87*	0.85*	0.51*	0.27*	0.26*	0.006*
India	0.86*	0.90*	0.59*	0.41*	0.79*	0.49	0.93*	0.98*	0.50*
Pakistan	0.77	0.78	0.20	0.84	0.87	-0.42	0.18	0.19	0.69*
Sri Lanka	0.71	0.48*	-0.52*	0.76	0.59	-0.44	0.62	0.29	-0.0006*
Burma	0.53	0.52	0.46*	0.65	0.61	0.88*	0.48	0.38*	0.03
Indonesia	0.79	0.72	0.04	0.77	0.70	0.11	0.85	0.83	0.46
Philippines	0.49*	0.37	0.39*	0.54*	0.55*	0.40	0.27*	0.14	-0.12*
Thailand	0.56	0.57	-0.09	0.76	0.46	-0.40*	0.66	0.64	-0.09
Vietnam	0.59	0.54	-0.49	0.75	0.79	0.15*	0.12*	-0.02*	-0.19*
Iran	0.75	0.73	0.37*	0.66	0.65	0.33*	0.73	0.73	0.73*
Turkey	0.49	0.77	0.60	0.66	0.85	0.30	-0.03	0.58	0.70
Egypt	-0.19	-0.15	0.40*	-0.12	-0.15	0.06*	0.36	0.44	0.46*
Nigeria	0.05*	0.32*	0.22	-0.09*	0.26*	0.52	0.10*	0.23	0.14
Mexico	0.44*	0.30*	0.24	0.31	0.51	0.38*	0.62*	-0.07	0.43
Brazil	-0.005	0.14*	0.20*	0.15	0.91*	0.78*	0.25	0.41*	0.14*
Argentina	-0.01*	-0.02*	0.11	0.44	0.19*	0.12	-0.33*	0.51*	0.54*

* production lagged by one year.

For some countries there is a negative correlation between cereal production and calories derived from noncereals. This suggests a pattern of substitution between cereal and noncereal commodities. No clear pattern emerges in terms of the magnitude of these correlation coefficients from one period to the next: correlations between cereal production and total food consumption appear to drop in 10 countries but to increase in 6 others. These 6 countries are India, Indonesia, Thailand, Iran, Egypt, and Argentina.

In addition to these descriptive statistics, two sets of regressions were run to determine (a) whether the cv in total food consumption was related to GNP per capita and total food consumption per capita; and (b) whether the deviations from the expected value of cereal production, cereal consumption, and total food consumption are changing over time, thereby indicating increased instability.

Concerning the first question, statistically significant results were that the higher the average GNP, the lower the cv in total food consumption in the period 1972-80. And the higher the average total food consumption per capita, the lower the cv of total food consumption during the period 1966-74 (see Table 6.4).

To answer the latter question, the absolute value of the difference between the expected value (based on fitted trend lines) and actual value of cereal production, cereal consumption, and total food consumption, all in per capita terms, were regressed on time. Between 1966 and 1980, 6 of the 16 countries showed increased deviations from the trend in cereal production (see Table 6.5). But only in 2 -- Mexico and Brazil -- was this also statistically significant. In both of these countries the deviations from the trend in total food consumption, however, declined during the same time. In only one case -- Thailand -- is a significant increase in the deviations from trend consumption (total food) observed. However, fluctuations in the production of cereals did not significantly increase. Between 1966 and 1974, 4 countries had declining variability in total food consumption, while none displayed an increase in variability. Between 1972 and 1980, total food consumption variability increased in 4 countries and decreased in 3 others. In combination, the data on cvs, correlation coefficients, and the simple time trend regressions give no strong indication of a growing problem of consumption variability in the aggregate. If indeed there is a trend toward increased variability of cereals production, a combination of stocking and trade policies has mitigated the consumption consequences as measured in terms of aggregate country-level data.

An indication that such policy induced stabilization of consumption differs among the selected countries is obtained from the correlation analysis presented in Table 6.6. Change in per capita food consumption from one year to the next ($C_t - C_{t-1}$) is correlated with change in each of the major components on the right side of equation (6.1). In a number of countries the change in total food consumption from one year to the next during 1966-80 is negatively or only slightly correlated with the change in cereal production between two corresponding years. Bangladesh, India, Egypt, Nigeria, Mexico, Brazil, and Argentina are to be noted in this context. While in Bangladesh, India, and Nigeria changes in stocks are more closely correlated with fluctuations in consumption, they are mainly correlated with trade and feed use in Egypt and Mexico. Particularly high

Table 6.4--Regressions of the coefficient of variation of total food consumption on mean GNP and per capita food consumption

Independent Variable	Coefficient of Variation of Total Food Consumption					
	Model 1			Model 2		
	1966-80	1966-74	1972-80	1966-80	1966-74	1972-80
Intercept	5.6	11.8	4.7	9.5	11.8	1.14
Mean GNP per capita	-9.9×10^{-4} (1.7)	-7.4×10^{-4} (1.4)	-9.5×10^{-4}* (1.4)			
Mean Food consumption per capita				-28.3 (0.8)	-48.3* (1.8)	15.8 (0.49)
	$R^2 = 0.19$	$R^2 = 0.14$	$R^2 = 0.22$	$R^2 = 0.05$	$R^2 = 0.22$	$R^2 = 0.02$

Note: t-statistics are in parentheses.

* significant at 10 percent level.

Table 6.5--Regressions of the deviation of actual from expected production and consumption as a function of time

Country	1966-1980				1966-1974				1972-80			
	Cereal Production	Cereal Consumption	Total Food Consumption	Noncereal Consumption	Cereal Production	Cereal Consumption	Total Food Consumption	Noncereal Consumption	Cereal Production	Cereal Consumption	Total Food Consumption	Noncereal Consumption
Bangladesh	-S	-N	-N	-S	-N	-N	-N	-N	-S	+N	+N	-S
India	-N	-N	-N	-N	+N	+N	-N	-N	+N	-N	-N	+N
Pakistan	-S	-S	-S	-S	-S	-N	-S	-N	+N	+N	+N	-N
Sri Lanka	+N	+N	+N	+N	-N	+N	+N	+N	-N	+N	+N	-N
Burma	+N	-N	-S	-N	-N	-N	-N	+N	+S	-N	-N	-N
Indonesia	-N	-N	-N	-S	-N	+N	+N	+S	-N	-S	-S	-S
Philippines	-N	-S	+N	+N	+N	+N	+N	-S	-N	-N	-N	+N
Thailand	-N	+N	+S	+N	-N	+N	-N	-N	-N	+N	+N	-N
Vietnam	-N	-N	-N	+N	-N	+N	+N	-N	-N	+N	+S	-N
Iran	-N	+N	+N	-N	-N	+N	+N	-N	-N	-N	-S	-N
Turkey	+N	+N	+N	+N	+N	+N	-N	+S	-N	+N	+S	-N
Egypt	-N	-N	-N	+N	-S	-S	-S	+N	+N	-S[a]	-S	-N
Nigeria	-S	-N	-N	-N	-N	-N	-S	-N	-S	-N	+S	-N
Mexico	+S	-S	-S	+N	-S	-S	-S	-N	+S	+S	+N	+N
Brazil	+S	-N	-N	-N	+N	-N	-N	+N	+N	-S	-N	-S
Argentina	+N	-N	-S	-S	+N	+N	+N	-N	+N	-S	-S	-N

Note: S is significant coefficent of variation, N is not significant.

[a] 11 percent

Table 6.6--Correlations between changes in per capita food consumption, and changes in total food production, net exports, stock changes, and feed use, 16 countries

Country	Production	Net Exports	Stock Changes	Feed Use
Bangladesh	0.12	0.21	0.43	0.01
India	-0.45	0.39	0.87	0.91
Pakistan	0.51	-0.14	-0.24	0.21
Sri Lanka	0.58	-0.24	-0.18	0.38
Burma	0.64	-0.46	-0.42	0.71
Indonesia	0.72	-0.71	-0.63	0.81
Philippines	0.39	0.01	0.35	0.43
Thailand	0.68	-0.30	-0.31	0.60
Vietnam	0.40	-0.58	-0.36	0.72
Iran	0.49	-0.42	-0.56	0.34
Turkey	0.78	-0.11	-0.71	0.80
Egypt	0.07	-0.56	-0.30	0.60
Nigeria	-0.22	-0.11	0.33	0.17
Mexico	0.04	-0.33	-0.05	0.52
Brazil	0.13	0.10	0.22	0.07
Argentina	-0.15	-0.06	0.08	-0.12

correlations between production and consumption change are registered for Indonesia and Turkey.

Consequences of Market Instability

In the above macrolevel analysis, the distributional consequences, and therefore the nutritional consequences, of IPV were not considered. For example, the data on the probability of consumption levels falling 2.5 to 5 percent below trend-level consumption found in Table 6.7 may seem innocuous at first glance. However, just as aggregate consumption is not evenly distributed, transitory shortfalls in consumption are not, either. Thus the potential arises, for example, that a relatively small 2.5 percent shortfall in aggregate consumption may result in a dramatic 10 percent decline for 30 percent of the population under some plausible assumptions (Green and Kirkpatrick 1982).

Similarly, it is likely that interyear consumption instability is considerably higher in rural areas than urban centers. Imports will be more likely to compensate supply shortfalls in urban areas, and urban markets are better integrated, so that prices will be more stable. This further compounds the likelihood that a 2.5 or 5.0 aggregate shortfall in consumption is not shared equally by all households.

There is evidence from a limited number of regional-level and country-level studies that the instability measured at the market levels, as discussed above, does have implications for nutritional status, once again as measured in terms of national statistics. This should come as no surprise, since declines of 10 or 15 percent of calorie intake would likely have deleterious nutritional consequences on marginally nourished individuals. For example, Kumar (1986) suggests that nutritional status is affected by fluctuations in food production in sub-Saharan Africa to a greater extent and more directly than elsewhere. Similarly, the data from UNICEF in Botswana and Catholic Relief Services in Ghana show wide swings in the prevalence of underweight children from one year to the next (Pinstrup-Andersen 1986).

Another study by Anderson and Scandizzo (1984) employs data on macrolevel production variability and relates it to variables such as life expectancy and child mortality at the national level. Their cross-country comparison found that the coefficient of variation of production was a significant independent variable in explaining life expectancy and child mortality when GDP and other income distribution variables were controlled for. Presumably this is explained by the effects of production variability on consumption instability. It could be hypothesized that individuals were more likely to become sick and die in countries where lean times were more pronounced.

So while these analyses do not make clear the dynamics of the relationship between IPV at the household level and nutritional and health outcomes, they provide a tentative admonition about the deleterious effect of IPV. The need to consider the consequences of IPV at the household level is manifest.

Table 6.7--Instability in per capita cereal consumption in low-income, food-deficit countries, 1965-77

Continent and Country	Probability of Shortfall in Per Capita Cereal Consumption	
	2.5 percent	5 percent
Africa		
Botswana	38.21	27.09
Cameroon	22.97	6.81
Central African Republic	34.83	21.77
Chad	41.68	33.36
Benin	29.46	14.01
Egypt	29.81	14.46
Ethiopia	25.78	9.68
Gambia	11.31	0.78
Ghana	42.47	35.57
Guinea	24.20	8.08
Ivory Coast	40.13	30.85
Kenya	28.77	13.14
Lesotho	27.43	11.70
Madagascar	13.57	1.39
Malawi	36.32	24.20
Mali	33.72	20.05
Mauritania	37.45	25.78
Mauritius	24.20	8.08
Mozambique	23.27	7.35
Niger	38.97	28.43
Rwanda	32.64	18.14
Senegal	27.76	12.10
Sierra Leone	35.16	16.85
Somalia	32.64	18.41
Sudan	37.83	26.76
Tanzania	22.66	6.81
Togo	31.21	16.35
Uganda	39.74	30.50
Upper Volta	32.28	17.62
Zambia	25.78	9.85
Zaire	42.86	35.94

(continued)

Table 6.7--(continued)

Continent and Country	Probability of Shortfall in Per Capita Cereal Consumption	
	2.5 percent	5 percent
Asia		
Afghanistan	29.80	14.46
Bangladesh	15.62	2.17
Sri Lanka	25.46	9.51
India	33.00	18.94
Indonesia	41.68	33.36
Nepal	31.92	17.11
Pakistan	38.97	28.43
Philippines	35.16	16.85
Yemen Arab Republic	29.46	14.01
People's Democratic Republic of Yemen	33.00	18.94
Latin America		
Bolivia	14.46	1.66
Dominican Republic	46.41	42.86
El Salvador	37.45	26.11
Guatemala	24.51	8.23
Guyana	40.52	31.21
Haiti	29.81	14.69
Honduras	30.85	16.11
Jamaica	45.62	41.29
Paraguay	40.90	32.64

Source: Green and Kirkpatrick, 1982.

Note: Data used are trend-adjusted cereal consumption per capita.

HOUSEHOLD-LEVEL EFFECTS OF IPV

Before discussing the effects of instability on different types of households in different economic settings, it is important to reiterate that the domain of this paper is whether and why increased in tability in yield results in increasing consumption variability and, perforce, nutritional status. We take as a given that there is a decreasing marginal utility to consumption of foodgrains and calories. The corollary of the assumption is that a household will be better off if consumption is spread evenly from one year to another rather than being concentrated in a given year or set of years.

The important issues are therefore (a) to identify the circumstances under which an increase in yield instability will bring about a combination of movements in prices and incomes that results in variability in real income and effective demand for food at the household level, and (b) to determine why IPV may be of little consequence for some but may represent a truly aggravating state of affairs for others, entailing serious nutritional risks.

A further consideration in addressing these issues is that defining household food security solely in terms of the extent of deviation from the trend level, while compelling, neglects another important fact. Households can be food insecure (that is, acutely aware of the precariousness of consuming an adequate diet) despite smooth levels of consumption. Thus our definition of household food insecurity encompasses the notions of chronic and intermittent deprivation -- the harmful effects that they bring about in combination.

Three categories of households may be delineated. In the first, individuals are in a perpetual state of impoverishment, whereby they virtually never achieve an adequate level of food consumption. There are certainly seasonal and annual fluctuations in the level of deprivation of these chronically undernourished households. However, simply smoothing out their deprivation will do little to make them less insecure about their food problems. For a second group of households and individuals, the converse is the case -- they are virtually never insecure about being malnourished although there may be considerable deviation above and below their trend level of consumption. In the third group are those individuals and households that face fluctuations in their access to sufficient quantities of food in order to maintain growth and activity levels, to perform work, and to avoid other functional consequences of undernutrition.

There also remains a question as to whether households that intermittently suffer from inadequate diet are in fact different or distinguishable from the chronically malnourished. It may well be that transitory consumption levels below requirements manifest themselves in chronic nutritional disorders such as stunting as well as acute episodes characteristic of wasting.

A final link between acute but intermittent episodes of deprivation and chronic hunger is that low food production may result in poor households selling off productive assets (for example, land and cattle), entering into tied and potentially exploitative labor contracts, borrowing at usurious interest rates, or becoming indentured to local marketers through the obligation of selling next

year's harvest at a low price in return for foodgrain in the present year. Research documenting such events is scarce. However, to the extent this spiral of disaccumulation of assets and capital is extant, it suggests that year-to-year instability in income portends heightened vulnerability, which can contribute to chronic impoverishment.

Effects of IPV on Real Household Income

To analyze the effects of instability in food production on the food security of the household, one needs to distinguish four types of households: surplus farmers, deficit and marginal farmers, agricultural laborers, and nonagricultural workers.

Moreover, the analysis must be able to determine the effect of IPV on real income under three possible price policies (trade regimes): (a) the closed economy with flexible prices; (b) the open economy that alternates between being a net exporter and a net importer of its major staple, in which case fluctuations in output will cause marked shifts in the marginal price (from a c.i.f. to an f.o.b. situation); and (c) the open economy where yearly output variability does not cause a shift from an exporter situation to that of an importer, or vice versa.

In the first two cases, prices are assumed to vary dramatically from one year to the next in response to changes in the level of production -- increasing in years of relatively lower output and declining in years of high domestic output. In the last case, prices are assumed to be relatively fixed, although affected by international prices. A complete fixed-price scenario is achieved through an explicit government pricing policy emphasizing stability. The scenario may involve import subsidies and tariffs to smooth out the vagaries of international prices. It is, however, distinct from a flexible price environment where domestic production influences domestic prices, either through local supply and demand or through foreign exchange constraints.

In addition to distinguishing between socioeconomic groups and price policy, determining the effect of IPV requires knowledge concerning a variety of other characteristics of the microeconomy. In assessing the effects of instability on the landless laborer, small farmer, and nonagricultural worker, one must consider how wages are determined. Do they reflect the marginal product of the worker, or are there structural factors (for example, high unemployment) or institutional arrangements that determine wage formation? The answer to this and to similar questions conditions the effect of IPV on various socioeconomic groups.

While it is not possible here to detail the effect of IPV on each of the four economic groups in different trade regimes, Table 6.8 provides a simplified illustration of some of its complexities. For example, in a flexible price environment, if IPV is accompanied by increased interregional or intercrop covariances, there may be little effect on the stability of surplus farmer incomes. At the same time, the nonagricultural wage laborer will face much greater fluctuations in real incomes due to fluctuations in the price of wage goods.

Table 6.8--Effect of increased production variability on year-to-year stability of real incomes. four occupation groups

Occupation/ Wage Formation	Flexible Prices		Fixed Prices	
	Increased Covariance	No Increased Covariance	Increased Covariance	No Increased Covariance
Surplus farmer	-	+	++	+
Agricultural wage laborer				
Neoclassically determined wages	++	+	+	-
Fixed wages (nutritionally or institutionally determined)	+	-	-	-
Nonagricultural wage laborer	++	+	-	-

- is income stability not effected.

+ is income stability affected.

++ is income stability affected greatly.

Conversely, in a fixed price environment, if IPV is accompanied by increased covariances in production, the swings in supply will not affect prices but only the output of the farmer. Fluctuations in the value of the marketed surpluses will be large. At the same time, if wages are fixed on efficiency grounds or through institutional arrangements, the earnings of the agricultural worker will not be affected by IPV. If, however, wages are determined neoclassically, accounting for profit, the lower value of the marketed surplus will translate directly into increased fluctuations in the poor's ability to access food.

Ultimately, the effect of IPV on the incomes of different household types is an empirical question and an important area for further research.

Relationship Between Household Income and Consumption Variability

Concern over income fluctuations stems largely from its putative relationship to consumption. While it is useful to note that IPV may have deleterious effects on the economy, such as delays in the adoption of new technologies, disaccumulation of wealth, and drops in demand, the greatest concern is the danger it represents to the nutritional well-being of marginal households in the lean production years.

There is in theory the possibility for exploiting opportunities for savings and dissavings to smooth out consumption expenditures,

even if there are large fluctuations in real income. The intertemporal transfer of income from one year to the next can smooth out income and cash flow. Households also can adjust the kinds of foods they consume and time purchases of durables and semidurables for years of plenty. Interperiod consumption is contingent upon access to financial institutions and well-functioning capital markets, reasonable interest rates, or the ability to store food stocks. The acuity of the individual households in managing their investments, coupled with the costs of doing so, will determine the benefits of intertemporal smoothing. Thus poorly functioning financial intermediaries, high interest rates, and poor storage and marketing infrastructures are serious constraints to interyear buffering.

Farmers who grow excess food and have facilities for on-farm storage are unlikely to be strained by one or two years of lower than expected incomes or higher than expected prices. A poor household, however, may not have the assets to carry over from one period to the next. Thus the poor will probably face a period of disaccumulation and deprivation if a year of dissavings is not followed by an upturn in their earned income.

Relationship Between Household and Individual Consumption

The link between household consumption variability and that of the individual remains largely a mystery. Just as the household has considerable latitude in terms of intertemporal adjustments, so in theory the household can adjust the intrahousehold allocation of resources to maximize their objective function, such as nutritional well-being. For example, consider the household that is in a vulnerable position year after year. In a bad year, the parents may take a disproportionately small share of the household food to protect the well-being of the children. This may also coincide with the relative decrease in work output, which accompanies a small harvest. Or conversely, the parents may be forced to discriminate against their children in order to maintain their own minimal level of intake to allow them to perform productive work. Further study is required to determine how and to what extent variability in household income is accompanied by shifts from an investment to an equity strategy of intrahousehold allocation of resources.

Relationship of Individual Consumption to Nutritional Status

Variability in an individual's consumption portends swings in nutritional status. However, some qualifications need to be considered. First, the human body, like the silo, can play a role in storage. The literature on autoregulation suggests a potential for metabolic adjustments in periods of decreased intake (Srinivasan 1980; Sukhatme and Margen 1982). And of course, the possibility of reducing energy expenditures, an adjustment mechanism that certainly does have costs in terms of ability to work and the quality of life, is another form of regulation (Beaton 1983). Each of these forms of coping with variability is indeed complex and remains the source of considerable controversy in the medical and biological sciences.

Closing the Loop: Effect of Nutritional Fluctuations on Productivity

Perhaps the most troublesome aspect of IPV is that it compounds itself through the link between low output and low labor productivity, which in turn reduces output in the subsequent year. There is a growing literature that indicates that nutritional status affects worker productivity (Strauss 1984; Immink and Viteri 1981a, 1981b; Deolalikar 1984; Latham 1985).

Thus productivity losses and the increased morbidity and mortality associated with low nutritional intake in the previous year may reduce the quantity and quality of labor outputs. Whether farmers reduce their activity levels in response to less energy intake or leave the land in search of other work in years of low production, the results may be even lower production, income, and intake in the following year.

POLICY OPTIONS

In considering measures to reduce the potentially deleterious effects of IPV, a number of general issues demand consideration. First, there are potential conflicts between variance reducing and mean increasing measures. For instance, in the development of germplasm there may be trade-offs between the objective of reducing yield instability resulting from climatic variability and the objective of increasing yields. The conflict is resolved, however, if crop output can be raised sufficiently, thereby generating employment and reducing prices, so that fluctuations become less consequential in terms of nutritional well-being. Similarly, efforts to stabilize prices or consumption have economic costs, both in terms of financial and manpower resources.

Second, a distinction can be made between targeted and nontargeted methods to promote income and price stabilization. Many measures may be prohibitively expensive when applied at the national level. When these measures are targeted to at-risk households, however, the cost may be well within manageable boundaries. Since well-to-do households are more effective in buffering instability in prices and income, there is a strong argument on nutritional grounds to target interventions to counter the effects of IPV on poor households.

Price and Supply Stabilization

Domestic prices can be smoothed by keeping supply and demand in balance so that a targeted price is achieved. Price stability by itself, however, does not necessarily imply that consumption variability is minimized.

Valdés (1981) indicates that national-level food security problems do not arise primarily out of price instability on international markets. Rather, real income variability due to domestic production variability, as well as changes in the volume (not price) of imports, are the major constraints to national food security.

Thus demand stabilization requires accounting not only for variability in prices but for variability in income as well; in addition, there is a correlation between these two factors.

Stabilizing the supply of food at the national level can be achieved through a combination of stocking and trade. It has been extensively argued that trade is a better and cheaper way to stabilize supply than buffer stocks (McIntire 1981; Siamwalla 1984), although maintaining a well-managed stock of around 5 percent of grain consumption is suggested as a complement to a national food security program (McIntire 1981).

There are exceptions to this logic of using trade rather than storage to stabilize consumption. The first exception is a precipitous rise in grain prices. However, a country can hedge against such a possibility by playing the futures markets. The second exception is a landlocked country with poor transport infrastructure, where trade may be prohibitively expensive. A third exception is a country whose imports represent such a large volume that world price may be affected by its trade activities. However, this prospect of inelastic supply of imports is limited to a few, although important, cases. Fourth, and most significant, is the country that is nearly self-sufficient in foodgrain production. A good harvest may result in it being a net exporter; a bad harvest means it would be a net importer. Increased stability may cause more frequent shifts in this country's market clearing price, from the f.o.b. to c.i.f. price. The fact that these price differences can be on the order of 100 percent in some African countries strongly commends relying on stockholding between periods and promoting intraregional trade, rather than international trade, so that a country can avoid switching from an f.o.b. to a c.i.f. price.

Infrastructure Development

Improved marketing infrastructure, both for agricultural inputs and food crops, is another fruitful method for reducing consumption instability in the face of IPV. Integrated factor markets (labor, capital) will provide an outlet to cope with the potential adverse effects of covariances that accompany IPV, and integrated product markets will mitigate the effect of local production variability on local prices by facilitating the flow of goods and services from one geographical area to another. Such integration in effect reduces the link between supply and price in a given locality, thereby addressing the problem of fluctuations that may occur due to local market conditions. It is also likely that market investments will encourage risk sharing over a broader population as well as help implement targeted and nontargeted schemes to reduce the effects of fluctuations.

In addition, improved storage facilities, including on-farm storage, would facilitate carrying stocks over from one period to the next. And improved accessibility to savings institutions would promote intertemporal smoothing of consumption, even in the face of income variability.

Targeted Programs

If government stabilizes aggregate demand through a combination of buffer stock and trade policies, the nutritional well-being of certain consumers may still be in jeopardy, such as those who suffer income shortfalls due to employment losses a in bad year. Income generating schemes and transfer programs, such as employment guarantees, food-for-work projects, and food subsidies address the problem of at-risk households.

Generating employment would counteract cyclical variability in production. Few countries, however, have either the managerial or financial resources to operate flexible employment programs. The fact that the years of low production are the years when domestic resources are most scarce and the need for employment generation most acute is a procyclical problem that reduces the likelihood of rapid and meaningful government response. Furthermore, minimum wage laws, which could reduce fluctuations in earnings among landless and urban workers, are notoriously difficult to enforce. They may also have adverse side effects due to the distortion of factor market prices.

Food-for-work projects, which use donated resources, may have the advantage of being viable in a time of severe domestic resource constraints caused by a year of low production. Furthermore, the fact that food-for-work provides not only employment opportunities but is wage good is an additional benefit in a year of shortages.

Food subsidies traditionally are not responsive to year-to-year fluctuations in the food situation in recipient countries. In fact, given the surplus disposal element of food aid programs, the quantity of food aid globally programmed is countercyclical to the needs of developing countries. This makes for a situation, such as in the early 1970s, when food aid allotments were reduced despite acute need (von Braun and Huddleston 1984). However, food subsidies are an effective way of transferring income to the poor (Pinstrup-Andersen and Alderman 1984). Consideration could be given to employing a flexible price wedge, which could be larger in lean years and smaller in years of high output.

Another targeted strategy is crop insurance. However, crop insurance has the potential of promoting inequality and of doing little to help those in greatest need. Simply, the landless wage laborer or small farmer benefits least from this form of implicit income transfer. While there are spin-off benefits, such as reducing risk to producers and thereby encouraging greater investment, which in turn increases production and, possibly, labor absorption, this strategy must be applied cautiously. Targeting its benefits is crucial.

Improved access to consumption credit or enhanced ability to save through stocking behavior is another targeted strategy. As fluctuations increase, the ability to adjust intertemporal consumption becomes urgent. The goal is to reduce the elasticities of consumption variability with respect to income variability. This requires that financial markets function well and that they do not discriminate against the poor. In this regard, special arrangements for the poor for repaying loans and for procuring credit with little collateral may be required. The ability of the poor to smooth consumption is constrained not only by access to credit institutions

but also by short planning horizons. The poor may be more concerned with survival in the present than with conjecturing about the future.

CONCLUDING REMARKS

In this chapter we have discussed the effects of increased production variability and covariances on consumption and nutrition. The major concern is the effect on different household types. However, national-level data and policy options were explored because of the direct link between the food economy of the country and the food economy of the household. The limited data available on inter-year fluctuations in consumption and nutrition at the household level, however, limit the empirical basis for this chapter. Nevertheless, the interplay between stochastic events and government policy and their combined effect on household food security illustrate the importance of agricultural research taking into account the deleterious consequences of production instability. In addition there is a need for developing trade, storage, and pricing policies that reduce the negative consequences of instability on the consumption and nutrition of poor households.

An unspoken theme, however, is that the negative consequences of fluctuations are another manifestation of underdevelopment. Poor countries and poor households are beset with constraints, be they structural or not, which limit the ability to prevent, and thereafter to cope with, IPV. These constraints will largely be overcome in the course of agricultural development and economic growth. Technology that increases output, creates employment, moderates prices, improves market integration, and so forth is the goal of development. It represents the long-term solution, which, in general, poses little conflict with the intent of protecting the poor from the short-term effects of IPV.

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Part II

Evidence and Cause of Change in Yield Variability and Yield Correlations

7

CIMMYT Presentation: Yield Stability in Bread Wheat

Arthur Klatt, W. H. Pfeiffer, and H. J. Braun

In the past 20 years, germplasm developed by Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) has been adopted by national programs throughout the world; varieties emanating from this germplasm occupy more than 45 million hectares in the developing world. The widespread adoption of these varieties combined with improved agronomic practices has led to dramatic increases in production.

However, critics claim that the widespread use of these high-yield varieties has increased the risk profile of millions of Third World farmers. They claim that increased production has come at the expense of greater variability. Yet a paper presented by Hazell at this workshop (Chapter 2) demonstrates that production variability for wheat decreased in many developing countries from the decade of the 1960s to the present time. Since varieties derived from CIMMYT germplasm currently cover approximately 45 percent of the area devoted to bread wheat in developing countries, it can be inferred that this germplasm, combined with the technological changes that accompanied the new varieties, played a major role in this greater production stability.

CIMMYT's breeding strategy is designed to develop broadly adapted germplasm that performs well in various zones or regions around the world, under both high-input and low-input conditions; that is, germplasm with spatial-, temporal-, and system-independent yield stability. CIMMYT's wheat research program involves shuttling experimental germplasm between two principal locations in Mexico having very different environmental conditions. These locations include near optimal, irrigated conditions and disease stressed environments. In addition, germplasm is tested at a number of other locations in Mexico that collectively represent many of the wheat production environments found in the world. Also, CIMMYT's advanced lines undergo multilocational testing in about 100 countries each year. Thus, within Mexico, breeding can be done for a broad spectrum of diseases and environmental stresses, while screening and testing on a global basis exposes these materials to a wide range of environmental conditions. This greatly enhances our ability to identify germplasm with high-yield potential, broad adaptation, and a broad spectrum of disease resistance, thereby leading to stable production performance.

ANALYSIS OF DATA FROM INTERNATIONAL SPRING WHEAT YIELD NURSERY

To test the stability of CIMMYT germplasm, we analyzed 15 years of data from the International Spring Wheat Yield Nursery (ISWYN), utilizing various statistical procedures.[1] Four conclusions can be drawn from this analysis, keeping in mind the conditional nature of the analysis:

- High-yielding varieties (HYVs) are at least as stable as locally developed varieties (LDVs) under all conditions, but they also give higher yield.
- HYVs are at least as efficient in the use of inputs as the LDVs.
- HYVs are more responsive to improved production conditions.
- All three of these characteristics are combined in what CIMMYT defines as true HYVs.

The ISWYN is a replicated yield trial that contains 49 spring wheat varieties and advanced lines originating from CIMMYT and many countries. It is one of several yield trials and is used to measure the adaptation of advanced materials and to compare them to varieties from other countries. They are generally grown by more than 100 cooperators in 60 to 70 countries. The varieties represented in the trial can be subdivided into four groups: (a) CIMMYT bread varieties released directly by national programs, (b) initial crosses made by CIMMYT but which are subject to further selection at the national level, (c) locally developed varieties having some CIMMYT germplasm in their pedigrees, and (d) locally developed varieties without CIMMYT germplasm in their pedigrees.

To investigate the yield stability of these varieties, we evaluated the "total environment" without identifying the specific environmental factors affecting yield stability. Thus the production conditions prevailing at a given site during a given crop cycle were denoted as the environment. The environment's production potential was then measured by the mean yield of all varieties tested in that environment. The yield of the highest yielding variety in each environment indicated the maximum production potential. Most models used for the investigation of yield stability are based upon the assumption that a positive linear relationship exists between the performance of a variety and growing conditions; that is, varieties will yield more grain as the general production potential of the site increases, taking into account all production constraints.

Varieties can respond to productivity levels four ways, as depicted in Figure 7.1. CIMMYT seeks group 1 types because they are superior across the entire range of environments.

Figure 7.2 gives a more detailed picture of the mean yields, coefficients of regression, and yield stability parameters (measured as the sum of the squared deviations from the regression line) for the four groups. For each group, the relative values of each parameter were accumulated across the 15 ISWYN yield years. The variation across ISWYNs illustrates that each group contains high-yielding, highly responsive, and highly stable varieties. Since each group

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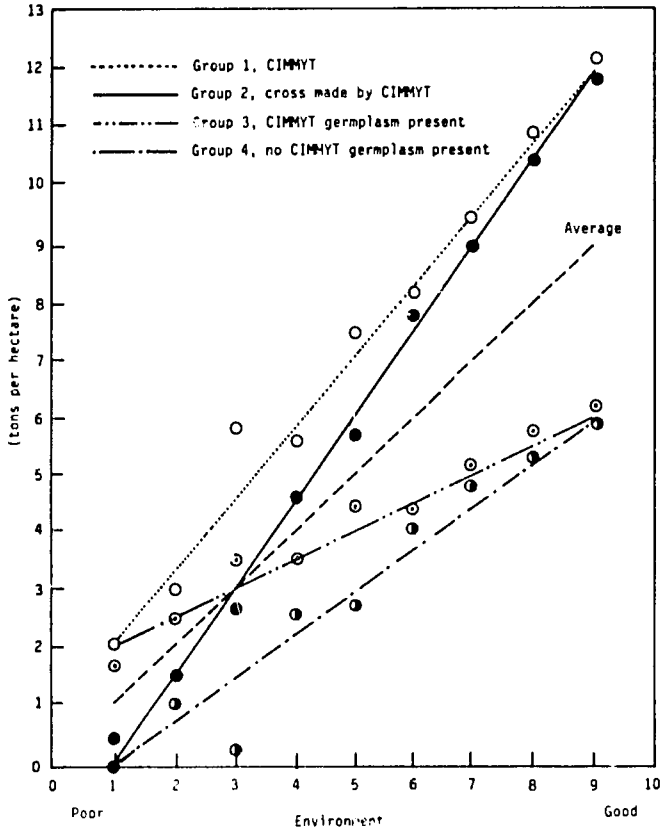
[1]For a fuller treatment of this analysis, see Pfeiffer and Braun (Workshop Paper 23).

Figure 7.1. Yield response to environment of four groups of bread wheat varieties

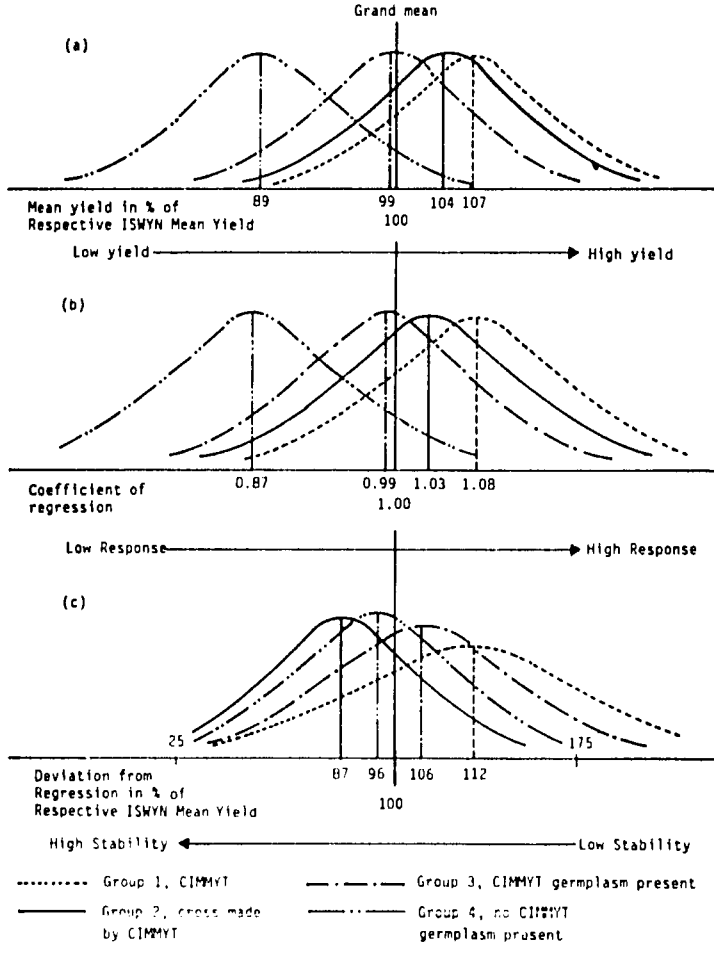


contains a large number of varieties, the general response patterns of the groups will be emphasized.

Yield Performance

Figure 7.2a indicates the yield superiority of group 1 varieties in each ISWYN. This superiority is independent of change over time in the composition of the nurseries. Yield differences remained constant in absolute terms for the 15 years tested, although the relative yield differences between groups decreased as the mean yield steadily increased. Yield differences among groups are statistically significant. It is evident from Figure 7.2b that the responsiveness to improved production conditions of varieties in groups 1 and 2 were above-average or high, whereas the responsiveness of varieties in groups 3 and 4 were below-average.

Figure 7.2. Distribution of mean yields (a), coefficient of regression (b) and yield stability parameters (c) for four groups of bread wheat varieties across ISWYNs 1-15



The yield data from each of the 15 ISWYNs show a high positive correlation between the mean of the varieties and their coefficient of regression (r = 0.84). This indicates that high yield across environments can only be obtained using highly responsive varieties; that is, those with high coefficients of regression. When production conditions were poor, yields were generally low for all varieties, and differences were small. The low coefficients of regression associated with locally developed varieties, which some people interpret as resulting from superior yield performance in poor environments, are actually due to poor yield in high-yielding environments. Locally developed varieties are unable to respond to

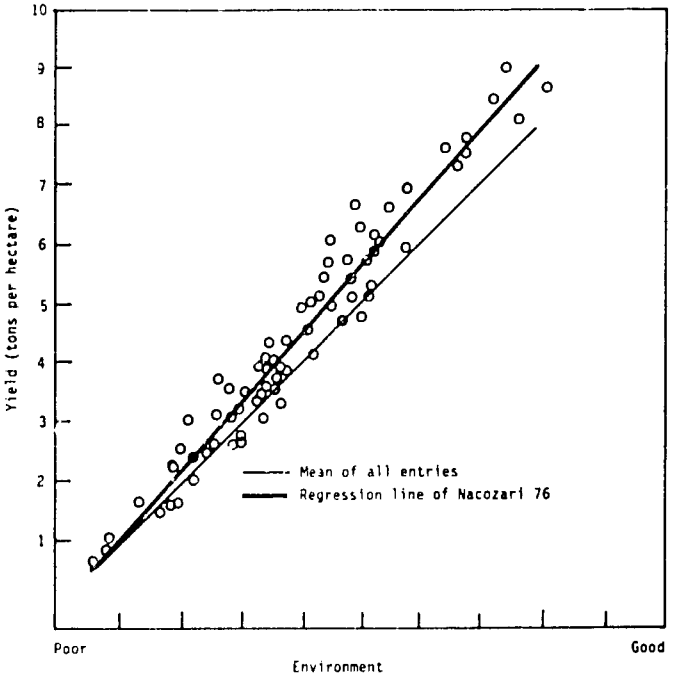
improved growing conditions, while high-yielding varieties do respond. Thus high-yielding varieties can be characterized as input efficient and input responsive.

Figures 7.3 and 7.4 illustrate the analysis of two input-efficient and input-responsive varieties, Nacozari 76 and Veery "S." These varieties demonstrated superior yield performance across the entire range of environments. Note that the yield of Nacozari was not very different from the mean of all entries in the poor environments, but as production conditions improved, its yield became significantly greater than the average. Veery "S" yielded significantly better than the mean of all entries in nearly all environments. These two varieties are true high-yielding varieties.

Yield Stability

From Figure 7.2c it is evident that each group contains varieties with stable yields and unstable yields. Our analysis indicates that group 2 varieties were significantly more stable than those in

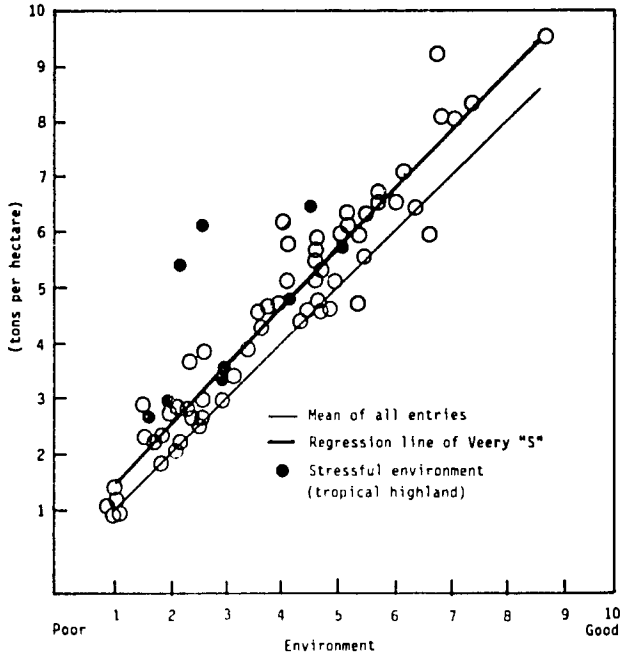
Figure 7.3. Yield of Nacozari 76 bread wheat variety in the 76 environments of the 12th ISWYN



Source: Pfeiffer 983

Note: Y = 1.15X - 0.12

Figure 7.4. Yield of Veery "S" bread wheat variety in the 73 environments of the 15th ISWYN



Source: Pfeiffer 1983
Note: Y = 1.05x+0.52

groups 1, 3, and 4. CIMMYT-bred varieties were as stable as varieties in group 3, and significantly more stable than varieties in group 4. However, yield stability alone is not a sufficient criterion to decide what is and is not a good variety. By our definition, good varieties must combine high yield stability with high yield potential, high input efficiency, and high input responsiveness. The slightly higher yield stability of group 2 varieties over group 1 varieties may be misleading, since the yield stability of some outstanding group 1 varieties is underestimated. For example, Nacozari 76 is high yielding and has high input responsiveness, but it also ranked highest in yield stability (Figure 7.3). In contrast, Veery "S" has low yield stability when expressed as the sum of the squared deviations (Figure 7.4), but it significantly outyielded all other entries across all locations. In Figure 7.4, the solid points indicate environments with either high incidence of major diseases or specific requirements for adaptations. Note that three of these points lie far above the regression line for Veery "S," thus indicating the superior performance at those specific sites. These large deviations, which are all positive, distort the results and cause a high sum of squared deviations from the regression line, which implies low yield stability. If these points are omitted from the

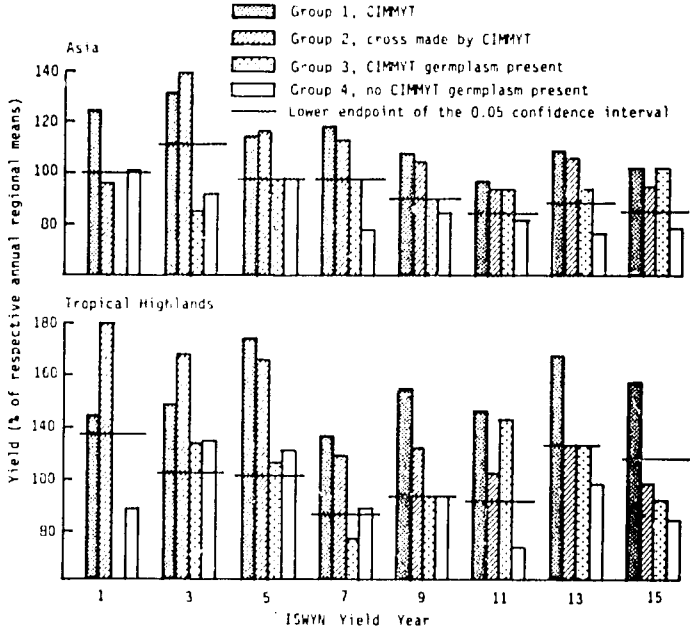
analysis, Veery "S" also has high yield stability. This has caused us to search for a more practical stability parameter.

Performance in Different Regions and Environments

Figure 7.5 presents the performance in Asia and in the tropical highlands of the highest yielding variety from each of the four groups. One would assume that group 3 and group 4 varieties, (developed locally) would have an advantage on a regional basis. However, the data indicate superiority of the best varieties from groups 1 and 2, both across years and regions. In Asia, local crosses using CIMMYT germplasm (group 3) showed improved performance in later years, but group 1 and group 2 varieties still performed at the same level. In the various tropical highland locations, it is evident that the best group 1 varieties are clearly superior to all other varieties tested in recent years.

A new performance level was reached in the 15th ISWYN with genotypes derived from crosses between spring and winter wheats. The Veery "S" mentioned earlier significantly outyielded all other entries across all locations, included in this nursery. It was the

Figure 7.5. Yield performance of highest yielding bread wheat variety from each of four groups, across ISWYNs 1-15

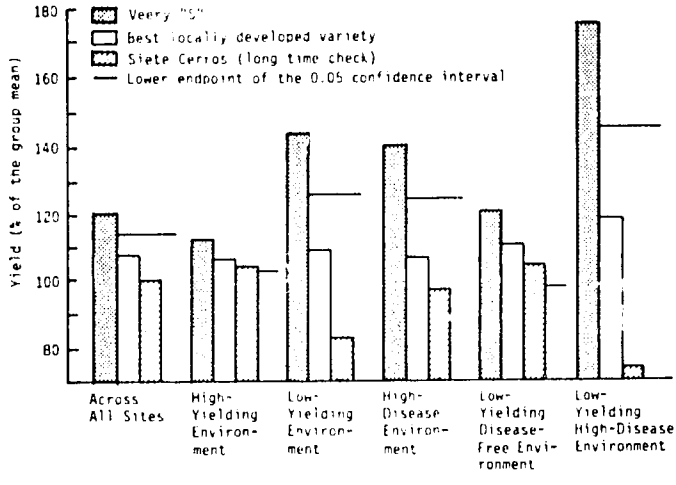


best performer in the tropical highlands, in the South American lowlands, in the irrigated areas of northwest Mexico and the southern United States, and under rainfed conditions in the northern United States and Canada. In the Middle East it yielded slightly lower than the top-yielding variety, and in Asia its yield was not significantly different from the top-yielding variety. This outstanding performance of the Veery lines has been verified by further analysis in ISWYNs 16 through 20 and from two years of data from regional trials in Mexico.

A final illustration of the progress achieved is given in Figure 7.6. Seven environments were formed using such criteria as mean yield and production constraints, like heavy incidence of disease. In Figure 7.6, we show the performance in the 15th ISWYN of the Veery line, the best locally developed variety, and the long-time check variety, Siete Cerros, which is also a CIMMYT-developed variety. The yield advantage of Veery is expressed in higher yields across all environments, though its yield was not significantly different from the other two entries in the high-yielding environments or under low-yielding, disease-free conditions.

Often diseases cause an environment to be classified as low yielding, due to the general lack of resistance of the varieties being tested. However, the environmental conditions may permit very good yield levels if disease resistant varieties are grown. Figure 7.6 demonstrates the superiority of CIMMYT germplasm in these environments.

Figure 7.6. Yield of Veery "S" bread wheat variety, the best locally developed variety and the Siete Cerros variety in five environmental groupings of the 15th ISWYN



VARIABILITY OF WHEAT PRODUCTION IN MEXICO

So far we have discussed yield stability in a global context as it pertains to CIMMYT germplasm. Below are additional findings from an analysis done by the economics program of CIMMYT on the variability of national wheat production in Mexico.

Official data on wheat area, yield, and production were obtained for 17 irrigated regions for the period 1951-81. The 17 regions currently account for about 50 percent of total national wheat production. The so-called high-yielding varieties were introduced in the mid-60s, and therefore the data were partitioned into two periods, 1951-65 (pre HYV) and 1966-81 (post HYV).

Yield in the second period increased by 93 percent over yield in the first period, and the coefficient of variation decreased 12 percent. Average production was up 108 percent and the coefficient of variation declined by 30 percent. The variance of both yield and production increased significantly. Yield changes accounted for 77 percent of the increased production, and area accounted for only 9 percent.

Application of Hazell's (1982) variance decomposition method led to the following conclusions. Of the increase in the variance of total wheat production between the two periods, 85 percent was due to increased production variances within regions and only 15 percent was due to increased production covariances between regions. Also, within regions, changes in the mean and variability of yields accounted for 58 percent and 10 percent, respectively, of the increased variation in total production.

One might expect positive production correlations among regions to emerge from nationwide policies that call into play similar responses by farmers regardless of region. If such national policies have a stronger effect over time, the positive correlations among regions could be expected to increase in intensity and in number. Our data for wheat do show increases in the number of correlations greater than 0.4 in absolute value: 9 negative correlations were found in the first period, 12 in the second; 12 positive correlations were found in the first period, 16 in the second. However, the total for each period represents only 20 percent of the number of possible interregional correlations. Only 5 correlations showed consistent patterns in both periods. Of these, 2 were between widely separated regions, while 3 were between regions in the same coastal state of Mexico. We would argue that the first 2 correlations are the consequence of random factors, while the last 3 relate to weather and the availability of irrigation.

These enumerations are consistent with our earlier assertion that production covariances among regions contribute little to the increase in the variance of wheat production. The observations also imply that national policy has contributed little to the increase in variance of total wheat production.

We did some additional analysis on the five largest wheat producing regions. Four of these regions contributed more to production increases than to increases in variance. After dividing the data into two equal periods, we ran simple linear regressions of yield on time for each region and period, and then looked at the R^2, estimated b values and large residuals.

In each of the five comparisons, the R^2 value decreased from the first to the second period, indicating greater variability around the linear regression line. Interestingly, in only one of the five cases was the estimated b value materially larger in the second period, giving evidence of the earlier rapid advance in yields as disease resistant varieties and access to inputs called forth more intensive production practices.

We were, however, more interested in the residuals, expecting to see biological explanations for marked departures from the trend. With few large residuals in evidence (defined as 20 percent of actual trend), we focused on those that were negative. Preliminary checks suggest that these large residuals are associated with disease, with late planting because of storms, with late frost, and with other such factors. This preliminary work again suggests that natural factors are playing a prominent role in increased variability.

We expect to pursue these issues further in future research, but the analysis so far affirms that yield changes within regions account for the major portion of the increased variation in wheat production in Mexico.

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8 Summary and Assessment of the Wheat Papers

C. James Peterson

In Chapter 2, Hazell shows that variability in total world wheat production has significantly declined since 1970. However, workshop papers showed that production has become considerably more variable in many areas of the world. Even discounting areas with increasing production variance, yield stability continues to be an important concern in regions where semiarid rainfed conditions or harsh winters prevail. This consequently affects a large percentage of the total world wheat acreage.

CHANGES IN YIELD RESPONSE

In the past, local wheat varieties and landraces were considered to possess good stability as a result of their local narrow adaptation and relative heterogeneity. This high stability was, in part, a reflection of the low genetic yield potential of older varieties and their inability to respond with higher yields to either improving environmental conditions or production inputs such as fertilizers or irrigation. Production was relatively stable, but stable at relatively low yields.

Workshop papers by Fischbeck (7), Pfeiffer and Braun (23), and Peterson et al. (22) show that modern high-yielding wheat varieties have greatly increased genetic yield potential and the ability to respond effectively to favorable environmental conditions and production inputs such as fertilizer and irrigation. The increasing variance in production levels indicated by several conference papers can, at least in part, be related to the increased genetic yield potential and responsiveness of modern varieties.

Dramatic improvement of genetic yield potential and responsiveness of modern varieties has been a major contributor to increased production levels. Using Findlay and Wilkinson regression stability analyses, Peterson and his colleagues (Workshop Paper 22) show that in the Midwest regional nursery programs, the regression b values of the long-term nursery check variety Kharkof declined steadily from 0.9 in 1959, when the check was fairly representative of the then current varieties, to 0.6 in 1984. In effect, the environmental responsiveness of the nursery varieties increased from a regression value of 1.0 to approximately 1.4 relative check varieties over the last 26 years.

New high-yielding varieties have effectively widened the difference in productivity between poor or marginal environments and more favorable environments. Also, the difference in yield levels in a single environment with and without application of inputs has increased. The importance of the interaction of genotype and environment has greatly increased. This alone has several implications for production levels and production variance.

Modern varieties have a large yield advantage over local landraces and older varieties when environments or inputs permit expression of the genetic yield potential. However, as environmental yield potential decreases, as under marginal or highly stressed conditions, or as inputs are withdrawn, the relative yield advantage of modern varieties decreases. It must be emphasized that it is the yield advantage that decreases as, even in marginal environments, current high-yielding varieties are usually more productive, or at least equal in productivity to local landraces. In such cases, the environmental constraints to expression of yield are so great that genetic differences have little effect.

Current varieties can exploit favorable environmental conditions and application of inputs to produce the maximum yield level possible under a specific growing condition. This also means that current varieties and higher yield levels are more sensitive to fluctuations in weather and to variation in application of inputs, especially fertilizer and irrigation. In the U.S. Midwest this was shown by Headley and French (Workshop Paper 15) as resulting in increased variance associated with weather-technology interactions.

Older varieties and landraces may appear more stable over environments, but this is actually a function of their lower yield levels, inability to respond to favorable conditions and inputs, and lack of genetic yield potential. The change in the environmental response curve of modern varieties can contribute to increased production variance as expressed in increased genotype by environment interaction variance, especially within a region that has a wide variation in environmental conditions and availability of inputs. Since most wheat is produced in semiarid, highly variable environments, it is likely that, as many workshop papers suggest, breeders have contributed to increases in production variance.

The apparent increase in variance attributed to the use of modern high-yielding varieties actually has nothing to do with the introduction of semidwarf wheats or any other specific genetic traits. Rather, the increased variance can be more aptly attributed to increased genetic yield potential and yield responsiveness of modern varieties to inputs and favorable environments. Within the classical interpretation of the Findlay-Wilkinson model, modern varieties with very high b values would be considered less stable. Over time, this is not true, however, as indicated by increasing mean yields and no change or even reductions in deviations from regression. Currently, varieties are as stable or more stable than in the past, but on a very different environmental response curve.

CHANGES IN THE GENETIC BASE

In several papers, concern over the narrowing genetic base of wheat varieties and contributions of genetic vulnerability to in-

creased production variance has been expressed. I think most breeders will agree that the genetic base of wheat varieties in most countries has significantly broadened over the last 20 years, and vulnerability has decreased with the use of modern varieties. Distribution and availability of germplasm on an international basis has significantly improved, and breeders are working with larger genetic bases than in the past. In the U.S. Midwest, the number of different, although arguably related, varieties -- occupying over 100 thousand acres of production -- has increased significantly from only 21 in 1939, to 45 in 1959, to over 100 in 1985. Current use of genetic material from wheat relatives, especially rye and agropyron, is expanding the genetic base of wheat varieties. Realization of efforts in biotechnology and genetic engineering will contribute to future enlargement of the genetic base of wheat and contribute to reductions in vulnerability. While breeders recognize that diversity in current varieties may not be sufficient, it is improving and will continue to improve.

CHANGES IN YIELD VARIABILITY

While modern varieties have shown potential to increase yield variance over a wide region, it is the magnitude of the variance that is of concern. Most will agree that total variance of production has increased with increasing yield levels. However, as shown by Fischbeck in Bavaria (Workshop Paper 7), Austin and Arnold in England (Workshop Paper 2), and Hanus and Rizos in the European community and Germany (Workshop Paper 11), the coefficient of variation has remained relatively stable. Wan et al. (Workshop Paper 32) conclude that while total variance had increased in New South Wales, Australia, it was not of sufficient magnitude to cause concern. Peterson et al. (Workshop Paper 22) show that in the U.S. Midwest the variance attributed to genotype x environment interaction has significantly increased. If the variance is expressed in relation to mean production as a cv, however, the variance has remained relatively stable at about 13 percent in the southern region and has increased only slightly from 10 percent to 15 percent in the northern region.

Tarrant (Workshop Paper 29) indicates that the absolute variability in Soviet cereal production is increasing and the influence of important factors that have compensated for yield variability between production regions has declined. Although variability is increasing no faster than expected with increasing production levels, any change in absolute variability of such a large region will have a great effect on world food supply and price structures.

In most countries, changing production techniques and increased use of inputs such as fertilizer, herbicides, and irrigation have made an equal contribution to increased production levels, as have improved varieties. The application of inputs, per se, does not increase yield variability, as shown by Hanus and Schoop (Workshop Paper 12) in experiments with fertilizer and fungicide applications. However, the variability of application of inputs can have a profound effect on yield variance.

Austin and Arnold (Workshop Paper 2) show clearly that observed yield variability in England is a consequence of variability in a

large number of factors, each having a relatively small effect on yield. This concept can be extended to variation in factors that have a large effect on yield levels, such as fertilizer, irrigation, herbicides, and fungicides, and suggests that variation in input availability, application, and prices has a large effect on potential yield variability. Especially with the increasing responsiveness of modern varieties to inputs, the changing levels of production variance in many countries can most readily be attributed to variation in input availability, allocation, and prices.

Conference papers by Nguyen (Workshop Papers 19 and 20) suggest that increased yield variability in Syria and the Soviet Union has resulted from policies directly affecting allocation and availability of inputs, especially fertilizer. Production variance in Egypt has declined, and Hazell et al. (Workshop Paper 13) indicate that high levels of variability in the 1960s were a result of problems in land reform and rigid quotas for allocation of cropland. Gill (Workshop Paper 10) discusses the important role of government policy for promoting cereal production in India and stresses the need for adequate and timely supplies of inputs and credit for stabilizing future cereal production levels. Stone and Zhong (Workshop Paper 28) suggest that increased yield variance in China may be due to increased interaction of central policy with supply of modern inputs, which are so critical to high yield. Hazell (Workshop Paper 14) shows that world cereal prices have become much more variable since the early 1970s. Variation in price structures will have a considerable effect on input use and management decisions in many developed countries and will therefore surely affect yield variability.

As a breeder, I have much apprehension and concern over papers using regional or national production data that attempt to determine or hypothesize underlying biological causes for changes in production variance. As mentioned in several discussions, the time frames of data chosen have a large effect on the outcome of analyses. Nguyen (Workshop Paper 21) shows that the production variance of wheat in the U.S. Midwest between 1950 and 1980 declined with increasing yield, except for the early 1960s, when stem rust epidemics caused large variations in yield. Since that time no major disease epidemics have occurred. If these years had been excluded, the measured variance might have increased, as suggested by Headley and French (Workshop Paper 15) and Peterson et al. (Workshop Paper 22). National and regional production statistics must be used with great care and with an understanding of the biological, technological, and political factors that may have overriding influences on production.

CONCLUSION

In conclusion, I must stress that stability in wheat varieties has not decreased. Yield variability or variations in productivity have increased as a result of increased genetic yield potential and increased responsiveness of modern varieties to inputs and favorable environmental conditions. As a direct consequence, variations in the allocation, availability, and prices of inputs -- and even weather variation -- have an increasing effect on yield variability and are the primary causes of apparent changes in production variance.

9

Report of the Working Group on Wheat

Roger B. Austin

The group noted that most of the evidence on changes in variation in yield was based on two consecutive periods, each 10 to 15 years long. The existence of any underlying trend in variation in yield could not be made from data from such a limited number of years, irrespective of the method of analysis used.

Surveying the evidence presented at the workshop, one set of figures showed that the coefficient of variation of yield was unchanged for 9 countries, decreased for 13, and increased for 6 (Hazell, Chapter 2). Other figures showed no change in the coefficient of variation in 4 countries, a decrease in 6, and an increase in only 3. While the coefficient of variation in cereal yields was not generally or consistently greater in the second period than in the first, the absolute variation in yield generally increased.

A summary of this kind obscures several important changes, however. In favorable environments, such as in western Europe and in the Indian Punjab, large increases in yield occurred in response to greater inputs, improved varieties, and more skilled management. In these countries the coefficient of variation of yield decreased. In other countries, where new technologies, both in terms of varieties and inputs, were in the process of being adopted, coefficients of variation sometimes increased, perhaps because of the variable degree and success of adoption of the new technologies. An increase in the coefficient variation of yield might be expected in other countries if wheat production were shifted or extended to more climatically marginal areas.

In the context of food policy, variation in production, rather than in yield per unit of land area, is of most concern nationally. However, group participants disagreed as to whether the absolute variation in production or the coefficient of variation in production is the more relevant, or whether some other measure of food availability, such as the coefficient of variation in cereal production per capita of population, is more meaningful. However, for the largest producers -- United States, U.S.S.R., China, and India -- the absolute variation in production is of greatest significance because

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*The group consisted of Roger B. Austin, Nazmi Demir, Lloyd T. Evans, K. S. Gill (chairman), H. Hanus, Robert Herdt, H. K. Jain, Arthur Klatt, Hung P. Nguyen, Martin L. Parry, C. James Peterson, W. H. Pfeiffer, Bruce Stone, and John R. Tarrant.

of the consequences for world trade in cereals. In most wheat producing countries, the variation in production was caused by variation in yield per unit of area rather than variation in area sown. Where interannual variation in yield was becoming greater, it was because of increased covariances for yield among regions within countries.

The group accepted that there is now good evidence of increased covariances in production and agreed that these covariances arise from two probable causes (assuming no trend in the variability of those elements of the weather important for yield). One cause is fluctuations in general economic conditions, which might tend to synchronize variation in the amounts and the timing of inputs that determine yield. The second cause, discussed in more detail by the group, is the possibility that a decrease in the range of genotypes grown might contribute to increased covariance. Varieties with improved disease and pest resistance should decrease yield variability in both percentage and absolute terms, though increasing effort in the future may be required to maintain this position. In this sense, therefore, production may be potentially more vulnerable to the relaxation of effort in plant breeding.

It was frequently claimed, usually by those not involved in plant breeding, that the genetic base exploited in variety breeding was becoming narrower, leading to an increased vulnerability of varieties to epidemics of pests and diseases or to continentwide stresses (drought, cold). The group observed that, in the period before transnational breeding programs were established, there was a great diversity in the varieties grown but most of them lacked important genes for disease and pest resistance, for dwarfism, for photoperiod insensitivity, and so on. When genes for these features were introduced, they were initially present in relatively few varieties, which were widely grown throughout the world. In this sense the general (background) genetic base narrowed, despite the advantage in yield gained from incorporating those genes into varieties. As national programs developed, the desirable genes were incorporated into a wider range of genetic backgrounds. If national programs expand, the genetic base of wheat will probably become larger, not smaller -- and need not be a matter of long-term concern.

The group considered that the use of the terms <u>adaptability</u> and <u>stability</u> in the context of variety performance frequently led to confusion, and it preferred the term <u>spatial and temporal stability</u>. For some factors affecting yield, like pest and disease resistance, years and sites would be interchangeable, so that sites could substitute for years, enabling breeders to make more rapid progress in selecting for improved performance. For environmental factors affecting yield, like amount of rainfall and rainfall distribution, such a scheme would not work as well.

In conclusion, the group emphasized that with the increasing intensity and complexity of production systems, involving more inputs and the need for greater precision in timing, production and yield are potentially more vulnerable to unplanned lapses in management, both at the farm and public sector level. Further, while it was not the remit of the group to discuss this issue, it observed that future food security will depend as much on general economic conditions as on the efforts of plant breeders.

10 IRRI Presentation: Yield Stability and Modern Rice Technology*

John C. Flinn and D. P. Garrity

Hazell (Chapter 2) and others have argued that recent increases in the yield instability of cereals in the developing world were a consequence of (a) institutional factors, such as higher correlations between prices, or supply restrictions due to poorly developed infrastructure; (b) agroclimatic factors such as droughts and floods; and (c) biotic factors largely associated with increased genetic uniformity within crops across regions. Few studies -- exceptions are provided by Mehra (1981), Ray (1983), and Walker (1984) -- have attributed changes in production variability to the characteristics of the modern varieties (MVs), themselves,[1] and to the socioeconomic environment in which they are grown.

The nature of modern rice technology and its inherent implications for increasing or decreasing rice yield stability are discussed in this chapter. First, we review the evidence of whether stability in aggregate has increased in Asia with the adoption of MVs. Second, we examine experimental data to determine whether the components of modern rice technology are likely to stabilize or destabilize yield. Third, we review research strategies likely to result in second-generation MVs and methods of crop management having higher productivity and stability than first-generation MVs or traditional rice varieties.

YIELD STABILITY IN ASIA

The rate and extent of MV rice adoption varies markedly among (and within) Asian countries. So do policies that influence MV adoption (price, irrigation, research, extension, and so on). Therefore the choice of periods for time trend analysis must be country specific and based on structural shifts in MV adoption or major policy changes.

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*This is a summary of Workshop Paper 8.

[1]Modern rice varieties (MVs) were developed during the last two decades and are dwarf to semidwarf, mainly photoperiod insensitive, and responsive to modern agronomic practices. We prefer the term MV to HYV because they are only high yielding when high levels of inputs are also used.

Table 10.1 reports changes for eight Asian countries between periods defined by changes in rice policies, programs, and MV adoption. On this basis, yield instability may have increased in Burma, China, India, and Indonesia in aggregate, but decreased in Bangladesh, the Philippines, Sri Lanka, and Thailand. Although Burma and Indonesia show slight increases in yield variability, the first period in each case was characterized by stagnant low yields, while the second period exhibits large and, in most cases, continuing yield increases.

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

Table 10.1--Change in rice production, area, and yield by adoption of modern variety rice, eight major rice growing countries

Country	Before Adoption of MV Rice[a]	After Adoption of MV Rice[a]	Change in Coefficient of Variation		
			Production	Area	Yield
			(percent)		
Bangladesh	1959-73	1974-84	-56	-52	-58
Burma	1959-76	1977-84	-21	-17	4
China	1959-77	1978-84	15	-46	37
India	1959-73	1974-84	32	61	30
Eastern	1959-70	1971-82	3	25	-1
Southern	1959-68	1969-82	132	410	66
Northern	1959-69	1970-82	-7	61	-2
Indonesia	1959-67	1978-84	-45	-33	49
Philippines	1955-65	1975-84	-36	-33	-64
Sri Lanka	1959-75	1976-84	-64	-51	-60
Thailand	1955-65	1966-84	-55	-55	-36

Note: Coefficients of variation are computed from means and standard errors of second-order polynomial time trends except when time trend is not significant.

[a] Periods for time trend analysis are based on each country's changes in agricultural policies and on its rate of adoption of modern variety rice.

Carlson (Workshop Paper 4) examined the causes of rice yield variability using panel data from 13 Asian countries. He concludes that the cv of both rice yields and total production significantly decreases with higher MV adoption and irrigation development. Ray (1983) examined instability in Indian agriculture and shows that weather and price variables were significant determinants of yield and production stability in rice production. However, variables associated with technological change, like MV adoption and irrigation rate, were not included in the analysis other than through a trend variable.

TECHNOLOGY AND YIELD STABILITY

Coffman and Hargrove (Workshop Paper 5) and Carlson (Workshop Paper 4) discuss how the morphology of MVs influences the comparative yield stability of MVs and other varieties. We do not duplicate this effort but we provide examples of the association between MV traits and yield stability.

Stability and Adaptability

Much of the success of MV rices is attributed to the benefits of multilocational testing that has led to the identification of widely adapted varieties. Adaptability may be important to crop improvement scientists, but breeding for wide adaptability has associated costs. Because selection is based on multilocation performance, varieties selected may not necessarily be the best for a specific location. The performance of a genotype on one site over time is measured as yield stability, while the performance of a genotype across locations is measured as adaptability (Evenson et al. 1978).

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

It is assumed that adaptability is highly correlated with stability. Whether or not this is true is a central issue in the effectiveness of the breeding process in producing varieties that have stability as well as high yield.

There is a very large body of literature for the major cereal crops on the interaction between genotype and environment. This work received strong impetus from Finlay and Wilkinson (1963) and Eberhart and Russell (1966). However, these and other studies make no distinction between the concepts of stability and adaptability. Evenson et al. (1978) used analysis of covariance to test whether the two parameters were related, using a set of rice varieties selected from the first three years of irrigated rice yield trials of the International Rice Testing Program and several years' results of similar trials conducted by the All India Coordinated Rice Improvement Program.

They found contrasting results for the two data sets: no relationship between adaptability and stability in the IRTP data set but a strong positive correlation between the parameters in the AICRIP data set. Given the short time span of the IRTP data and the implausible stability coefficients obtained for some of the genotypes, we retested the hypothesis, using Evenson's model and data from 10 years of IRTP trials.

The varieties included in the analysis were those tested in IRTP nurseries for a minimum of four years. IRTP trials are designed for frequent turnover of entries, as new improved materials become available. Thus only a few of the several hundred varieties tested during the past decade have been retained for a four-year period or more. Data from the upland rice yield trials and the irrigated trials were analyzed to provide two contrasting sets of varieties tested in different ecological conditions.

Low coefficients of adaptability or stability indicate a relatively low yield differential for a variety across sites. A high coefficient indicates that the variety performs poorly in low yield environments but yields well in more favorable environments. The coefficients of upland varieties vary from as low as 0.86 for adaptability and 0.87 for stability (IR6115-1-1-1) to as high as 1.06 and 1.29 for IR2061-522-6-9 (Table 10.2). The coefficients of adaptability and stability were positively correlated among the sets of entries from both the irrigated and upland yield trials.

The coefficients of stability tended to be higher than the coefficient of adaptability in both variety sets. These data, plus those of Mackill et al. (1985), who show that the regression coefficient of variety yields versus site mean yield remain consistent across entries in international rainfed lowland rice trials, adds weight to the contention that adaptability and stability are highly associated. However, varieties chosen in this manner are not a substitute for varieties developed for the specific needs of Asia's diverse agroclimatic rice environments and market preferences.

Drought Environments

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

The characteristics of MV rices allow them to respond to higher nutrition and uniform water supply by producing higher grain yield

Table 10.2--Adaptability and stability of rice cultivars tested in the International Rice Testing Program

Environment and Cultivar[a]	Stability		Adaptability	
	Coefficient[b]	Standard Error	Coefficient[b]	Standard Error
Irrigated				
IR42	1.08	.07	0.99	.06
IR51-282-8	1.05	.09	1.10	.06
IR54	1.16	.10	1.07	.09
IR8	1.03	.06	1.06	.04
IR26	0.97	.07	0.89	.08
IR36	0.96	.04	0.93	.03
MRC-603-303	1.01	.07	1.00	.05
MTU3419	1.16	.11	1.08	.08
IR1561-228-3-3	1.02	.09	1.02	.07
IE + 2845 (RP-1899-24-4)	1.05	.08	1.18	.07
Upland				
IR1529-430-3 (IR43)	1.12	.08	1.08	.08
IR2035-242-1 (IR45)	0.96	.16	0.93	.99
MRC172-9	1.26	.25	1.09	.11
C22	1.00	.16	1.09	.12
IR2061-522-6-9	1.29	.15	1.06	.15
IR6115-1-1-1	0.87	.08	0.86	.18
IR52 (IR5853-118-5)	1.06	.09	0.90	.14

Source: Final reports of IRTP nurseries for 1974-83, Philippines: IRRI. See Evenson et al. (1981) for method of analysis and further interpretation of the coefficients.

[a] Tested four or more years.

[b] Significant at 1 percent level.

per crop and per field day. But where water control is inadequate, the structure and function of the MV rice plant may predispose it to be more severely affected by water deficit or excess than older varieties. In some drought-prone environments, the shorter stature, shallower root system, higher tillering, and photoperiod insensitivity of MVs more frequently cause severe damage or crop failure.

Early maturity is a necessary character in rice growing areas with a short wet season. The shorter duration of an MV may enable it to better fit the limited period of available moisture and to escape terminal water stress, which would affect a late-maturing MV during flowering or grain filling. A large proportion of Philippine farmers growing rainfed rice prefer early maturing rices (105-115 days) because of their enhanced ability to escape drought.

In other drought-prone environments, however, with long rainy periods but erratic rainfall distribution (for example, northeast Thailand and the Cagayan Valley in the Philippines), the short-duration, photoperiod-insensitive varieties are highly unstable and clearly inappropriate (Gines et al. 1984). Short-duration varieties are genetically programmed to proceed through each successive growth state (tillering, floral initiation, spikelet development, flowering) in a limited time. Severe and prolonged drought interrupts this development, resulting in drastic yield reduction. A photoperiod-sensitive variety flowers in a certain month regardless of when it is planted. When planted at the normal time, early in the growing season, it passes through a long preflowering phase. This longer growth period enables more effective drought recovery. Short-duration, photoperiod-insensitive varieties, however, have little phenological buffering. Growth lost at one stage cannot be so effectively compensated for.

Insect Management

Prophylactic application of broad-spectrum insecticides, as recommended in most extension programs, is expensive, often ineffective because of pest resurgence and resistance, and environmentally hazardous. These shortcomings led to the concept of integrated pest management (IPM), which involves the selection of insect-resistant varieties and the judicious use of insecticides when insect damage exceeds threshold levels (Heinrichs et al. 1979).

The on-farm benefits of three insect control strategies -- no insecticide application, action thresholds, and prophylactic sprays -- were evaluated on insect-resistant rice varieties over five years in the Philippines (Smith and Litsinger 1985). The mean net benefits were similar across treatments, but cvs were less for the untreated (0.15) and the IPM treated plots (0.23) than for the prophylactically treated plots (0.31). One reason for the similarity in net benefits was that, although yields of the zero treatment tended to be less than the IPM and prophylactic treatments, costs were higher for the IPM treatment because of surveillance costs and for the prophylactic treatment because of insecticide costs. The Philippine Ministry of Agriculture reports that threshold spraying was more profitable than preventive sprays in 75 percent of 105 on-farm trials. Herdt et al. (1984) similarly found that insecticide applications based on action thresholds dominated alternative insect control measures.

Weed Management

Modern rice varieties are shorter and more erect, and so are less weed competitive than the taller, drooping older varieties (De Datta 1981). This, in principle, implies increased yield variability in MVs, where weeds are a problem or uncontrolled.

In Asia, the most dramatic recent change in weed management in rice is the rapid and widespread adoption of herbicides. This shift in weed control techniques was prompted by a combination of technical and economic factors -- the synthesis of selective herbicides such as

butachlor and thiobencarb, which effectively control weeds in irrigated and shallow rainfed rice, coupled with falling real prices of herbicides and increasing labor costs for weeding (De Datta and Flinn 1985).

A shift from hand weeding to herbicides could increase yield variability in some circumstances: (a) if herbicides later become unavailable or their price increases drastically and labor is either no longer available or too costly; (b) if the herbicides' effectiveness under severe moisture stress drops; (c) if herbicide-resistant weed species become dominant as weed populations shift with herbicide use over time (Vega et al. 1970). In practice, the latter has not been a major problem. A combination of crop rotation, water management, tillage practices, and the use of nonselective herbicides controls such weeds that occur, particularly in environments without water stress (S. K. De Datta, personal communication).

A weed control problem in rice cultivation persists in less-favored rainfed and upland environments, because herbicides have yet to be found that are consistently effective in rice fields under both wet and dry conditions. Labor for hand weeding (often over 30 days per hectare) is costly, and while tillage may be effective, many upland rice farmers lack the power or money for timely tillage. Therefore the rice growing environments most likely to be destabilized by weeds are those that are already low yielding and adverse.

Disease Management

Varietal resistance continues to be the main disease management strategy for rice in Asia. Fungicides have not become part of disease management in South and Southeast Asia, although they have in temperate regions such as Japan and Korea. Clearly, disease outbreaks, such as the rice tungro virus outbreaks in parts of Indonesia in 1981, will continue to occur and to cause yield loss. However, modern breeding strategies, which include genotype selection under hot-spot locations, ensure that new materials are either available or in the pipeline to combat diseases when they become potentially serious problems. One example was the availability of IR56 to replace IR36 in regions of Indonesia where the latter had become susceptible to rice tungro virus.

Management techniques may also reduce the likelihood of disease infestation with intensified rice production. For example, varietal rotation between wet season and dry season has been introduced in Indonesia to reduce the probability of another outbreak of rice tungro virus (Manwan and Sama 1985). The success of varietal (and gene) rotation as a strategy for disease management requires a well-developed agricultural research, extension, and seed industry. Varietal rotation becomes feasible as the expertise of national rice programs increases, which is the case in Asia (International Rice Research Institute 1985).

Fertilizer Use

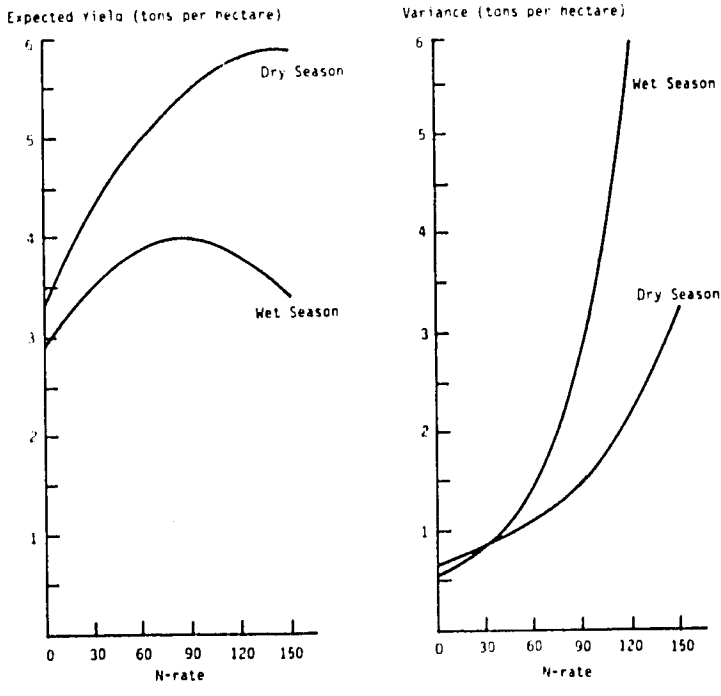
Rice yield variability is known to increase as nitrogen (N) rates increase (Evans and De Datta 1979). This variability is induced through strong interaction between applied nitrogen and the

levels of random factors such as solar radiation, water regimes, and pest incidence (De Datta 1981).

The relationships between mean yield, yield variability, and N-rate were estimated from trials conducted in Laguna by IRRI's Agronomy Department. IR36 was selected for analyses because this variety (a) had the longest sequence of usable data (1976-84) and (b) was one of the most popular irrigated rices in tropical Asia in the early 1980s. The relationship between N-rate and yield variability was estimated via a random coefficient model, as described by Smith and Umali (1985).

The maximum expected yield of IR36 was 4.0 and 5.9 tons per hectare (t/ha) reached at 86 and 147 kilograms of N per hectare (kg N/ha) in the wet and dry seasons, respectively. Yield variances increased with N-rate, more rapidly in the wet than in the dry season (Figure 10.1). The risk-neutral, high-profit N-rate was 51 kg N/ha in the wet season and 110 kg N/ha in the dry season, given current farmer-effective prices and a 100 percent interest charge on fertilizer cost.

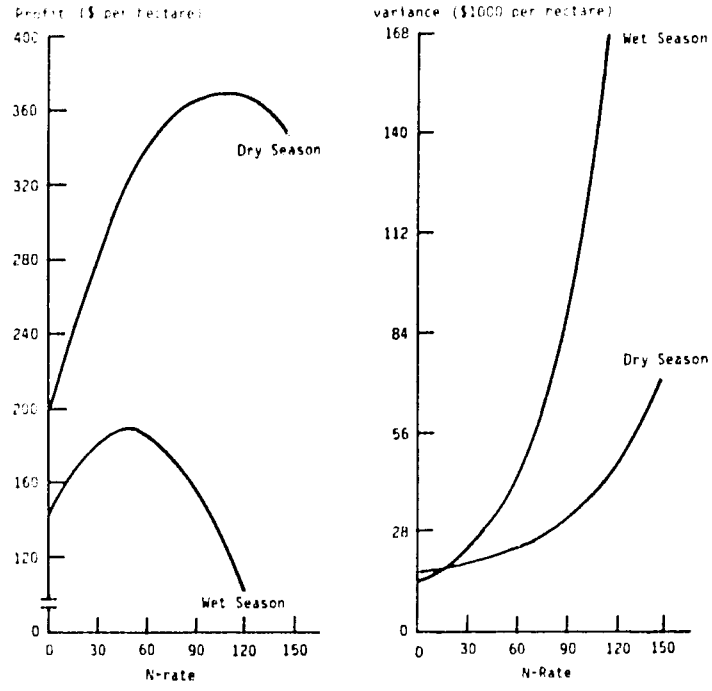
Figure 10.1. Relationship between N-rate, yield, and variance of yield for IR36, wet and dry seasons, Laguna



The low-resource farmers' concern to avoid risk may make them unwilling to apply high expected-profit N-rate, because although profit increases as N increases (up to a point), so does profit variability (Figure 10.2). A useful rule of thumb is that farmers are prepared to incur additional risk (as measured by the standard deviation of outcome) provided that the increase is less than twice the increase in net benefit resulting from the change in technology (Ryan 1984). If the trade-off is more than two, then the innovation is unlikely to be attractive to most farmers.

The change in the standard deviation of profit induced by a marginal reduction in N-rate from the optimal level exceeded 20:1 in both the wet and dry seasons. Thus if risk is a determinant of fertilizer use, it is unlikely that a moderately risk-averse farmer would apply the high-profit N-rate. The N-rates where the trade-off between stability and level of profit was 2 to 1 were at 35 and 92 kg N/ha in the wet and dry seasons, respectively. This implies a 31 percent and a 16 percent reduction in N-rates below the high profit levels to accommodate risk aversion. However, these reductions in N-

Figure 10.2. Relationship between N-rate, profit, and profit variance of IR36, wet and dry seasons, Laguna



rates imply less than a 5 percent reduction in yield but a 20-27 percent reduction in yield variance. Expected profit was reduced only 2 percent or less, while the standard deviation of profit was reduced more than 10 percent when risk-averse decision criteria were used.

INCREASING YIELD STABILITY

According to the Food and Agriculture Organization, balancing rice supply and demand by the year 2000 will require a 2.8 percent per year production increase over the period 1980-2000, which can be compared with a 2.4 percent growth rate achieved during 1960-80. Most of this increase will be produced and consumed in Asia. Competition for land in Asia for other crops, livestock, and nonagricultural uses results in its shrinking availability for rice cultivation. Therefore, the only pathway open to most Asian countries to increase rice production is through higher productivity and increased cropping intensity. This can only be achieved by technological advances in water and fertilizer management and in rice varieties capable of responding to these inputs.

Improved Varieties

Modern rice varieties will continue to be grown under more intensive management systems. Therefore, problems of pest adaptation will continue as a threat to high yields and to yield stability. Research managers recognize the importance of breeding for multiple disease and insect resistance to counter the dynamic threat of pest infestation. Their efforts have led to recently released MVs possessing higher pest resistance than previously released varieties.

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

Of great concern is the issue of large areas being planted to one variety or to a few closely related varieties, which increases the probability of widespread insect and disease outbreaks. For example, IR36 was grown on some 11 million hectares of rice lands in South and Southeast Asia each year in the early 1980s, which attests to its adaptability and demonstrates farmers' preference for IR36 over other available varieties. The concern, however, is the lack of alternatives better suited to farmers' specific conditions.

The problem of large areas planted to single varieties should decrease as national rice programs breed varieties better adapted to local conditions. This capacity is aided by the International Rice Testing Program, which coordinates an international network to provide national programs with a wide range of rices to evaluate under their own conditions. For example, 29 of the IRTP nurseries

planned for 1986 are tailored to rather specific environmental stress conditions. Most entries in these nurseries were not bred by IRRI but by national program scientists.

Crop and Soil Management

Soil health research addresses the problems of toxicities and nutrient imbalances and of yield maintenance under increased cropping intensity. As rice production is intensified, a progression of deficiencies -- nitrogen, then phosphorous, followed by zinc and possibly sulfur -- is likely (De Datta 1981). The International Network for Soil Fertility and Fertilizer Efficiency in Rice (INSFFER) -- a network that includes national rice programs, IRRI, and the International Fertilizer Development Center -- specifically addresses issues of soil fertility in rice. INSFFER collaborators conduct research to increase the efficiency of nutrient use (by promoting integrated nutrient supply systems involving organic and biological sources of fertilizer in addition to mineral fertilizer) and to maintain rice yields under intensified cropping. Such programs will help to lead to increases in the stability and sustainability of rice production.

Researchers now accept that it is necessary to adapt and modify technology to meet the needs of specific agroclimatic environments before farmers' adoption is likely. Basic to this approach is that the stability and sustainability of farming systems can be enhanced if (a) farmers are offered a range of technological options rather than a single predetermined package and (b) farmers participate in the technology evaluation process. This is a quantum shift in philosophy from the tendency to advocate broad recommendations thought to suit the majority of farm environments.

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11 Summary and Assessment of the Rice Papers

Randolph Barker

Five papers deal directly with the issues of yield and production variability in rice. Seven other papers to which I shall refer (not all of which were presented at this workshop) are concerned with variability in rice and other cereal grains.

Coffman and Hargrove (Workshop Paper 5) note the dramatic change in cultivated rice varieties in the last twenty years, with modern varieties spreading more rapidly and extensively than any other technological change in the history of agriculture. The narrowing of the genetic base in the fewer varieties being grown and the cytoplasmic uniformity of the modern varieties give cause for concern. Modern varieties have been bred principally for high yield under favorable environmental conditions. Being less tolerant to drought and other unfavorable climatic conditions and less resistant to insects and diseases, they have been a contributing factor to production and yield variability in some areas.

AGGREGATE STABILITY

The above factors notwithstanding, there is evidence to suggest that yield variability in rice is lower than in other crops and that variability has declined following the introduction of modern varieties. Comparing the period 1960/61 to 1970/71 with the period 1971/72 to 1982/83, Hazell (Chapter 2) shows that the coefficient of variation (cv) for world rice production declined and that the cv for rice in the latter period is the lowest for all cereals. Weber (Workshop Paper 33) suggests that the relative stability in rice production is due to the large portion of the rice area that is irrigated (one-third of the area and one-half of the rice production in South and Southeast Asia and essentially all of the rice in China and East Asia). However, this picture of stability may not reflect conditions in many of the nonirrigated rice growing environments, including those in much of Africa and Latin America.

Four of the conference papers and Hazell's (1982) study of India measured the cv of rice production by country and by regions within countries (Table 11.1). One to three specific regions account for nearly all the increase in each country's cv. For example, both Hazell (1982) and Flinn and Garrity (Workshop Paper 8) identify South India (Andhra Pradesh, Maharashtra, and Tamil Nadu) as the region accounting for the bulk of the increase in the cv of India's rice production.

Table 11.1--Change in the variability of rice production after adoption of high-yield varieties, selected areas

Area	Rise in CV	Drop in CV	Areas with Highest Increase in CV
	(number of areas)		
India, 14 states	9	5	Andhra Pradesh, Maharashtra, Tamil Nadu
China, 18 provinces	7	11	Henan, Quondong, Vunnan
Asia, 14 countries	6	8	Malaysia, Nepal, Taiwan
Philippines, 7 regions	1	6	Central Luzon
Punjab, 11 districts	5	6	Ludhiana, Bhatinda

Sources: India, Hazell (1982); China, Stone and Zhong (Workshop Paper 28); Asia, Carlson (Workshop Paper 4); Philippines, Flinn and Garrity (Workshop Paper 8); Punjab, Gill (Workshop Paper 10).

Note: First and second periods vary among analyses, but are generally taken to represent pre-HYV and post-HYV introduction. CV is coefficient of variation.

Furthermore, only one or two production years were the major contributors to the cv. It is usually easy to identify the cause of this extreme variation. For example, the high cv in Malaysia is due primarily to the drought conditions in 1978, which made it impossible to grow a dry season crop in the 100-thousand-hectare Muda River irrigation system. In Central Luzon, extraordinary flooding in 1972 reduced production about 30 percent below trend. Dry season production was also severely cut back due to drought in the 100-thousand-hectare Upper Pampanga River Irrigation System in 1983. There have been similar serious shortfalls in rice production due to brown planthopper damage in Indonesia in the mid-1970s and due to blast and cold weather damage in South Korea in 1980. Therefore, we can conclude that yield and production variability still present a problem in some circumstances despite the consistent evidence that cvs have not increased.

As Hazell suggests, a decline in the cvs may be accompanied by an increase in covariance across regions as production practices, varieties, and inputs become more uniform. Table 11.2 shows the results of three studies that, following the 1982 Hazell methodology, estimate the percent contribution of covariance to the change in variance of rice production. Stone and Zhong (Workshop Paper 28) hypothesize that the high contribution of covariance in China may be due to families all over China being more responsive to central policy and to market influence in general than they were in the 1950s. The lower covariance contribution (50 percent) estimated by Flinn and Garrity in the Philippines may be due to the regions being much smaller and the islands being subject to a diverse set of microclimatic conditions.

Table 11.2--Decomposition analyses: total contribution of inter-regional covariances to changes in variance of rice production

Source	Country	Covariance Source	Percent Contribution of Covariance	Largest Variance by Location
Hazell (1982)	India	Interstate	71.3	Rajasthan, Uttar Pradesh, Tamil Nadu
Stone & Zhong (Workshop Paper 28)	China	Interprovince	87.8	Jiangsu, Guangdong, Hubei
Flinn & Garrity (Workshop Paper 8)	Philippines	Interregion	50.3	Mindanao, Central Luzon

INPUTS AND YIELD VARIABILITY

Carlson (Workshop Paper 4) developed a model that quantifies the effect of inputs on the variability of production and yields. His model takes the coefficient of variation as the dependent variable and includes nitrogen per hectare, percent area irrigated, percent area in HYV., and a time period dummy, as independent variables. His equations are estimated for 13 Asian countries with two time periods and for 7 Asian countries with 3 time periods. His results contrast with those of Barker et al. (1981), in that the latter study shows increasing variance but decreasing cvs with higher levels of fertilizer input.

Carlson lacked information on the effect of pest-resistant varieties. Young and Mount (1982) and Barker et al. (1985, p. 91) show the relationship between level of insecticide, degree of varietal resistance, and yield stability. Although there is a tendency for the variability in yield to be reduced with higher levels of insecticide application, the pattern is not consistent.

IRRIGATION AND YIELD VARIABILITY

I noted previously the situation where an increase in dry season irrigation can result in an increase in cv (Malaysia, Central Luzon, and probably southern India). Rosegrant (Workshop Paper 26) in his analysis of river diversion irrigation schemes in the Philippines reports that, while irrigation tends to stabilize wet season yields, it increases the variability in dry season yields. Flinn and Garrity (Workshop Paper 8) report that the cvs for irrigated rice areas in the Philippines are lower than those for rainfed areas, lending support to Carlson's findings. But Rosegrant concludes that irrigation development cannot be looked upon as a factor leading to more stable production and thus reducing the need for food reserves. Given the importance of irrigation in rice, there is a need for further study of this issue.

MEASURING VARIABILITY

The analysis by Bindlish et al. (Workshop Paper 3) raises important methodological issues. They question whether detrending production and yield data provides the appropriate measure of variance. They argue that expectations play a crucial role in the analysis of variability and that this follows from considerations relating to risk and uncertainty. Stated differently, risk and uncertainty arise because of unexplained variability in agricultural output over time. Expectations held by both government and farmers about impending output are likely to differ because these two sets of decision makers have access to different information.

Three expectations models were formulated. The first was based upon the assumption that farmers adjust input levels to weather conditions just before planting. The second adaptive expectations model is based upon the assumption that decision makers respond to the production levels of the previous three years. The third trend

based model, following the procedures used in many of the workshop papers, defines variance in terms of deviation from trend.

The study is based on data from 44 rice producing districts in India for the period 1956/57 to 1978/79. Two statistical analyses were conducted, using different methods. One of these methods focused directly on the pooled residuals for all districts and computed a single estimate of the aggregate variance. The second method, following Hazell's procedure, computed the variance for individual districts as well as the covariance among districts and took the sum of these two components. The results differed markedly. It follows that conclusions regarding the incidence of variability are largely determined by (a) how one defines expectations and (b) the statistical measures used to measure variability. More attention needs to be given by researchers to the rationale for these choices.

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12 Report of the Working Group on Rice

Gerald A. Carlson

STABILITY OF RICE PRODUCTION

All of the evidence suggests that yield and production variability in rice is less than for other cereal grains, and the coefficient of variation has not increased as a consequence of the introduction of high-yielding varieties.

Irrigated rice, which accounts for about one-half of the total world rice area and two-thirds of world rice production, tends to be more stable in yield and production than nonirrigated rice. However, drought continues to be the major source of production shortfall and yield risk. This is true even for the irrigated areas, where dry season crop production is often extremely variable. Furthermore, advances in production due to the success of new technology in the irrigated areas, coupled with a decline in world rice prices, have increased the income vulnerability of surplus production in the nonirrigated areas.

Despite the general consensus among the group that increased variance was not a serious problem, there was also a consensus that measuring variance strictly on the basis of the coefficient of variation was not adequate. The increase in the cvs can frequently be attributed to a few outliers in the time series. We need to document the reasons for shortfalls in production and yield in specific locations and time periods. Furthermore, we need more studies of the skewness of old and new varieties under varying input levels and varying environmental situations -- particularly moisture levels.

GENETIC VULNERABILITY

In a strict sense it can probably be argued that the rice crop is now more vulnerable to potentially large losses. The genetic

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*The group consisted of Randolph Barker (chairman), Vishva Bindlish, Gerald A. Carlson, W. Ronnie Coffman, John C. Flinn, Victor Nyanteng, Mark W. Rosegrant, David E. Sahn, Tong Zhong, and Eduardo Venezian.

vulnerability is a consequence of a narrower range of genotypes being grown, more uniform cultural practices, greater dependence on purchased inputs, and highly mobile disease vectors and insect populations. At the same time, however, agricultural and economic development, particularly in those areas where HYVs have been most successful, has led to an increased capacity to respond to adversity. In short, the reduction in genetic variability across space seems to have been largely compensated by the potential to increase genetic variability over time. When varietal resistance breaks down, there are normally backup varieties in the research network that can be quickly multiplied and disseminated.

ADAPTABILITY AND STABILITY

Varieties are typically tested across sites for adaptability rather than over time for stability, since the latter would take too long. The group questioned whether the present system for selecting sites and testing across sites adequately reflected the nature and magnitude of variability experienced at specific sites over time. There was agreement that it was necessary to continue to screen and select varieties by planting across sites, but it was felt that the judicious selection of sites would help to assure that across-site variability was a good proxy for over-time variability.

IRRIGATION AND STABILITY

It has already been suggested that yield variability in rice may be lower than in other crops at least in part because of the large portion of the rice area that is irrigated. As indicated above, irrigation tends to stabilize yield and reduce risk in the wet season. However, much of the expansion in irrigation involves a considerable expansion in irrigated area during the dry season, and droughts can result in a serious shortfall in dry season production. Thus the expansion of irrigation should not normally be viewed as a means of stabilizing production and reducing the need for surplus stocks. Genetic approaches to increase drought tolerance, such as development of short-season varieties, may be important even for the irrigated areas.

BREEDING FOR STABILITY

The group felt that a balance needs to be struck between breeding for environments with high-yield and high-input potential and breeding for less favorable environments. The International Rice Research Institute in its early years emphasized high yields under favorable environment. Subsequently, it gave increased attention to breeding for insect and disease resistance in those same environments. Over the past decade there has been a greater focus on the unfavorable environments - rainfed, upland, and deepwater rice as well as areas with soil problems or low temperatures. In the effort to breed for tolerance to adverse environmental conditions --

drought, flood, soil salinity, cold weather, and so on -- the success to date has been limited.

THE COVARIANCE PROBLEM

Covariances in yield across regions in rice have been increased by more uniform cultural practices, the spread of irrigation, and the narrowing of genotypes. While weather patterns have not changed radically over Asia, the interaction of weather with all three of the above factors is the major source of increased covariance. The group felt that covariances probably have not been increased by input market breakdowns or increased rice price variability. These observations are based on very little data and analysis, and analysis of regional and country-level data suffer greatly from aggregation bias.

13 CIMMYT Presentation: Yield Stability of CIMMYT Maize Germplasm*

H. N. Pham, S. R. Waddington, and J. Crossa

One important aim of the Maize Program of the Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) is to promote yield stability in every phase of the population improvement and testing scheme, through which it develops and distributes improved germplasm to national agricultural researchers around the world. This study attempts to gauge the effect of the Center's approach (which it follows in cooperation with national research programs) on the yield stability of that germplasm at two stages: (a) multilocational variety testing and (b) on-farm testing. Stability was evaluated using the regression approach developed by Eberhart and Russell (1966, 1969). Stable varieties are defined as those having a unit regression slope and small deviation from regression, the second characteristic being the more important of the two. It is also considered desirable that such varieties give a high mean yield.

STABILITY OF EXPERIMENTAL VARIETIES IN MULTILOCATIONAL TESTING

The first part of the study examined yield stability of experimental varieties (EVs) developed on the basis of international trial results from two tropical maize populations of intermediate maturity (populations 32 and 49) and two of late maturity (populations 21 and 43). The EVs were formed over two or three consecutive cycles of population improvement and tested during the period 1979-84 at sites (ranging in number from 17 in 1984 to 41 in 1982) in South, Central, and North America; East, West, and southern Africa; South and Southeast Asia; and the Middle East.

Four salient points seem evident from the data. First, although in a given trial the average percent difference between yields of the EVs and those of reference entries (which served as a basis for comparing trial entries over different years) did not change much from cycle to cycle, a few superior EVs were present in most cycles. Second, all the EVs had regression slopes equal to or greater than 1.0, indicating that the genotypes are quite responsive to better growing environments. Third, over the cycles, newer EVs were just as stable or more so than EVs formed from earlier cycles. Among

*This chapter is a summary of Workshop Paper 24.

intermediate maturing EVs, those from populations 32 were found to be more stable at cycle n + 1 than at cycle n. Two out of six EVs from population 49 were stable at cycle n + 1, whereas the single EV formed from cycle n was unstable. As for late maturing maize, EVs from populations 21 and 43 at cycle n + 2 were at least as stable as EVs developed from cycles n + 1 or n. The fourth point is that, at any given cycle of improvement, some EVs were not only high yielding but also had a unit regression slope and a small deviation from regression. These characteristics of the EVs can perhaps be attributed to CIMMYT's breeding scheme, in which broad-based materials are developed and improved, and to EVs generated through testing at numerous locations in international trials.

STABILITY OF IMPROVED VARIETIES IN ON-FARM TESTING

The second part of the study considered results of on-farm trials conducted in representative developing countries from which sufficient reliable data were available at the time of writing. Results from variety trials conducted in a number of countries, including Guatemala, Paraguay, and Ghana, were presented. In these trials local varieties were compared with improved experimental varieties (many of CIMMYT origin) for yield and yield stability. These comparisons were made at the farmers' level of inputs and management in broad areas termed megaenvironments, to which the improved genotypes were considered to be adapted. The results indicate that under those conditions, improved varieties generally give higher average yields. However, they vary considerably over a range of environments. Improved and local varieties tend to yield similarly in poor environments, but the improved varieties are much more responsive than local materials in the better environments.

Farmers can alter many aspects of their maize production systems, in addition to just changing variety. These alterations in levels of inputs and management can greatly affect genotype performance. Trials conducted in Veracruz, Mexico, compared an improved variety with a local variety over a range of environments at both the farmers' level of inputs and management and at a higher level. The improved variety (Tuxpenito) showed no advantage over the local one at the farmers' level of inputs and management but was superior, with little change in stability, at the higher input level. In contrast, under the latter conditions, the local variety was less stable and yielded poorly in the better environments.

Similar trials conducted in Ghana compared farmers' varieties and practices with an improved variety (La Posta) and two levels of agronomic inputs (one slightly higher and another considerably higher than the farmers'). The results indicate that the improved variety plus agronomic inputs give higher yields (with regression slopes closer to one) than local varieties plus farmers' practices. In addition, the higher levels of technology give high marginal rates of return and, if anything, a lower risk of failure with the investment.

Many other such trials have been carried out in Mexico, Honduras, Panama, Costa Rica, Haiti, Colombia, Tanzania, and Pakistan, among others. Where improved varieties are known to have been well

adapted to the local megaenvironment, the trials have shown results similar to those reported here.

Cases could be cited in which improved varieties have performed no better than the farmers' varieties under their management. As was shown earlier, in some parts of Mexico, where local varieties have been developed through thousands of years of maintenance and selection by farmers, the superiority of improved varieties over these local ones becomes apparent only when the farmers' agronomic practices are changed also. The degree of improvement obviously depends on the caliber of the local varieties. Given the lack of convincing data to the contrary, we conclude that good improved varieties have much to offer farmers growing maize in developing countries with very limited resources.

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14 Summary and Assessment of the Maize Papers

Jock R. Anderson

I have difficulty with CIMMYT's contribution (Chapter 13 and Workshop Paper 24) because their work on yield stability in maize is virtually all done within the framework ascribed to Eberhart and Russell -- although I believe it should be earlier authors such as Finlay and Wilkinson (1963). I have a concern that the results of Eberhart and Russell's method of seeking insights are not robust to changing analytical nuances of the technique, especially the linearity of the model. I established this myself in 1973 by contrasting linear, log, and semilog regression relationships in analyzing some CIMMYT International Spring Wheat Yield Nursery data. The method may create new artifacts in results analogous to those related to the method of detrending discussed orally by Hazell.

There is also a question of the speculativeness of the CIMMYT work, which has to be read in connection with the limited effect of CIMMYT related maize populations and composites (notwithstanding that this may now amount to some 5 percent of the maize area planted in the developing world) and the seeming increases in cvs at the global and regional levels reported by Hazell (Chapter 2). One thing certain is that, if there is any guilt related to increasing maize yield variability, it is not to be assigned to CIMMYT!

The CIMMYT paper speaks of the number of environments being "more than sufficient" for the purpose at hand. I really wonder about this. This issue is even more prominently to the fore in the results reported for on-farm tests in Guatemala (especially), Paraguay, Ghana, and possibly Mexico. I suspect that the miserably unfertile, tiered cropping situations encountered on many small farms in the Third World are not very adequately represented in the data and analyses that have led to the comfortable conclusion that (so-called) improved varieties are more productive in both good and poor environments. This is notwithstanding the happy results for Veracruz (at least for advocates of local varieties) that local varieties performed well at moderate input levels.

Variability, measured Hazellianly, subjectively, and perhaps impressionistically, has been trending upward in U.S. maize yields. Duvick (Workshop Paper 6) argues persuasively that farming practices, especially those related to mechanization, timing of planting, use of nitrogen fertilizer, and varietal popularity contribute most significantly to this trend. The "one big farm" or "togetherness" aspect of much of U.S. maize production is surely an important, growing although perhaps nigh-saturated, modern phenomenon.

Apart from the major special case of cytoplasmic-based susceptibility to southern leaf blight in the early 1970s, there seems to be little that is overly ascribable to genetic uniformity per se. To be fair to the potential complexity and controversy of the issue, it must be noted that the evidence is not all in. While the indices of concentration of inbred lines may be salutary and even encouragingly diverse for public lines, this is only of the order of one-quarter of the crop, and data must somehow be assembled on the homogeneity of private material to be at all definitive.

The residual obscurities are not made any more comforting by the shift to single-cross hybrids, nicely documented by the author.

Duvick's conclusions, along with those of Hazell on yield variability, are supported by Headley and French (Workshop Paper 15). They conclude that U.S. maize growers are facing increases in absolute risk of yield loss and, in many reporting districts, are also coping (or increasingly not coping, financially speaking!) with increasing relative risk. They note the forces for even more input saturation as producers strive for survival. I note with interest Headley's verbal intervention as to the need for concentration on matters that are amenable to intervention but did not find these, for instance, in the paper by Headley and French.

With these generally positive remarks about Workshop Paper 15, let me be somewhat more negative about the paper by French and Headley (Workshop Paper 5). The methods used by them may have their own validity but, by purging out the major measurable and often common explanations to investigate through only the residuals the robustness of Hazell's results for more disaggregated data, I think they have thrown out the baby with the bath water, and accordingly, and in spite of what is said in this paper, I presently see little strong evidence of conflict with Hazell's results for the ultimate policy oriented macromanagement issues of changing stability.

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15 Report of the Working Group on Maize*

Donald Winkelmann

VARIABILITY OF MAIZE PRODUCTION

The global coefficient of variation (cv) for maize production increased from 3.6 percent during 1960-71 to 4.0 percent during 1972-83 according to Hazell (Chapter 2). Most of this was related to the United States, where the cv increased from 6.6 percent to 9.6 percent. And most of this increase is attributable to an increase in the covariance of production among regions within the United States, which is evidence of greater synchronization in maize production. In contrast, the analysis by Headley and French (Workshop Paper 15) comparing the 1935-45 period with the 1964-80 period -- and including a variable for rainfall -- shows a decline in the cv for maize production in the United States. It would be useful if Headley were to put his analysis on a comparable basis with that of Hazell so as to ascertain the effect of weather on the cv.

The role of weather was given much attention by the group, and it was agreed that its effect on intensively produced commodities will be high. This brought up a comparison between the United States, where the cv increased, and France, Italy, and Hungary, where production intensity is comparable with that in the United States but where the cvs declined. It was also pointed out that maize is extremely sensitive to drought at flowering time, and that, with synchronized production practices, widespread weather patterns could have dramatic effects over a wide area. Some members of the group wondered about the possibility that high cvs are associated with new producers of maize, but this does not appear to be a fruitful hypothesis.

It was observed that maize production in the United States changed its character in 1955 with the advent of cheaper nitrogenous fertilizer, and that production trend lines show a sharp break at that time. That period also marked the advent of single crosses and greater planting densities.

It was observed that variability in production would have differing consequences for poor and rich countries, for importers and

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*The group consisted of Donald N. Duvick (chairman), Gregory Edmeades, J. Friedrichsen, Hartwig de Haen, Peter B. R. Hazell, J. C. Headley, H. N. Pham, Wolfgang Vogel, Adolph Weber, and Donald Winkelmann.

exporters, and for mostly rural and mostly urban countries. Most of the concern about variability is with uncontrolled variability--that caused by weather or disease for example -- but it was noted that what is controlled in one country may be uncontrolled in another.

Breeders, it was judged, must continue to concern themselves most with yield and with what one authority called extensibility, and in doing this they will emphasize the elimination of constraints on yield, especially those emerging from biotic stress.

WHO IS CONCERNED?

Farmers, consumers, governments, and plant breeders all worry about downside risk (that which decreases yields below trend). Plant breeders work to raise yields by eliminating the effects of biotic stress, and this also reduces variability from uncontrolled factors. As for upside risk, only governments tend to worry about this. Their concern relates to the cost of support programs, storage of excess, and demoralization of the market (the Ghana case was offered as an example).

The variance of maize production has increased, and the cv is up in many cases (most notably the United States). This is of concern in the sense that one would rather not have it, but it is not evident that we should be willing to accept appreciably lower rates of increase in yields for "likely" reductions in variability. The present increases relate to more intensive cultivation, which is simply more sensitive to the perturbations from weather and policy. There is still the question of what will happen to variability in the future.

GENETIC VULNERABILITY

There is no evidence that the number of varieties in use in the United States has declined nor that the number of inbred lines has declined. Of course, some of the different varieties have similar pedigrees, and many different varieties have similar phenotypic responses. It was noted that there is now a faster replacement of varieties than in the past, offering diversity over time. One participant spoke favorably about the role of the private sector in reducing vulnerability, arguing that a number of private companies would tend to produce more varieties than would one public company. Even so, there is a legitimate cause to be concerned with genetic vulnerability.

16 ICRISAT Presentation: Yield Variability in Sorghum and Millet

Thomas S. Walker and John R. Witcombe

The objective of this summary is limited. Only the main findings in the four ICRISAT papers are highlighted (Workshop Papers 17, 30, 31, and 35). Additionally, we report the results of collaborative research between the All India Coordinated Sorghum Improvement Project and ICRISAT on yield variability in improved and local sorghum genotypes. We do not attempt to make a comprehensive assessment of past ICRISAT or national program research on yield variability in sorghum and millet in the semiarid tropics.

PEARL MILLET YIELD VARIABILITY IN SOUTH ASIA

The International Pearl Millet Adaptation Trial (IPMAT), which has both hybrids and varieties as entries, has been grown multilocationally in India and Pakistan. The data for grain yield over five years were analyzed in a number of ways to examine the stability of the entries.

A regression analysis shows that the hybrids were generally higher yielding than the varieties but were less stable (Table 16.1).

Table 16.1--Millet yield in the International Millet Pearl Trials, 1979-84

Year[a]	Mean Grain Yield		Adjusted Mean Square Error[b]		Mean Slope	
	Hybrids	Varieties	Hybrids	Varieties	Hybrids	Varieties
	(kilograms per hectare)					
1979	2,300	2,237	163,533	61,222	1.02	0.98
1980	2,096	1,974	62,791	33,085	1.01	0.99
1981	2,236	2,262	117,970	33,189	1.04	0.97
1983	2,068	2,109	157,951	50,968	0.97	1.02
1984	2,028	1,773	62,228	40,166	1.07	0.96

[a] Trial not held in 1982.

[b] Adjusted following the method of Eberhart and Russell (1966).

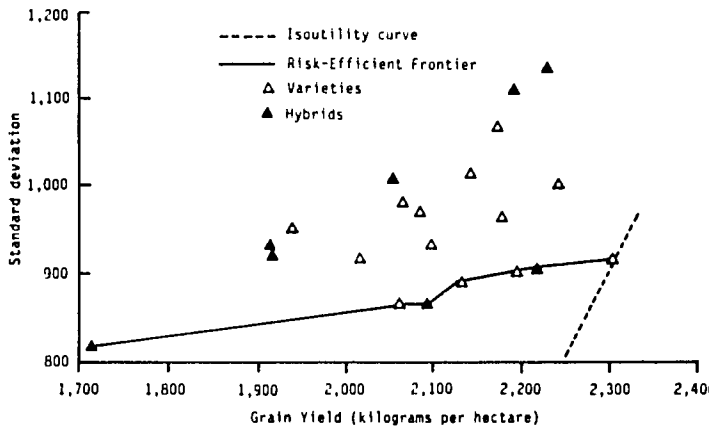
The most important source of genotype x environment interaction in the regression analysis was due to the deviation from the regressions (S^2d values) rather than to variation between the regressions. The varieties were superior to the hybrids in this respect, having lower than average S^2d values.

Although regression analyses are helpful in testing selection procedure, it is an inescapable conclusion that to obtain an overall picture of how stability and mean yield are to be traded off, other analyses are required. A mean-variance analysis (Binswanger and Barah 1980) shows that the highest yielding genotype was always preferred among the risk efficient entries (Figure 16.1). Similarly, a first-degree stochastic efficiency analysis (Anderson et al. 1977) indicates that the hybrids, despite their inferior stability in a regression analysis, were more risk efficient than the varieties.

The analyses demonstrated that the breeders' procedure of selecting among the highest yielding entries across environments is satisfactory. Such an emphasis will usually select entries that perform well in poor environments and that would be chosen by risk-averse farmers.

One variety from an advanced cycle composite, ICMV 81111, combined both high yield and stability. A variety both high yielding and stable is a desirable alternative to a hybrid, particularly in view of the simpler seed multiplication procedures and the reduced susceptibility of varieties to ergot and smut. Moreover, as discussed in Walker (Workshop Paper 30), individual hybrids in India have proven to be most unstable in yield from year to year due to their rapid increase in susceptibility to downy mildew. There is every reason to expect that the more genetically diverse variety would become susceptible in a less rapid and spectacular manner.

Figure 16.1. Millet yield in the international pearl millet trial, 1979 to 1984[a]



[a]Trial not held in 1982.

SORGHUM YIELD VARIABILITY IN INDIA

A mean-variance analysis was used to measure stability (intertemporal) and adaptability (over space) components of variance with multilocational, multiyear, yield data for sorghum in India (Barah et al. 1981). Adaptability and stability were highly correlated. Only the stability component is relevant for farmers in their adoption decision. Measures of farmers' risk aversion were used to rank genotypes according to preferences that take account of both yield and stability. Since yield differences were large and risk aversion moderate, preference-based ranking did not differ markedly from yield-based rankings.

These results are comforting to sorghum breeders in India and perhaps elsewhere as well. Rankings based on yield and risk preference were very closely related, entirely agreeing with the results obtained for pearl millet. However, further analyses of sorghum are required to see whether this is also the case with less fertilizer or plant protection. Furthermore, adaptability and stability are highly related, supporting a multilocational breeding and testing approach in the pursuit of both low risk and high yields.

PEARL MILLET YIELD VARIABILITY IN NIGER

To examine yield variation and variability with traditional and improved technologies in West Africa's Sahel, a series of tests were managed by farmers in western Niger in 1982 and 1983 in four villages, with a total sample size of about 100 farmers. Each farmer had one plot of three treatments: T1 -- local millet without chemical fertilizer; T2 -- local millet with 30 units of nitrogen (urea) and 18 units of phosphate; and T3 -- improved millet with the same fertilizer dose as T2.

Fertilizer with both local and improved cultivars (T2 and T3) significantly increased mean yield; however, planting an improved genotype (T3) had no significant effect on yield (Table 16.2). Based on mean data for the village by year combinations, the mean standard deviation increased from T1 to T2 to T3. Treatment 3, with a lower mean yield and a higher standard deviation, was stochastically inefficient compared to T2. Compared to T1, the increased yield of T2 amply compensated for additional risk. Fertilizer increased yield of the local variety fourfold, for a unit change in standard deviation. All but the most extremely risk-averse farmers would prefer T2 to T1.

These results support the emerging story on millet production in West Africa that, up to the present, improved genotypes have not consistently yielded appreciably more than local cultivars and that moderate doses of fertilizer, particularly phosphate, can be profitably applied with little or no increase in risk.

SORGHUM AND PEARL MILLET YIELD VARIABILITY IN INDIA

Hybrids released in the late 1960s account for about 40 percent of sorghum and 60 percent of pearl millet planted area in India.

Table 16.2--Millet grain yields in Western Niger by treatment, four villages

Treatment	Village 1 1982	Village 1 1983	Village 2 1983	Village 3 1982	Village 3 1983	Village 4 1983	Mean
Treatment 1[a]							
Mean yield (kg/he)	168	277	355	195	173	298	244
Standard deviation	115	143	134	96	133	176	133
Treatment 2[b]							
Mean yield (kg/he)	277	428	572	413	404	412	418
Standard deviation	125	170	171	195	163	238	177
Treatment 3[c]							
Mean yield (kg/he)	330	543	501	356	417	341	415
Standard deviation	165	197	242	140	204	199	191

[a] Local millet without chemical fertilizer.
[b] Local millet with 30 units of nitrogen (urea) and 18 units of phosphate.
[c] Improved millet with same fertilizer as treatment 2.

Usually they are sown in rainfed fields, where small doses of fertilizers are applied. To what extent have improved hybrid technologies been responsible for increased variability in sorghum and pearl millet production?

We analyzed data on grain production in 48 and 40 major producing districts in India for sorghum and pearl millet, respectively. We used a statistical decomposition method developed by Hazell (1982). Two 12-year periods (1956/57 to 1967/68 and 1968/69 to 1970/80), corresponding to before and after the release of the sorghum and pearl millet hybrids, were selected to represent the eras before and after the green revolution.

Instability in sorghum and pearl millet production increased in terms of both total variance and coefficient of variation (cv) from the first 12-year period to the second. For sorghum, the cv of linearly detrended production increased from 8 percent to 16 percent and the F ratio of the variances was 40.2. For pearl millet the cv increased from 11 percent to 34 percent, and the F ratio was 16.6.

Increased production variance stemmed overwhelmingly from increased production covariances among major producing regions for both sorghum and pearl millet. More than 90 percent of the increase in production variance for both crops was attributed to changes in interdistrict production covariances. What was surprising was the strength of yield covariances in conditioning those changes (Table 16.3).

Why have sorghum and pearl millet yields become increasingly covariate over time and across districts? For sorghum, changes in yield covariance between the first and second period for each district pair were positively and significantly linked to the level of hybrid adoption, changes in rainfall covariance, and extent of

Table 16.3--Sources of increase in the variance of sorghum and pearl millet production in India, 1956/57 to 1967/68 and 1968/69 to 1979/80.

Source of change	Sorghum	Pearl Millet
	(percent)	
Within-district production variances	5	8
Interdistrict production covariances		
Yield	84	52
Other	11	38
Total	95	92

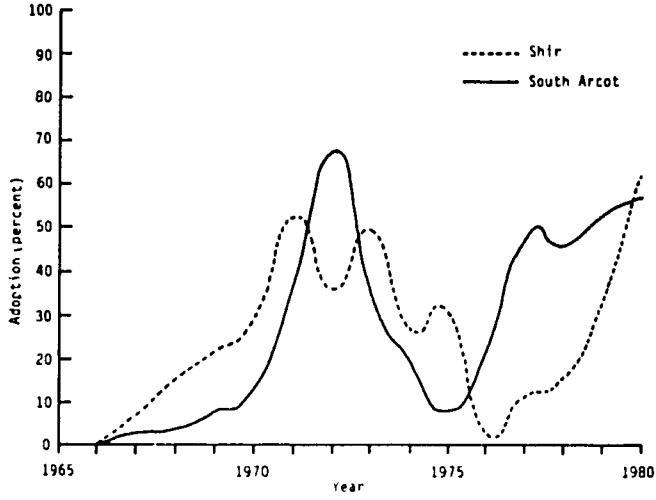
irrigated area. For pearl millet, the level of hybrid diffusion and irrigated area was positively and significantly associated with changes in yield covariance.

In other words, the production and genetic environments are becoming more similar over time, and it is this growing similarity that is mainly responsible for increasing production variability at the national level for these crops. Increased yield covariances are to be expected, because hybrids have a narrow genetic background. For example, the bulk of hybrid sorghum area in India is planted to four hybrids, CSH1, CSH5, CSH6, and CSH9. The latter three have the same male parent, CS3541. Most of the commercially available pearl millet hybrids in the period under study were produced from the same seed parent.

The first-generation pearl millet hybrids, HB1, HB3, and HB4, became extremely susceptible to downy mildew, resulting in significant economic losses in the early 1970s after inoculum had built up in farmers' fields. In response to those losses, farmers in several major producing regions reverted to local types. Hybrid adoption rates plummeted. In the middle and late 1970s, hybrid adoption again picked up as farmers accepted the second-generation hybrids, which at that time were much less susceptible to downy mildew. Similar, atypical adoption patterns in producing regions as far distant as Tamil Nadu and Maharashtra bear ample testimony to the problem of increasing production covariances caused by the release of supersusceptible cultivars (Figure 16.2).

Judicious varietal release strategy and sound trade and storage policies can cost-effectively offset most, if not all, the instability costs arising from increasing yield covariance. However, in the absence of such efficient policies, investing in crop research to maintain and enhance resistance to yield reducers and to broaden genetic variation will have stability benefits at the national level over and above returns to increased production. In any case, more covariate regional yields and the resulting increased production variability were a small price to pay for productivity growth attributed to the sorghum and pearl millet hybrids.

Figure 16.2. Adoption of pearl millet hybrids in Shir (Maharashtra) and South Arcot (Tamil Nadu), 1966-80



HOUSEHOLD INCOME VARIABILITY IN INDIA'S SEMIARID TROPICS

Much of the investment in breeding, pathology, entomology, and physiology at the centers of the Consultative Group on International Agricultural Research is aimed at developing higher yielding and more stable yielding varietal technologies, which increase output and improve equity and nutrition. Could these technologies also enhance the welfare of farm households by reducing variability in household income and consumption? The answer to that question hinges on the nexus between variability in crop yield and fluctuations in household income. We examined that relationship for resource-poor farm households in India's semiarid tropics (SAT).

We relied on household panel data from three ICRISAT study villages representative of three soil, climate, and cropping regions of India's SAT. Income data from the "continuous" cultivator households (those that remained in the panel from 1975/76 to 1983/84) were analyzed. For these 81 households, information on fluctuations in income was summarized by the cv of net household income. A cv was estimated for each household based on nine years of income data deflated by a village-specific consumer price index.

Risk benefits were estimated under a scenario of perfect yield stabilization for the common crops in each village. Although the mean household income cvs for the producers of these crops varied from 33 percent to 47 percent, the risk benefits from perfect stabilization of commodity yield ranged from modest to negligible (Table 16.4).

Ironically, risk benefits were largest in irrigated paddy, the crop with the lowest yield cv. Removing variability from the yield

Table 16.4--Risk benefits from simulated perfect crop yield stabilization

Crop and Village	Number of Farms	Coefficient of Variation of Household Income	Mean Reduction in Household Income Variability	Mean Proportional Risk Premium
			(percent)	
Irrigated paddy in Aurepalle	9	46.6	15.4	2.9
Castor in Aurepalle	23	44.8	4.4	1.3
Local sorghum in Aurepalle	21	34.4	1.0	0.2
Local sorghum in Shirapur	21	34.0	-3.9	-0.2
Desi cotton in Kanzara	26	33.0	0.8	0.2
Hybrid sorghum in Kanzara	18	34.4	0.6	0.3

of only one crop was simply not an effective way to reduce income variability for the vast majority of farm households in the study villages. For the rainfed crop with the largest risk benefits, perfect yield stabilization would only reduce household income variability by about 5 percent. Such a modest change would be worth less than 2 percent of mean household income. Stabilizing the yield of one crop taps at most 25 percent of the potential risk benefits from perfect crop income stabilization.

Perfect crop yield stabilization does not buy much in the way of risk benefits, because most farm households rely on multiple income sources, particularly earnings in the local labor market. Diversified cropping patterns are also the norm in dryland agriculture in India's SAT; hence farm households are not overly dependent on revenue from a single dominant crop. Furthermore, area vulnerability in dryland agriculture severely erodes the effectiveness of policies or technologies that work through yield to reduce variability in household income and consumption. Mean area variability exceeded mean yield variability for each of the common crops.

These results support the notion that little if any economic value should be attached to the supposed risk reducing attributes of improved varietal technologies for resource-poor households in India's SAT. Such technologies should be evaluated with regard to their effect on mean yield or output levels, equity, and nutrition. Risk benefits derived from supposed reductions in variability in household income and consumption are likely to be too small in practice to be measurable. More generally, focusing on crop yield stability to diminish variability in household income and consumption for small farm households in India's SAT is a misguided means to an

end. Likewise, we should not be overly concerned that the improved varietal technologies adopted by farmers may have accentuated yield variability. Increased yield variability is unlikely to manifest itself in markedly heightened household income variability.

Risk benefits from technologies that dampen yield variability may be more substantial in Africa's SAT because resource-poor households may rely more heavily on crop income than similar households in India's SAT. Also, those households are most likely to have fewer effective private and institutional means to compensate for shortfalls in current income. More research on household risk benefits is needed in Africa's SAT.

CONCLUSION

What emerges from all these papers is a common theme: yield stability is not an overriding or even an important objective for research on sorghum and millet improvement. Mean yield and profitability should remain front and center on the agenda of objectives. Economic gains from research by breeders, pathologists, entomologists, and physiologists will be manifested in the form of higher mean yields.

In those regions where sorghum and millet hybrids have been adopted, maintenance research and a sound varietal release and testing policy are fundamental to protect farmers against the dynamic risk of increasing disease and pest susceptibility. That is one source of yield variability that sorghum and millet scientists clearly can do something about.

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17 Summary and Assessment of the Sorghum and Millet Papers

Jock R. Anderson

McIntire and Fussell (Workshop Paper 17) have contributed a significant and valuable body of microlevel data on millets in West Africa. However, their paper is tantalizing for what questions are not really clarified by either the data or the analysis.

For instance, the issue of risk modifying effects of either fertilizer or cultivar or both seems very obscure. The analysis of variance framework does not seem especially useful here, at least in its present incarnation. As the authors confess, there is the additional problem that the analysis focuses on yield effects rather than on gross margin. It is to be presumed that such work is in hand, and regrets should be expressed for their absence here as a source of insights to input policy in a challenging part of the developing world.

The partitioning of yield increase is similarly frustrating in the plasticity (or fluidity) of the policy implications. Head variation is identified as the major pure source of effects in contributing to yield variance, but immediately, and appropriately in my view, cautioned as being suspect. The prospect of selecting against tillering adaptability is frightening indeed in moving against one of nature's great stabilizing devices.

Walker (Workshop Paper 30) shows that the variability of sorghum and pearl millet production in India, as measured by variance and coefficient of variation, has rather incontrovertibly increased, largely because of the "togetherness" effect: more people doing more smart things (growing better cultivars, using more variable factors, especially irrigation) with the same trend. This may have macro-implications, but given the implicit enthusiasm for farmers to continue to pursue such strategies, and given the moderating effects of demand substitution and trade polices already noted in the paper, there seems to be little need for any additional policy intervention in these crops in response to new technologies.

Witcombe (Workshop Paper 35) has provided an interesting analysis and a useful paper. I am delighted to see concepts of stochastic efficiency being used in this context. I never persuaded my CIMMYT colleagues in 1973 that they should take the plunge. However, I found the description of methods used in processing the probability distributions to be inadequate and, without further details, I am reluctant to endorse or criticize the procedures. It does seem, however, that the concentration on poor yields makes the

interpretation of the "probability" curves anything but straightforward.

Given this pioneering exploitation by plant breeders of stochastic dominance, I could not understand the author's enthusiasm for mean standard deviation analysis, since it is so much weaker as a criterion.

My other concerns relate to the substitutability of cross-sectional and time-series data, but these concerns apply to most of the plant breeding papers.

There is some controversy over the primary breeding objective argued by the ICRISAT people, that is, "mean-yield is all that matters." This may be a pragmatic result in India where there has seemingly been no conflict between increasing means and reducing measures of variability, such as standard deviation. However, it is surely too early to say this in general, and for Africa in particular. My prejudice is to encourage breeders to pursue "risk efficient" improvements, which will not only improve means but also reduce downside unfavorable yield experiences.

I expect that there is a mixed story for breeders and policy makers -- mixed according to region and zone. In India, a two-pronged breeding approach seems required:

- For the more favorable areas where hybrids are already widely adopted, emphasis should be given to a continued search for high yield potential, for example, by breeding for all-India trial success.
- For the more marginal areas, the needs of resource-poor farmers must be addressed, especially by appropriately targeted and focused breeding efforts. In India this can best be done through the agricultural universities, which can pursue registration on a state basis. This will be frustratingly slow because potential gains are very modest, but progress can be made on some important yield reducers.

In Africa, the main priority seems to be improving the policy environment, especially with regard to input (particularly phosphorus) supply systems. To the extent that this can be improved, available varieties are already profitably responsive, though this could be further improved by breeding. However, in other areas with poorer infrastructural prospects (especially because of high transport costs), small marginal breeding achievements for resource-poor situations are important and should be sought vigorously.

18 Report of the Working Group on Sorghum and Millet*

John R. Witcombe

It was recognized that in many countries there was insufficient data to measure changes in the variability of sorghum and millet production and that in Africa it would be too difficult or expensive to collect the required data. There was evidence from India and the United States for sorghum and from India for pearl millet that there had been an increase in variability. However, it was only a source of concern in pearl millet, where there was a need to increase the number of seed parents and have a release policy based on zones of crop adaptation.

The group thought that both sorghum and millet have become more susceptible to changes in the biotic environment due to increased genetic vulnerability. To overcome this, there should be a greater diversity of varieties in space and time.

Adaptability and stability can be the same concept; there is excellent evidence in India for sorghum that this is the case. However, the main environment parameter, rainfall, needed to vary equally across locations and time for stability and adaptability to be equivalent. How true this is depends on how covariate the rainfall is between regions in any year. Consequently, it was concluded that in India, with noncovariate rainfall between regions, adaptability and stability tended to be the same, but that in West Africa and Australia the reverse applies. More research is needed on this topic.

Millet and sorghum are not grown extensively under irrigation, so variability in production is unrelated to irrigation. However, it was noted that both sorghum and millet tend to be pushed to more marginal areas upon the introduction of irrigation schemes, and this could have led to greater variability in yield.

It was noted that the breeder is often restricted to breeding for success in trials rather than for broad adaptability or for specific regions. Nevertheless, the widespread adoption of varieties in many cases demonstrates that trials systems, although imperfect, can be adequate, and broad adaptability is therefore not the sole solution. A two-pronged approach is required: mainstream breeding

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*The group consisted of Jock R. Anderson, Michael H. Arnold, J. de Haas, T. Engelhardt, John McIntire, Joachim von Braun, Winfried von Urff, Thomas S. Walker, and John R. Witcombe (chairman).

for broad adaptability and more specific breeding for particular regions or zones of adaptation.

Breeding strategy for Africa was much discussed, but no firm conclusions were arrived at. The same situation prevails in CGIAR, whose policy for Africa is subject to change. One way to refine breeding objectives is to examine breeding successes in other crops. There was hope that, in pearl millet, hybridization between Indian and African material may lead to success. The opinion was expressed that fertilizer, particularly phosphate, would be effective in increasing and stabilizing yields and that the use of fertilizer may be more cost effective than trying to breed for adaptability.

19 Summary and Assessment of the Barley Papers

M. S. Mekni

Few crops in the world possess the extraordinary capacity of adaptation to contrasting environments that barley does. It grows at different latitudes and elevations and under a wide range of soil and temperature regimes. Farmers in marginal areas often depend entirely on barley, which reflects the ability of the species to produce an economic crop where other cereals usually fail to survive. Yet compared to the research efforts invested in improving other major cereals, very little work has been done to better exploit barley's potential. This lack of emphasis has been costly for barley.

A major research effort in the sixties led to increased wheat yields through the adoption of higher yielding varieties and better management practices. These new varieties and techniques have resulted in a broadening of the area of adaptation of wheat, making its cultivation economically profitable in traditional barley growing environments and relegating barley to more marginal areas. The absence of advances in barley improvement in some situations, therefore, is due to advances in wheat improvement. For example, the rapid expansion of wheat in India has marginalized barley growing. And in Tunisia, where wheat yields for a time increased faster than population growth (Weber, Workshop Paper 33), barley yields have remained stagnant. An important source of variability in barley yields is therefore the movement of barley cultivation to lower fertility conditions. Numerous other factors also influence yield and production; some factors are technological in nature, while others are induced by changes in economic policies.

TRENDS IN AREA, YIELD, AND PRODUCTION

The global area covered by barley has increased significantly during the last two decades despite noticeable decreases in parts of Asia and North and South America (Table 19.1). The average barley area harvested during 1979-81 increased 21 percent over 1969-71. The expansion of barley cultivation occurred mainly in the U.S.S.R. (+54 percent), Oceania (+26 percent), and Europe (+24 percent). Due to severe disease epidemics, reductions were sharpest in South America (-30 percent).

Improvements in barley yields in most parts of the world brought about a larger world output than expected on the basis of area expansion alone (Table 19.2). Areas that made the largest yield

Table 19.1--Global barley area harvested, three time periods

Country or Region	1969-71	1979-81	1982-83
		(1,000 hectares)	
U.S.S.R	21,782	33,490	30,768
Asia	12,532	10,937	11,003
Europe	16,438	20,440	19,960
North America	8,676	8,106	8,662
Africa	4,252	5,629	4,802
Oceania	2,091	2,643	2,936
South America	1,004	701	668
Total	66,775	80,846	78,499

Sources: Food and Agriculture Organization, Monthly Bulletin of Statistics, June 1981, March 1982, and December 1983; Food and Agriculture Organization, Production Yearbook, vol. 33, 1979.

Table 19.2--Global barley yield, three time periods

Country or Region	1969-71	1979-81	1982-83
		(kilograms per hectare)	
U.S.S.R	1,613	1,335	1,554
Asia	1,157	1,501	1,491
Europe	2,949	3,383	3,431
North America	2,275	2,508	2,747
Africa	978	844	845
Oceania	1,240	1,331	1,233
South America	1,047	1,215	1,103
Total	1,875	1,965	2,090

Sources: See table 19.1.

gains were Asia (+29 percent), North America (+16 percent), and Europe (+16 percent). Production advances were most significant in Europe (+42 percent), where they resulted from improved yields and an increased area. In Asia a 13 percent production increase was obtained despite a 13 percent decrease in area, because yields increased sharply (+29 percent). In the U.S.S.R., however, a huge expansion of the cultivated area (+54 percent) was followed by a relatively modest increase in production (+27 percent), because yields dropped sharply (-17 percent). In Africa, both yield and production remain stagnant despite a slight expansion in total area.

VARIABILITY OF BARLEY YIELDS

Weltzien and Zahlouta (Workshop Paper 34) show that more efficient use of the scanty rainfall of the semiarid areas is possible if the nutritional status of the soil is improved. Hanus and Schoop (Workshop Paper 12) and Hanus and Rizos (Workshop Paper 11) also indicate that, while yields can be increased by the use of fertilizers, yield variability need not increase. Weber (Workshop Paper 33) indicates that, while differences in yields between favorable and unfavorable years have widened, improvements in management practices have brought about a buffering effect in bad years. This buffering is important because it is not the variability brought about by high yields in good years that concerns farmers in semiarid regions but rather extremely low yields in bad years. Moreover, if average yields over time can be shifted upward, then it seems possible to significantly decrease the negative effects of yield variability.

Fertilizer experiments carried out at the International Center for Agricultural Research in the Dry Areas demonstrate that nutrient deficiencies, particularly phosphorus, exacerbate the effects of drought. Improved soil fertility allows faster initial growth, a better ground cover, and a smaller loss of water through evaporation (Kuther personal communication). In very dry years, a greater accumulated biomass early in the season results in a larger harvest of grain and straw dry matter.

Weber (Workshop Paper 33) shows that, from a global perspective, the instability of barley yields is lowest in high-yield environments, such as those of western Europe and that production variability is dominated by variability in acreage. This is in close agreement with the findings by others, especially Hanus and Rizos (Workshop Paper 11).

Fischbeck (Workshop Paper 7) shows that in Bavaria higher yielding varieties and crops have pushed lower yielding varieties and crops to lower yield environments. Spring barley in particular is being replaced by wheat and winter barley and yield variability (measured by the coefficient of variation) is less stable for recent varieties than for older landraces of barley. However, while modern barley varieties outyielded old local landraces significantly (20 percent yield difference) under favorable conditions, the reported superiority of landraces is very small in poor environments (4 to 5 percent).

BREEDING FOR STABILITY

Attempts to measure the contribution of modern cereal varieties to the apparent increase in yield variability will continue to be elusive as long as we confine ourselves to regression procedures. The difficulty with the regression approach is that it lumps diverse situations into one graph. It is important to take into consideration the target environments when assessing stability, no matter how wide they may be. From the breeder's point of view, they can be grouped into two broad classes -- one where genotypes play a major role and the other where the environment dominates.

In the first case the genotypes' potential is generally below that of the possibilities provided by the environment, and in these situations, breeders should concentrate on increasing maximum yield, knowing that the percentages of poor years will be small. This is the case with barley in western Europe, for example.

In contrast, most other barley environments are sufficiently marginal, and the potential yield of available genotypes may already exceed the possibilities offered by the environment. Environmental manipulation, such as the use of irrigation, fallow, tillage, and fertilizers, is essential if the potential yield of the environment is to be raised. In such variable environments, breeders can contribute to higher average yields by selecting genotypes with wide adaptability to soil types, temperature regimes, and rainfall distribution, thereby helping to increase yields in unfavorable years.

20 Report of the Working Group on Barley*

G. Fischbeck

The group recognized that its deliberation on production variability in barley needed to be qualified by two basic differences between barley and other major cereals such as rice and wheat. First, barley has a comparative physiological advantage in marginal areas, and hence its acreage tends to be pushed into less favorable and more variable environments. Second, barley generally is planted to produce feed and only seldom to produce food.

The group reviewed the possible sources of change in variability. The evidence for differences in the yield variability of landraces and old or new cultivars is inadequate. Even if it could be demonstrated beyond doubt that such a link exists, the amount of yield variability explained would probably remain insignificant.

It is hard to separate out the effects of weather, inputs, and cultural practices, because interactions among them at the farm level are highly significant for changes in yield variability. This is clear from evidence from Europe and the Middle East.

There are possibly strong correlations between barley production and the production of other agricultural commodities. For example, ICARDA studies in Syria indicate a linkage among livestock, barley grain, and barley straw, and the area sown to barley is influenced by the price of meat and livestock products.

There are several factors that might contribute significantly to increasing yield correlations across regions: weather (in western Europe), input supply (for example, problems with fertilizer distribution in Syria), and homogeneous cultural practices. The influence of price variability also needs to be more thoroughly studied, especially the role of livestock prices relative to barley prices.

The widespread use of landraces in many dryland areas, as well as the broad spectrum of barley cultivars available to European farmers, casts doubt on the hypothesis that genetic vulnerability is a significant source of yield correlations between regions.

However, in view of the wide range of agroecological conditions under which barley is grown, target conditions need to be determined and breeding programs need to focus on achieving stability in these areas. The specific requirements of the large areas of marginal, dryland barley in the world should not be overlooked.

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*The group consisted of G. Fischbeck, John H. Holden, M. S. Mekni (chairman), Gil Rodriguez, Kutlu Somel, and Heinrich C. Weltzien.

21 Crop Varieties and Yield Variation: A Synthesis

Michael H. Arnold

There are two main ways in which crop varieties might contribute to increased yield variation: through reduced stability (both over different locations in a given production area and over seasons at the same location) and through increased uniformity, causing vulnerability to attack by new pests or diseases and greater fluctuations in yield associated with variations in weather.

STABILITY

The workshop recognized the efforts of plant breeders to achieve stability in new varieties and considered that any further contribution in this respect would be small relative to what might be achieved through other interventions, such as maintaining the availability and use of fertilizers. They would also be small relative to variability in weather conditions.

The workshop discussed whether multilocation testing in a single season (with the aim of achieving spatial stability) was an adequate method of achieving temporal stability (stability over seasons). It was agreed that the value of multilocation testing depended on the correlations of environmental factors among locations compared with the correlations among seasons at the same location. The magnitude of these correlations would clearly vary with the geographical area under consideration and with the nature of the environmental variable. Some thought geographical areas could be chosen to represent seasonal rainfall variation at a given location. Others thought that a similar approach could be successful with certain pests and diseases. It was clear, however, that a more systematic methodology was needed for estimating the probability of spatial and temporal variation being congruent for a given production area and a given geographical spread of multilocational testing.

Methods of measuring stability were still evolving. Simple regression analysis introduced by Yates and Cochran and developed by others (Finlay and Wilkinson; Eberhart and Russell) was still widely used, because of the simple visual method it provided for comparing the relative responsiveness of new and old varieties to the potential of the environment. Although the workshop recognized that these concepts were useful for discussing varietal types, the workshop reiterated the limitations of the method. It was noted that the new methodology was evolving, which employed the concepts of multivariate

or cluster analysis, but that these methods had not yet been widely or routinely adopted. One or two contributors to the workshop had related varietal performance to concepts borrowed from economists, such as risk aversion and stochastic dominance. These were interesting concepts that should be pursued to examine how widely they could be applied in plant breeding.

As a means of estimating changes in the relative performance of new and old varieties over longer periods of time, the desirability of maintaining substantial quantities of control varieties under gene bank conditions were generally stressed by several speakers.

It was recognized that it was not practical for plant breeders to evaluate their new varieties for more than a few seasons. Consequently, methods other than multilocation testing to predict stability were thought desirable. Trials could be conducted, possibly by multidisciplinary teams, in which potential new varieties could be exposed to various stresses and extremes of environment. In this connection, there was a need to marry the principles of on-farm testing more closely to the needs of plant breeders. It was recognized that, however desirable it might be to describe morphological or physiological characteristics of the plant associated with stability (such as degree of tillering), in practice this was virtually impossible to achieve.

The workshop discussed at length the trade-off between breeding for responsiveness (with its implications of reduced stability) and breeding for resource-poor farmers. It was clear that no single or simple solution to this problem would be found, but the evidence suggests that many new varieties had successfully contributed in both ways. There could be no escape, however, from the need to promote packages of new technology so that new varieties and the use of fertilizer would be adopted simultaneously.

VARIETAL UNIFORMITY AND GENETIC VULNERABILITY

The workshop stressed the consequences of varietal uniformity on genetic vulnerability. Although there were only a few recorded examples of large-scale catastrophes occurring from genetic uniformity (such as the association between T cytoplasm and southern corn blight in the United States and the widespread occurrence of downy mildew on susceptible pearl millet hybrids in India), the threat of similar catastrophes would always be present while single varieties or varietal types were grown over large areas. The workshop recognized that there was a general awareness of the vulnerability of uniform varieties and that plant breeders had already responded by broadening the genetic base of the material from which they were breeding.

Some plant breeders have developed multiline varieties or varietal mixtures. Evidence of their superiority in reducing genetic vulnerability is sparse, however, and for this reason and because of difficulties in producing and maintaining them in developing countries the principle has not been widely adopted. Plant breeders' main method of reducing genetic vulnerability will probably continue to be the incorporation of multiple resistance genes into single varieties. In this connection, the contributions from new techniques

emerging from molecular biology were noted. These could speed up the breeding process and might also produce new and durable forms of resistance to both diseases and pests.

VARIETAL EVALUATION AND RELEASES BY NATIONAL SYSTEMS

The workshop stressed the contribution that could be made to stability through diversity of varieties both in space and time. In this connection, it saw a need (not confined to developing countries) for an enlightened policy by all of those responsible for evaluating, recommending, and distributing new varieties.

The workshop noted a particular need to influence national testing authorities to organize their trials in such a way that all types of environment were adequately sampled, especially those at the lower end of the yield range. Special measures (such as increased replication) might be necessary to ensure the inclusion of results from low-yielding sites, as these were often the ones with the highest coefficients of variation.

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Part III

Approaches to Reducing Yield Variability

22 Summary and Assessment of the Papers on Breeding

Donald N. Duvick

This review encompasses five papers on breeding and five papers assigned to other fields but which deal with the effects of breeding on variability of cereal yields.

SUMMARY OF PAPERS

Holden (Chapter 4), in a general review, states that it is possible to breed for stability in pure line varieties. He expresses the opinion that breeders of high-yield varieties are likely to sacrifice stability of performance to some extent, in order to save those varieties with the highest yield potential.

Jain et al. (Chapter 5 and Workshop Paper 16) point out that high-yield varieties for the developing countries respond well to high inputs, but they note that the high-yield varieties also are more broadly adaptable than the farmers' varieties. This broad adaptability gives rise to very large acreages of a few varieties, which in turn bring on danger of epidemic spread of insect and disease. However, because of the great social need for more productivity, governments must learn how to manage the use of the new high-yield varieties. One suggested solution is for national governments in the developing countries to depend less on the international research centers for sources of germplasm and to increase the efforts of their own national programs, specifically intending to increase the number (and therefore broadening the germplasm base) of new high-yield varieties. The international centers then should decrease breeding research and increase crop management research, with the goal of developing management systems that will give greater stability to production of high-yield varieties. The authors make a cautionary statement about plant variety protection laws (plant patents, or "breeders' rights" laws), saying they will lower genetic diversity, because private seed firms (users of plant variety protection) sell as few varieties as possible, to maximize profits.

Coffman and Hargrove (Workshop Paper 5) point out the narrow germplasm base, both nuclear and cytoplasmic, of high-yield varieties of rice. Although more pest resistance is being bred into the new high-yield varieties, they will never have as broad a base of resistance as that in the multitude of landraces. They note that present high-yield varieties also are less tolerant of weeds, drought, and

flooding. Also, the lack of photoperiod response of the high-yield varieties means that unless managed properly they can be planted in a way that flowering dates (a sensitive time in the developmental cycle) coincide with periods of maximum heat and drought. As a consequence, poor yields can result. Furthermore, breeding for increased stress resistance will necessarily result in varieties with somewhat lower yield potential. The authors point out that, despite the many problems of the high-yield varieties, they have greatly increased rice production.

Austin and Arnold (Workshop Paper 2) show that wheat yields in the United Kingdom have quadrupled since 1830 and at the same time the coefficient of variation for yield has decreased. They note that, within a given region, variation from year to year is less when good farming practices (high inputs) are followed. They recommend that breeders pay more attention to selection for yield stability. Because high-yield varieties are more responsive to high inputs, there necessarily will be greater variability in yield of high-yield varieties in any given year until such time as all farmers apply inputs to the same high level. As U.K. wheat yields increase over time, standard deviations of yield per unit area increase in units of measurement (say, tons per hectare), but the variability calculated as percent of yield goes down.

Duvick (Workshop Paper 6) notes that maize yields in the United States have been more variable (in absolute units) during the past 15 years than in the previous 15 to 20 years but concludes that increased climate variability is the chief cause. He argues, however, that the widespread use of single-cross hybrids and uniformity in cultural practices across the U.S. corn belt probably also help increase the interregional correlations, which in turn cause an increase in year-to-year variability in aggregate maize yields. He does note that the genetic diversity of widely used inbred lines has not decreased and that newer hybrids are more resistant to environmental stress, diseases, and insects than older hybrids. In unfavorable conditions, yields of new hybrids are higher than yields of old hybrids (although as yields approach zero the advantage of new hybrids is minimal). In optimum growing environments, yields of new hybrids are much higher than those of old hybrids. Therefore, use of modern hybrids might increase environmentally caused yield variation in regions of widely varying climate.

Fischbeck (Workshop Paper 7) notes that wheat and barley in Bavaria had less variability in yield during the past 10 years than in previous years. However, from 1950 until about 10 years ago yield variability for both crops increased in regular fashion. Old varieties of wheat and barley yield about as well as modern varieties in low-input farming systems but fall well behind the modern varieties in high-input systems. The new varieties have higher coefficients of variation for yield than the old varieties when comparisons are made over low-, medium-, and high-input levels. This is because the new varieties have much greater yield potential.

Wan et al. (Workshop Paper 32) point out that variability of wheat yields in New South Wales, Australia, increased after the introduction of modern cultivars. But they state that average yields have also increased, and farmers are satisfied with the results.

Pham et al. (Workshop Paper 24) show data indicating that

improved maize varieties from CIMMYT yield about the same as local farmers' varieties in unfavorable environments but are more responsive in highly favorable growing environments. These comparisons were made in trials grown in farmers' conditions in Guatemala, Paraguay, and Ghana. In Mexico an improved variety was not superior in yield to the farmers' variety at the farmers' level of inputs but was superior, and just as stable, at high-input levels. The local variety, in contrast, was unstable at high-input levels. In Ghana, an improved variety was better than the farmers' variety at all input levels (farmers' level up to high-input levels).

Bindlish et al. (Workshop Paper 3) state that rice yields in India have not been more variable since the advent of high-yielding varieties, if variability is defined as to whether or not yields equal farmers' expectations, which depend on prevailing weather, soil, water, and fertilizer conditions.

Walker (Workshop Paper 30) says that adoption of high-yield varieties in India is positively correlated with increased instability of production for sorghum and pearl millet, although total productivity of both of these crops has increased. Possibly both crops are increasingly planted in marginal lands, which would increase the instability of production within districts but would not increase covariances across regions. High-yield varieties, although giving acceptable yields under poor environments, can expand their yields much more than the old varieties under good environmental conditions. Walker recommends that breeding research select for resistance to environmental constraints and also that it broaden genetic variability. He also suggests that governments carry out efficient trade and storage policies to solve the problems of rising instability in production.

Mruthyunjaya and Jha (Workshop Paper 18) find that high-yield varieties of cereals in India yield more and are not less stable than the farmers' varieties. These conclusions apply to performance within districts. Data are presented or cited for rice, wheat, sorghum, and pearl millet. They also note that returns from intercropping sorghum and cowpeas are higher than those from sorghum alone. However, yield variability does not seem to be any less with intercropping than with sorghum alone. In conclusion, they compliment agrobiological scientists for their good performance to date in developing varieties and management methods that give rise to both high yield and stability of yield. They suggest, however, that more needs to be known about factors responsible for yield variability.

Peterson et al. (Workshop Paper 22) say that the new U.S. hard red winter wheat varieties increasingly outyield old check varieties but are also less stable; the genotype x environment interaction is increasingly large in successive yield trials. This increase is due to new wheat varieties selected for narrower ranges of adaptation.

Witcombe (Workshop Paper 35), working with pearl millet, says that choosing entries on the basis of risk efficiency invariably results in choosing the entry with the highest mean yield across environments. Chosen entries also have moderately low -- but not the lowest -- standard deviation.

Gill (Workshop Paper 10) points out that varietal diversification is one way to stabilize total yields. Early maturing varieties are needed to allow for more rotation possibilities and high inten-

sity of cropping. He calls for improvement in certain management techniques both before and after harvest, thus indirectly saying that breeding is not the only available technique for getting more stable cereal production.

GENERAL OBSERVATIONS

In summing up the papers reviewed here, I find general agreement that yield variation (measured in absolute units) can be greater when high-yield, modern varieties are used, whether in developing countries or in countries with advanced economies. This variation, however, seems to be due not to the fact that high-yield varieties are apt to unexpectedly fail because of low inputs or poor environments but rather to the fact that they are highly responsive to favorable growing conditions because of their increased elasticity of response. When farmers do not uniformly apply high-yield inputs to high-yield varieties, yield variability within regions will increase. Conversely, when farmers do uniformly apply high-yield inputs to high-yield varieties, interregional correlations and interannual variability will increase; that is, year-to-year fluctuations in yield limiting or yield enhancing weather or economic variables will uniformly interact with the highly elastic yield potential of high-yield varieties. All the authors agree that average yields have increased and will continue to increase due to increasing adoption of high-yield varieties and the modern inputs they are uniquely able to use. Some authors therefore call for the government to help stabilize food supplies by promoting practices such as grain storage.

Several authors point out that a narrower germplasm base is an inevitable consequence of abandonment of innumerable farmers' varieties in favor of a few high-yield varieties. Other authors point out that breeding has already been successful in providing high-yield varieties with wide adaptation and good resistance to environmental stresses. It was also pointed out, however, that despite good progress in breeding for resistance to biological pests, no single variety (nor even several varieties) can be expected to meet all of the challenges of a continually evolving universe of diseases, insects, and viruses.

My own comment to this particular matter is that modern breeding technology gives the opportunity for rapid turnover of varieties offered to the farmer. Used intelligently, this opportunity allows breeders to repeatedly introduce new varieties with new kinds of resistance. Manipulated evolution in the breeding nursery can successfully counter natural evolution in disease and insect populations on the farm. Breeders thus can furnish genetic diversity over time to supplement the relatively small amount of genetic diversity in the farmers' fields at any single point in time.

Some of the authors comment on ways to broaden the germplasm base as new varieties are developed. One suggestion is that national programs greatly expand their efforts to find and use new germplasm, thus broadening the genetic base well beyond that furnished by breeding seed from the international research centers. It is also suggested that the elimination of plant variety protection (which is assumed to serve private business interests), or at least keeping

such protection and private seed firms out of developing countries, would help prevent a narrowing of the germplasm base.

My own thoughts are that encouragement of private plant breeding will, conversely, help to broaden the germplasm base. To have private plant breeders, national plant breeders, and breeders at the international centers all producing new varieties and hybrids in spirited competition with each other is likely the best way to make a broad range of germplasm available to the farmers of the world. Such competition also would probably speed selection in varieties and hybrids for maximum yield, tolerance to environmental stress, and resistance to disease and insect pests. It also would make possible better breeding for local adaptation, since more breeding programs would be in place.

Finally, it is my belief that high-yield varieties grown in the agronomic niche to which they are adapted have the most resistance to environmental stress and biological pests: they reach their inherent yield potential by successfully overcoming yield bottlenecks time after time. Therefore, high-yield varieties by definition are stable in regard to downside risks, such as bad weather and pests. On the other hand, they are also more variable in favorable conditions -- more likely to reach the upper limits of their inherent yield potential. I believe this is the message to be drawn from most of the papers I have reviewed.

23

Report of the Working Group on Breeding*

C. James Peterson

The breeding discussion group did not accept that new production technologies and cultivars, per se, are inherently more variable. Modern cultivars are more responsive to available inputs and favorable growing conditions, and a large part of any increase in production variance arises during the transition period of technology adoption and as a result of variations in the price and usage of inputs as affected by policy. Breeders have concentrated on reduction of downside risks for producers and acknowledge that more responsive varieties have an increased probability of upside risks and greater opportunity for unusually high yields.

Breeding efforts, especially in disease and pest resistance, already have had a significant effect in many marginal areas on reducing production variability and yield losses. It is very important to continue these efforts, for they can significantly reduce yield variation.

Cultivars distributed over wide production areas have had their place and have proven effective in increasing production levels. It is now important to further increase genetic diversity, especially diversity in resistance genes to provide barriers to pest and disease epidemics. Sufficient genetic diversity often is available from international centers, but more resources and appropriate policy, especially at the regional level, are needed to effectively manage and exploit available genetic diversity. This can be done only through strong national and regional programs and through the regionalized approaches of international centers. Thus there is a need to increase international cooperation and distribution of germplasm and to expand efforts in evaluating, cataloging, and maintaining germplasm.

With regard to improving production and stability on marginal lands, the group believes that breeders can have only limited impact in these areas. Environment continues to be the overriding factor in these areas. Improved crop management is an

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*The group consisted of Roger B. Austin, W. Ronnie Coffman, Donald N. Duvick, Lloyd T. Evans, K. S. Gill, Peter B. R. Hazell, John H. Holden, H. K. Jain (chairman), M. S. Mekni, C. James Peterson, W. H. Pfeiffer, H. N. Pham, Joachim von Braun, and John R. Witcombe.

essential prerequisite for plant breeding success. Genetic diversity for stress tolerance is available, but is limited, and testing is difficult in these low-heritability environments. An approach combining soil and moisture research, input analyses, and breeding work is needed. It was acknowledged that combined efforts and increased inputs can be costly, but increased breeding efforts in marginal areas also are costly. Stress breeding is highly location specific, and increased numbers of testing sites and materials would be needed. Breeders will need the help of economists in doing cost-benefit analyses to aid in making breeding policy and allocating resources. Breeding and research in marginal areas may require trade-offs in resources and benefits. The group also agreed that breeding for stress tolerance may increase production stability, but only relative to the yield potential of an environment. The best cultivar may still be one with high responsiveness, which may increase absolute variability in yield.

Drought resistance breeding was specifically discussed by the group and was considered to be very costly in terms of the needed resources for testing. Drought resistance was explicitly distinguished from drought escape, and the important effect of maturity was noted. In the context of policy, the problems inherent in drought resistant cultivars were related to problems in release policies and state testing programs in many countries. It is important that release policies be flexible and realistic in order to target cultivars for specific areas of adaptation and stress. It was noted that ICRISAT has given up breeding for drought resistance in sorghum as a result of difficulties in testing and cultivar release.

The group emphasized that a strong seed industry and a strong extension service are both necessary to a successful breeding and research program. In many countries, and especially in Africa, seed multiplication and distribution are serious constraints to increased production. Breeders can test and target varieties for environments only; it is not possible to target cultivars for individual farmers, who make the ultimate decision on which cultivars to use and how. Yield stability is related to distribution, to application of technology, and to policies affecting variety release and extension work. The need for more on-farm tests to identify cultivars appropriate for marginal areas was acknowledged.

The existence and importance of crossovers in yield and productivity between modern high-yielding cultivars and old less-productive cultivars or landraces in the poorer production environments, as related to Findlay and Wilkinson regression parameters, was debated at length. It was generally agreed that, in the first stages of a breeding program, crossover effects do exist and landraces may have a yield advantage in marginal or stress environments. However, once the gene pool and adaptation of materials in the program has improved, the likelihood of significant crossovers declines substantially. It is important that the environmental conditions of sites chosen for breeding and evaluation of cultivars adequately reflect actual production conditions and variation. Yield advantage of landraces in marginal conditions usually occurs in areas outside the range of testing and adaptation of modern cultivars. Crossovers in productivity of cultivars over environments are an important consideration in deciding on the area of cultivar adaptation and release.

It was noted that crossovers generally are discarded in breeding programs. Yield differences in marginal areas usually are small, and the importance of crossover effects will depend on the number of farmers operating in those high-stress areas.

Several workshop papers indicate that increasing covariance among production regions is an important factor in the increased production variance of several countries. The breeding group emphasized that there is no indication that biological factors, genetic similarities among cultivars, or genetic vulnerability, have contributed to the increased covariance among regions. The increasing correlations among regions may arise from breeding strategies that maximize the yield potential and production levels of each region. It is also likely that the availability and cost of inputs, along with weather factors and more input responsive cultivars, have contributed to the increased covariance.

In summary, breeders can and have contributed to increased production stability through cultivar development. Modern cultivars are not inherently more variable than old cultivars, but they are more responsive to application and availability of inputs and favorable environmental conditions. Improving yield and stabilizing marginal production areas will require an integrated approach, combining soils research, moisture conservation, management research, as well as plant breeding.

24 Summary and Assessment of the Papers on Input Management

Robert W. Herdt

Many papers presented to the workshop touched on the issue of how input use affected output variability. In this summary I comment only on those that devoted a major part of their analysis to the subject or reported empirical findings.

SUMMARY OF PAPERS

The paper with the longest time series of data examining variability was prepared by Austin and Arnold (Workshop Paper 2). Their data on interannual variation in U.K. national wheat yields show that, while yields increased over the four periods examined as varieties and inputs advanced to higher levels, the standard deviation of yield increased less rapidly, and the cv declined from 13.3 to 5.2 percent.

Period	Mean Yield (tons per hectare)	Standard Deviation (tons per hectare)	Coefficient of Variation (percent)
1832-59	2.08	0.276	13.3
1890-1917	2.12	0.179	8.4
1918-45	2.25	0.167	7.4
1948-84	4.12	0.216	5.2

Austin and Arnold also report on the results from a long-term (1852-1918) experiment at Rothamstead, comparing wheat yields under three fertilization treatments: no added fertilizer, a farmyard manure treatment, and a chemical fertilizer treatment. The results clearly show that while the application of inputs raises yields dramatically, there is no increase in the coefficient of variation.

Fertilizer Treatment	Mean Yield (tons per hectare)	Standard Deviation	Coefficient of Variation (percent)
None	0.86	0.215	24.9
Manure	2.43	0.406	16.7
Chemical	2.51	0.513	20.4

A similar trial conducted with modern cultivars between 1970 and 1978 yields similar findings.

Fertilizer Treatment	Mean Yield (tons per hectare)	Standard Deviation	Coefficient of Variation (percent)
None	1.70	0.29	16.8
Manure	5.87	1.06	17.0
Chemical	5.09	0.51	9.8

Carlson (Workshop Paper 4) presents a cross-country analysis of production variability in rice and the possible factors associated with it. While agreeing that the model may have some specific problems, Carlson offered it in the spirit of the Hayami-Ruttan meta-production function.

Changes in the measured cvs of area and yield for 14 Asian countries during two periods and for 7 countries during three periods are related through regression analysis to changes in several variables: area devoted to high-yield varieties, fertilizer use, irrigated area, and labor. His analysis shows that on average an increase in the percentage of the area in HYVs or irrigation is associated with a fall in variability, and that an increase in the nitrogen use per hectare is associated with a rise in variability.

Mruthyunjaya and Jha (Workshop Paper 18) present a most interesting set of yield data comparing the variability of semidwarf with that of local rice and wheat varieties grown by farmers in India. Crop cut data from a number of districts are analyzed for 1970/71 to 1976/77, thereby providing a reflection of the relative variability of the two types of varieties and their technology packages used by farmers. It is not clear whether the variability is computed from the individual crop cut observations or from the district aggregates, and it would have been useful if the authors had clarified this.

The rice data from 11 districts show that the mean yield of HYVs was higher than local varieties in all 11 cases, and that the cv of yield was higher for HYVs in 4 out of the 11 districts. The wheat data from 12 districts show that the mean yield of HYVs was higher than local varieties in all 12 districts, and that the cv of yield was higher for HYVs in 2 out of the 12 districts.

Hanus and Schoop (Workshop Paper 12) present the results of an interesting long-term (1975-84) experiment testing levels of fertilizer treatment, fertilizer timing, and fungicide application on wheat in Germany. They plotted the means and standard deviations of yields. The results show that standard deviations increased slowly as long as average yields increased steeply, but when rates of N approached the maximum yield, variability increased substantially. Variability was somewhat reduced by the use of fungicides, but the N level at which variability turned up sharply was little affected.

The analysis would have been considerably enhanced by the use of simple budgeting to examine the economics of alternative treatments and by a stochastic dominance analysis to determine the riskiness to farmers of the alternatives. As presented, the data indicate that increases in wheat yield variability due to increasing rates of fertilizer may be buffered somewhat by the application of fungicides, but not enough information is provided to determine whether farmers might decide to adopt such a practice.

McIntire and Fussell (Workshop Paper 17) report on a series of on-farm experiments in millet production for two years in six Niger villages. A traditional variety grown with fertilizer outyielded the same traditional variety grown without fertilizer in all six villages and also had lower cvs. An "improved" variety grown with fertilizer gave an increased yield in three of the six villages and gave an increased cv in four of the six villages. Thus in the first comparison, where mean yields were increased, the relative variability declined, but in the second comparison, where the mean yield increased in only half the cases, the variability of yields also increased.

The paper by Rodriguez and Anderson (Workshop Paper 25) presents a linear programming analysis of four farm plan options for highland and crop-livestock farms in Ethiopia, treating risk as an additional cost imposed on the farmer. Thus the solution to the risk model is equivalent to the profit maximizing solution that would be achieved with costs increased by the amount of the risk aversion scalar applied.

Rosegrant (Workshop Paper 26) presents a summary of a comprehensive simulation model that encompasses farmer decision making, alternative risk aversion assumptions, rainfall variability and its effect on irrigation water availability, and alternative irrigation maintenance procedures. A mass of on-farm research trials analyzed in a complex production function framework, plus a large amount of data from two irrigation systems in the Philippines, provide the empirical basis for the analysis; rainfall records provide the variability underlying the simulations. The model assumes that farmers maximize utility (defined through a risk constrained profit maximizing rule), and provides information on production, yield, and income. Rosegrant's model supports the following conclusions:

- Irrigation in the wet season has no effect on the variability of the area planted, but stabilizes yield, production, and income.
- Irrigation increases the variability of the dry season area planted, of production, and of income, but does not affect the variability of dry season yields.
- If maintenance of the irrigation system is good, the cv of production and income is roughly the same as that of an equal area of

rainfed rice, and average income is roughly twice that of the rainfed area.

- If system maintenance is poor, the cv of production and income goes up slightly, income and production go down slightly, but there is a different distribution of the income earned along the length of the canal.

GENERAL OBSERVATIONS

The whole reason for concern about variability is its possible effect on two groups of decision makers: farmers and government policy makers. Excessive risks may cause farmers to avoid adopting a new technology that would bring greater yield; thus there is a possible divergence between the interests of farmers and those of society. In order to evaluate this possibility, one should focus not on yield but on what the farmer receives -- gross margin, or "profit." Except for the Rosegrant paper and the linear programming model of Rodriguez and Anderson, none of the workshop papers recognize that inputs have a cost and that the criteria of interest should be gross margin.

If one is interested in evaluating alternatives for farmers, one ought to be examining risk, not simply the variability of income or yields. That is, one ought to compare the probabilities of achieving income of a certain amount with various techniques. One paper (Workshop Paper 1) presented data in this format, comparing two varieties; but as inputs were not involved, it is not reviewed here. A comparison of several strategies of pesticide application on rice is discussed in Herdt et al. (1984). It illustrates, in three series of experiments on rice in different locations in the Philippines, that a minimum "action threshold" level of pesticide provides the least risky alternative among four levels tested: zero, action threshold, high, and maximum. That is, the farmer who chooses the action threshold strategy has the highest probability of attaining a specified income.

One should not ignore the implications of product price changes that may accompany the adoption of new inputs. A model like Rosegrant's could be modestly expanded to reflect this consideration. One paper by Hazell (Workshop Paper 14) does touch on the issue of prices and finds that, despite the lack of collinearity between domestic and world prices, there is an increase in the collinearity of world prices across crops, a fact that may be associated with the underlying concern of the workshop.

REFERENCE

Herdt, R. W.; Castillo, L. L; and Jayasuriya, S. K. 1984. "The Economics of Insect Control on Rice in the Philippines." In Proceedings of the FAO/IRRI Workshop on Judicious and Efficient Use of Insecticides on Rice. Los Baños, Philippines: International Rice Research Institute.

25

Report of the Working Group on Input Management*

J. C. Headley

Appropriate and timely use of fertilizers, pesticides, and irrigation can reduce the effect of climate and pest induced shocks on yield and therefore on income variability, but farmers and extension advisors often lack knowledge of their availability and use. In discussing strategies for input use, the group considered the following to be important:

- Farmers should diversify across enterprises, varieties, and pesticides. Most low-income farmers already diversify across enterprises, but they may not be diversifying sufficiently across varieties or pesticides to reduce vulnerability. Insufficient diversification across pesticides can also lead to the buildup of resistant populations.
- Farmers should use such variance reducing practices as irrigation, pest control, and mechanization.
- Farmers should use gene deployment strategies where feasible to maintain disease, insect, and drought resistance.
- Governments need to give greater priority to ensuring that farmers have easy and reliable access to key inputs. This may require increased investment in rural infrastructure, especially roads, electrification, and storage facilities.
- The international research centers should do more to provide information to farmers about how best to cope with input shortages.

The above actions to reduce yield variability will have economic and social consequences. These are as follows:

- Diversification, by reducing the production of individual crops,may lead to higher unit costs. Consumers may therefore face higher prices and be worse off than under more specialized production strategies.
- Mechanization and the use of pesticides and herbicides may reduce the demand for agricultural labor (for example, hand weeding) and could therefore be detrimental to the landless and small farmers and result in outmigration.

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*The group consisted of Gerald A. Carlson (chairman), Gregory Edmeades, John C. Flinn, H. Hanus, J. C. Headley, Robert Herdt, Arthur Klatt, Mark W. Rosegrant, Bruce Stone, Tong Zhong, and Eduardo Venezian.

- Input in reliable and adequate quantities helps all farmers, but it may be particularly beneficial to low-income farmers, who are most likely to be denied access to inputs when supplies are short.
- Infrastructure investment could have a positive effect on agricultural laborers by increasing access to alternative employment opportunities, on low-income farmers by improving their access to markets, and on consumers by leading to more, and therefore cheaper, food supplies.
- Information on methods for coping with variability should have a neutral effect on laborers and a positive one on consumers and low-income farmers.

The group considered information and research needs related to input management and thought additional work on the following topics necessary:

- spatial and crop diversification analysis;
- pest management analysis;
- crop rotation analysis;
- irrigation investment analysis;
- new fertilization practice analysis;
- analysis of ways to improve input markets, including investments in roads, communications systems, water, and other infrastructure; and
- research to assist policy makers on input choices such as variety adoption, farm labor migration studies, input stockpile studies at the farm level, and input subsidies.

One member of the group (Gerry Carlson) also stressed the informational problems farmers have when adjusting to new, input responsive crops or varieties. Their previously accumulated knowledge about yield responses suddenly becomes redundant, and new knowledge has to be acquired, especially about appropriate input strategies in the event of drought or pest attacks. In this situation, Carlson argued the need for public assistance in obtaining and disseminating appropriate information, so as to take advantage of economies of scale in information. Input subsidies might also be relevant in the short term.

26 Summary and Assessment of the Papers on Farming Systems

Ulrich von Poschinger-Camphausen

THE STABILITY OF INTEGRATED CROP-LIVESTOCK SYSTEMS

Rodriguez and Anderson (Workshop Paper 25) used a linear programming model of small farms in the Ethiopian highlands (around 8 thousand feet) to evaluate the effect of changes in livestock technology on income variability in an integrated traditional crop-livestock system. The following scenarios were simulated:

- using local draft-ox either in singles or pairs;
- using an improved single-ox technology; and
- owning a cross-bred cow.

Constraints on the use of labor, land, and draft power and requirements for crop rotation and family subsistence needs were incorporated in the model through linear inequality constraints. The main crops were oats, barley, wheat, field peas, and horsebeans. Apart from draft power, livestock provided manure for crops and for fuel, milk, meat, and transport.

In the model results, livestock products account for 84 percent or more of the value of farm income. This proportion increases in the model solutions in which farmers are assumed to be more risk averse, that is, in which greater weight is given to reducing the standard deviation of income. These results suggest that livestock may play an important role in stabilizing farm incomes.

However, the authors offer insufficient details about the results to indicate why livestock contributes in this way. It would be useful to know the level and composition of livestock products in the model solution and to know about the riskiness assumed in the yields and prices of different products. It would also be useful to know what is assumed about the correlations between the returns of crops and livestock products. Are there offsetting patterns of variation, or do they reinforce each other?

It might be desirable to try to gain additional insights by deriving model solutions in which livestock activities are omitted. This would permit a direct comparison of the value of livestock in stabilizing total farm income. Much of the paper is concerned with comparisons of technologies from the International Livestock Centre for Africa with traditional technologies. While the results usefully support ILCA's work, they do not add much to our understanding of the interaction between livestock and crops in stabilizing income.

HOW SMALL FARMERS ADAPT TO RISK

Walker and Jodha (1986)[1] review methods by which small farmer households adapt to yield risks under rainfed conditions. They compare findings from India, El Salvador, and Tanzania, and seek to establish how well current risk management methods work in protecting household consumption and farm productive capacity.

Risk management practices embodied in cropping systems can be subdivided into those that relate primarily to diversification of resources and enterprises and those that relate to adjustments within cropping systems. The following methods were observed in the regions studied:

- planting crops in a spatially scattered pattern to take advantage of agroclimatic differences within short distances;
- planting crops with multiple uses to provide flexibility in their end use;
- planting mixed crops and integrating of livestock and crop activities;
- adapting plant spacing and input use to crop and weather conditions during the season; and
- using flexible planting dates and intercropping to respond to emerging weather and moisture conditions.

The authors also analyzed the loss-management mechanisms farmers use when crop income falls short of expectations. These mechanisms include informal sharing within families and villages, borrowing, storage, reduced or modified consumption, selling assets, and labor market participation. Nonfarm income can be an important source of compensation, but to be protected from the highly covariate nature of farm and nonfarm income, it has to come from outside the problem region.

Preliminary results from an ICRISAT study of three villages in the semiarid tropics of India show that the coefficient of variation of net household income averaged 35 percent, with a range of 15 to 85 percent. Despite risk adapting cropping strategies and farming systems, one drought was so severe that crop and livestock income contributed only 5 to 15 percent to total sustenance income that year. Private borrowing contributed 44 to 73 percent of income and public relief contributed 22 to 56 percent.

These village-level studies also provide some evidence on the efficiency of three risk management actions:

- Spatial diversification does not appear to be as strongly associated with net crop income stability as does crop diversification. The latter is negatively and significantly correlated with the coefficient of variation of net crop income.
- Tenancy arrangements can be effective in sharing production risks (between landlord and tenant), both within and between cropping years.
- Intercropping of millets, sorghum, and pigeonpea is not very effective in stabilizing yields. It does help to reduce pest and

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[1]This previously published paper was circulated to workshop participants.

disease damage, but expected yield compensation effects between crops do not seem to materialize.

Mruthyunjaya and Jha (Working Paper 18) also compared sole crop sorghum with sorghum based intercropping in India. They conclude that, while intercropping gives higher returns per acre on average, there are no obvious gains in stability. Personally, I wonder if these findings generalize to more complex and diverse cropping systems.

REFERENCE

Walker, Thomas S., and Jodha, N. S. 1986. "How Small Farm Households Adapt to Risk." In Crop Insurance for Agricultural Development: Issues and Experience, pp. 17-34. Edited by Peter Hazell, Carlos Pomareda, and Alberto Valdés. Baltimore: Johns Hopkins University Press.

27 Report of the Working Group on Farming Systems

Wolfgang Vogel

The group addressed itself to the question of what the best approaches are for the farmer and the farming systems researcher to reduce variability in production, income, and consumption. Attention was also focused on small-scale farmers under rainfed conditions.

REDUCING VARIABILITY IN PRODUCTION

The group identified four major sources of production variability -- soils, input supplies, weather, and prices. The first two involve less uncertainty, in that farmers have considerable information about them at planting time. In contrast, information on weather and prices is not known until later in the season, at which time farmers can only try to minimize their losses in response to unfavorable events.

Farm strategies to cope with variability can be classified into two groups -- diversification strategies and changes in practices. Diversification strategies include mixed cropping, intercropping, spatial diversification, and integrated livestock-crop systems. These strategies are costly in the sense that some income is forgone on average to reduce risk and that they are most relevant for coping with weather and price risks.

Changes in practices include the use of pesticides, resistant varieties, fertilizers, and irrigation, and temporal adjustments during the season in planting, crop thinning, input use, and so forth. Farmers can change their practices in response to most types of production variability. For example, they can apply lime or use acid tolerant varieties if soil acidity increases. Or they can skip fertilizer applications and intercrop with drought resistant crops if the rains turn out to be poor.

The two-fold character of farmers' responses to variation has important implications for farming systems research (FSR). Research on soils and input supplies should be directed at increasing mean yields under different practices in different environments (by

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*The group consisted of Jock R. Anderson, Michael H. Arnold, Randolph Barker, John McIntire, Gil Rodriguez, Kutlu Somel, Wolfgang Vogel (chairman), Ulrich von Poschinger-Camphausen, and Heinrich C. Weltzein.

improving, for example, soil fertility). Such research can affect variation, largely by reducing the frequency of very bad outcomes. Research on weather and prices should also aim at raising mean yields, but it also needs to consider the variation (and covariation) of improved practices because risk aversion, and not comparative advantage, is the origin of diversification. The aim should be crop improvement and crop protection, not improved practices, which, if they offer much less stability for a given increase in mean yields, will not be adopted.

REDUCING VARIABILITY IN INCOME AND CONSUMPTION

Farmers can mitigate the consumption and income effects of production variability by means of storage, trade, ownership of physical assets, insurance, participation in financial markets, and off-farm employment. In peasant economies, the principal mechanisms are grain storage and purchase, holding exchangeable assets such as livestock, and off-farm employment. Insurance and participation in financial markets are rarely encountered.

The working group believes that product market efficiency and labor markets, in particular, needed to be studied in an FSR context to provide information about the consequences of government policies. For example, many government interventions -- such as quotas on crop sales or restrictions on labor hiring -- increase instability. Another topic for study is improving the asset value of livestock, which constitute a major reserve against poor years. Improvements in animal health may be one way to increase their value as well as to reduce variations in those values.

IMPLICATIONS FOR FARMING SYSTEMS RESEARCH IN THE INTERNATIONAL AGRICULTURAL RESEARCH CENTERS

Since FSR groups are closely related to crop improvement programs in the international research centers, their major emphasis should be on reducing production variability by providing information on the sources and magnitude of variability. For example, they might provide crop improvement scientists with estimates of disease pressure and soil variability; or quantify risk and genotype-environment interactions.

Their secondary role should be to reduce consumption variation through work on commodity storage, and on asset, labor, and product markets. The former is largely a problem of technical efficiency, while the latter is one of economic efficiency. These measures will have no effect on production variability, but they might reduce consumption variability directly. Such work should be closely linked to policy analysis, because it can provide useful information to governments about the consequences of their policies.

28 Summary and Assessment of the Papers on Public Policy

Hartwig de Haen

Public policies are related to increasing production instability in two ways. Certain policies may be the (unwanted) cause of increasing variability. Other policies can be used to reduce yield instability or to overcome their undesired consequences.

None of the policy oriented papers presented at the workshop covers the whole range of issues underlying these two policy implications. Some of them even focus on other aspects of instability, such as the empirical evidence for increasing variability, farmers' risk management practices, or implications for consumer welfare. Yet, taken together, the papers provide a very useful source -- mostly hypothetical, some even empirical -- from which preliminary conclusions for further policy analysis can be drawn.

SUMMARY OF PAPERS

Nguyen (Workshop Paper 20) presents an empirical analysis of grain production in the Soviet Union. He shows that production instability increased drastically during the 1970s, mainly due to higher covariances of yields between crops. Nguyen dismisses weather variability as a cause of these yield covariances. One underlying source is agricultural expansion into regions with higher yield variances. But Nguyen concludes that a switch in central planning policies since the mid-1960s is the major cause. His hypothesis, which is still to be tested empirically, is that more rigid enforcement of procurement policies no longer allows collective farms to respond flexibly to erratic input supplies by substituting crops or adjusting input intensities. Thus a policy of central "allocation of shortages" has led to synchronized movements of yields across regions and crops. It would be interesting to investigate whether changes in procurement policies in developing countries may have had similar effects.

Tarrant (Workshop Paper 29) is also concerned about the variability of Soviet grain production, and he offers some further hypotheses with respect to production variability. One hypothesis is that of a two-year cycle of yields due to a sequence of soil depletion and recovery in the absence of sufficient external inputs. His major explanation for rising variability in national production is that production has grown faster in some regions than in others and that, as a consequence, interregional compensation effects can no

longer balance regional fluctuations as before. Tarrant does not confirm the allocation of shortage hypothesis. His conclusions are therefore not related to a revision of procurement policy or input planning but to a better balancing of regional production growth, which would help maintain the interregional compensation mechanism.

Walker and Jodha (1986)[1] address two microeconomic issues related to increased yield instability: traditional risk-loss management practices of farm households and the effect of such practices on efficiency and equity. The authors provide ample evidence from a wide range of locations where farmers try to cope with fluctuating yields either through compensation of losses (like adjustment of stocks and durables or additional off-farm employment) or through risk reducing farming practices (like diversification and adjustment of cropping patterns, including spatial scattering of fields and mixed cropping).

Given their (unfortunately limited) observation that farm incomes, consumption levels, and other indicators of producers' welfare do often vary substantially in spite of such risk-loss management, Walker and Jodha suggest that there remains a need for public action to protect producers. Such action would have to include attempts to avoid or adjust those public polices that adversely affect risk management practices. The authors present several such cases of adverse effects from Tanzania and India. These include the decline of village food reserves due to state marketing, the reduction of allocational flexibility due to acreage allotments and procurement, the narrowing of chances for spatial scattering due to settlement schemes, and the limits to off-farm employment by restrictions on migration.

The last part of the paper is of particular relevance for public policy. They argue that some of the above mentioned risk-loss management practices entail efficiency costs and have adverse welfare effects. Efficiency costs result because risk aversion may lead to a slower rate of adoption of new technologies and less exploitation of the cost advantages of specialized production patterns. Equity goals may be affected if the burden of adjustment is transmitted to other groups, such as landless laborers, whose chances of employment are negatively affected by job seeking small farmers. Unfortunately, empirical studies of such effects are scant, and hence cost-benefit analyses of alternative options for public policies, which could reduce farm-level production risks and therefore avoid costly risk management practices, suffer from lack of empirical observations also.

The second paper by Nguyen (Workshop Paper 19) contains another empirical application of Hazell's decomposition algorithm -- in this case to cereal production in Syria. The results are strikingly similar to those Nguyen found in his study of Soviet grain production. He shows that production instability increased substantially due to a rise in yield variability, to increased yield covariances between provinces, and to a growing positive correlation between area expansion (mainly of barley in marginal low-productivity locations)

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[1]This previously published paper was circulated to workshop participants.

and the variability of barley and wheat yields. As in the Soviet Union study, Nguyen relates this increased variability to the fact that the Syrian government enforced input quotas and land use planning, which reduces farmers' flexibility to respond to fluctuating physical and economic conditions. Unfortunately, the available information did not apparently allow the author to test his explanatory hypothesis empirically.

Sahn and von Braun (Chapter 6) took a more global look at the implications of increased variability in cereal yields for consumers and policy. They present a cross-section analysis of 16 developing countries from Asia, Africa, and Latin America, with the following conclusions:

- Variability in cereal production is greater than the variability in cereal consumption.
- Variability tends to be lower in countries with higher per capita GNP and consumption.
- An analysis of trends gives no significant indication of a rising trend in variability in consumption.

The authors conclude from this that societies, especially those with high incomes, have successfully implemented stocking and trade policies to protect consumers against the negative consequences of fluctuating food supplies. Whether such a conclusion is justified seems to me to require further analysis, because if production is much smaller than consumption (the net importer case), then the higher coefficient of variation in production may still imply the same absolute variation in consumption and hence no dampening effect from stabilization policies.

Sahn and von Braun use microeconomic analysis to illustrate very clearly that the effect of variability in production on household real incomes follows a complex mechanism -- including adjustment of quantities, prices, and wages -- which affect different types of households in a very particular way. In a closed economy, for example, shortfalls in production may be offset by rising prices such that real incomes may fluctuate less than production. While farmers with surpluses can normally stabilize consumption even when real incomes fluctuate, low-income farmers whose market surplus-deficit position varies with the erratic movements of production may not have such options as dissavings, withdrawal from stocks, or temporary reduction of other consumption. Landless laborers are particularly hard hit, because upsurges in food prices are often not immediately matched by any increase in nominal wages. Unfortunately, the empirical evidence is particularly deficient concerning both the intra-household distribution of fluctuations in consumption and the related nutritional consequences for vulnerable groups.

Finally, Sahn and von Braun explore a diverse menu of policy options to cope with instability. The ultimate goal of any policy intervention should be to stabilize consumption. The authors convincingly emphasize that this goal can best be achieved by adjusting trade fluctuations in domestic production. Yet this solution is only valid under ideal market conditions in a neoclassical world. Stockholding between periods of affluence and scarcity may be the preferred option for countries that want to protect themselves against a precipitous price rise, or that are landlocked, or that are near self-sufficiency, or that are faced by high costs of

trade and have a large wedge between c.i.f. and f.o.b. prices. The authors briefly discuss those (preferable) policies that could either reduce variability in production (investment, research, and extension in agriculture) or facilitate interregional compensation (investment in marketing infrastructure).

Finally, they conclude that even if these policies succeed in stabilizing the aggregate availability of food, there may still be vulnerable groups among the poor who can only be reached by targeted stabilization programs. Such programs could take the form of food aid, food for work (which the authors prefer because of employment generation effects), or food subsidies. The problem with such policies -- Sahn and von Braun touch on this only briefly -- is not only how they can be targeted on the poor but also how they can be kept flexible enough to vary cyclically with fluctuations in the real incomes of the poor. Theoretically, the need for such costly programs could be reduced by improved access to consumption credit or by support of savings. Yet it is doubtful whether the real poor can be reached by such policies.

A central hypothesis underlying most of the discussion in the papers is that the precautions farmers take against yield risks are all detrimental to efficiency and production growth. The production and input use patterns associated with profit maximizing behavior are not being realized. Under such conditions, multiple-risk crop insurance would appear to be an ideal solution. Indeed, as Hazell et al. (1986)[2] point out, the benefits of crop insurance schemes are, in theory, manifold: higher allocative efficiency, higher farm incomes, better performance of credit institutions, and higher national food supplies.

Yet, after reviewing the performance of insurance schemes in practice, Hazell et al. came to a rather negative conclusion. Major problems, including high administrative costs, limited controllability (unless insured risks are restricted to well-defined natural events such as hail or flood), moral hazard problems with farmers who tend to reduce management care for insured crops, and the limited relevance of yield variability for the overall socioeconomic risks a farm family faces. Hazell et al. provide a clear warning to policy makers who would make crop insurance compulsory or subsidize it on a permanent basis. This last can be very expensive compared to alternative ways of reducing yield variability and of offsetting its undesired repercussions, and experience from various countries shows that the social cost of subsidized multiple-risk crop insurance substantially exceeds its social benefits.

Walker (Workshop Paper 31) addresses the issue of "risk benefits" generated by more stable yields from the farmers' perspective. Risk benefits are defined as the amount of mean income a farmer is willing to sacrifice to obtain a smoother income stream. Walker presents the results of an interesting time series analysis from 40 households in three villages in the semiarid tropics in India. He concludes that, under the conditions of his sample farm households, a strategy of complete yield stabilization would generate only small

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[2]This previously published paper was circulated to workshop participants.

risk benefits. One reason is that yield fluctuations are partially compensated by movements in prices. Another reason is that crop income is not the only source of income: area variations cause fluctuations in income as well. However, as Walker points out very clearly, such conditions may not exist in other regions or for different types of farms, in which case the risk benefits from yield stabilization would be greater. He suggests this is more likely to be the case in the semiarid tropics of Africa than in India.

GENERAL OBSERVATIONS

The papers reviewed show very clearly that increased variability in cereal yields has various implications for public policy. A wide range of issues is mentioned, but unfortunately the empirical basis for the assessment of public policies is much less evident than the empirical foundation for the observation that variability has increased. Most of the policy effects highlighted in the papers are hypothetical. Further discussion and quantitative analysis will be necessary. Such work should address the following three questions:

- Why should policy makers be concerned about increased variability in cereal yields?
- Which policies should be implemented -- and which avoided -- to reduce such variability?
- Which policies could be used to overcome the undesired consequences of variability?

Why Should Policy Makers be Concerned about Increased Variability in Cereal Yields?

Instability in yields may have negative consequences for both allocative efficiency and equity and can thus be undesirable for society as a whole as well as for specific social groups. Particular attention should be paid to the food security of vulnerable groups when yields fall below trend. Policy makers may be concerned with the following five consequences of increased yield variability.

Reduced Efficiency in Crop Production. In theory, risk reducing farm management strategies tend to prevent the full exploitation of comparative advantage because they prevent desired patterns of regional and farm-level specialization, rapid introduction of innovations, and the optimal level of input use. Several empirical studies confirm this hypothesis; yet, others show that the adoption of innovations does not primarily depend on yield variability. Insofar as the increase in yield variability results from a higher interregional correlation of yields rather than from higher crop variances, one need not expect any loss in efficiency costs on individual family farms, anyway.

Economywide Destabilization. Economywide effects may go beyond the costs of inefficient crop production and include destabilization of national employment, tax revenue, and foreign exchange earnings. Such effects will be the greater the larger the share of cereals in GNP. None of the papers investigated such effects in detail.

Unstable Real Farm Incomes. Whether or not increased variability in cereal yields cause real farm incomes to fluctuate is an empirical question, and the answer depends critically on the correlation between yield and price fluctuations. A closed economy is more likely to compensate low yields with high prices. Unfortunately, time series of producer prices are much scantier than time series of yields, and this may explain why empirical analyses have not been presented so far.

Unstable Consumer Welfare. In theory, unstable consumption leads to reduced consumer welfare, at least if downward shifts occur at a very low level. If Sahn and von Braun's (Chapter 6) cross-country comparison is correctly interpreted, then one can say that various buffering mechanisms are in effect, which protect consumers from increased instability in yields. These results confirm previous studies. Yet it would be premature to conclude that these mechanisms are policy controlled. Household-level credit and savings adjustment could also be the reason.

Unstable Equity Among Producers and Consumers. Several papers formulate interesting hypotheses on equity effects. Generally speaking, one would expect that groups with economic or political power will transfer the burden of declining real incomes to the weaker groups in the system. Thus it was suggested in several papers that landless laborers would be particularly hard hit as rising food prices coincide with reduced probabilities of employment or with limited adjustments of wages, whereas farmers with surpluses and better-off consumers have various options to keep their consumption stable in spite of fluctuations in production or prices. While the effect of income changes on household demand patterns is generally quite well known, little is understood as to how consumption and nutritional benefits are distributed within a household. Further research on the social implications of fluctuating food supplies will certainly have to pay more attention to these equity effects, if policies are to be poverty oriented and cost effective. In order to focus compensatory policies, including employment stabilization and food aid, on the most affected parts of society, high priority should be given to target group identification.

What Can Be Done to Reduce Variability in Cereal Yields?

Breeding for Lower Vulnerability to Uncontrollable Environmental Factors. The most desirable approach to avoiding the negative economic and social implications of variability in yields is to put more emphasis on breeding cereal cultivars that respond less sensitively to fluctuations in external factors. Yet greater yield stability is only achievable at the cost of lower average yields. It would be highly desirable to investigate this correlation further and to distinguish yield response to variations in uncontrollable stress factors on the one hand and yield response to variations in input levels on the other hand. Further, the preference for lower variability in yields relates mainly to uncontrollable factors and not to input factors, such as fertilizer, for which a high response is a

precondition for efficient production growth. Moreover, genetic properties are not the only cause of increased variability, as several papers show. Therefore, other policy efforts may also be required, such as improvements in production systems, removal of market imperfections, and the avoidance of state interference in farm input supplies and resource allocation.

Improving Farming Systems. Farmers already practice a wide spectrum of risk management strategies in order to reduce the risk of income losses due to unpredictable variations in yields. Yet, as some of the papers show, there may be scope in some farming systems for further reductions in the probability of downward variations in yields, even without sacrificing average yields: improved mixed cropping, timely application of fertilizer, efficient water management, and so on. Both researchers and extensionists are challenged to contribute to such improvements.

Improving Market Infrastructure. In theory, more competitive markets with decentralized market infrastructure help keep marketing margins low, facilitate interregional and intertemporal transactions in inputs and produce, and favor technical progress in marketing and processing. Fluctuating regional supplies and prices can thus be better balanced through stock and trade policies, and farmers can base their decisions about production patterns and input use on more stable input availabilities and input prices. Which particular investments would be appropriate in practice needs location-specific investigations. Since improved markets would dampen price movements and reduce negative correlations between quantities and prices, consumers may gain more than surplus producers. The latter would gain, however, from the higher prices resulting from reduced average marketing margins.

Stabilizing Input Supplies and Decentralizing Crop Production Decisions. Governments in quite a few developing countries rigidly control the supply of inputs, either through public ownership of input factories or through import licensing. Some even control the whole distribution system down to the farm level. Egypt has even been trying to control the allocation of fertilizers by crop. Such policies, as well as prescriptions for land use patterns, are often not fully effective, at least in family farm systems where farmers tend to deviate from the plan in order to reduce income losses. Nor can one exclude the possibility that such state interventions cause considerable disturbance and destabilization in the production system compared to more decentralized input distribution and private decision making about input allocations. Nguyen's studies of the U.S.S.R. and Syria should encourage more empirical analysis of this issue in other countries.

Which Policies Could Be Used to Overcome the Undesired Consequences of Increased Variability in Cereal Yields?

As the papers illustrate very impressively, policy makers have at their disposal a wide range of instruments to overcome the

undesired consequences of variations in yields. The most important ones are

- trade (interregional and international);
- food reserve buffer stocks;
- support of producers through storage subsidies, crop insurance, and promotion of savings; and
- support of consumers through consumer credit, promotion of savings, and food subsidies (including food aid in various forms).

Although specific answers to the question as to which combination of policy options is most appropriate and cost effective would require further analysis and country-specific investigation, there are some lessons to be learned even from the theories and empirical findings presented in the papers so far.

One is that trade, both interregional and international, is the most efficient and flexible way to compensate fluctuations in production. Another is that food reserves can serve the purpose of stabilization, but possibly at rather high costs. Situations have been mentioned where food reserve stock policies are the preferable option. These relate to landlocked countries with near self-sufficiency, where fluctuations in production may cause extreme movements in prices.

Some difficult questions of great relevance for policy makers have not been touched at all, namely, what is the optimal size of a stock, which kinds of products should be stored, how can a strategic reserve be used as a buffer against seasonal fluctuations of prices, and, finally, how can one avoid a decline of private and cooperative reserve holding efforts? Irrespective of cost, the minimum size of a food buffer stock can be defined as the quantity of basic food needed to meet demand during the time it takes first shipments to arrive from outside to compensate for a shortfall of production of some given probability. But would a large stock size be cost effective, or could a foreign exchange reserve serve the purpose better? The International Monetary Fund's food facility as a source of credit for additional imports has been mentioned in this context. It would be a relevant research issue to study experiences with this promising policy instrument and investigate conditions for its further expansion.

Support of producers should concentrate on promoting storage and on establishing a favorable institutional framework for the mobilization of rural savings. Concerning crop insurance, Hazell et al. (1986) point out that, while theoretically an insurance scheme has many advantages, in practice, disadvantages, especially the lack of controllability, tend to prevail.

The most direct policy measure would certainly be to protect poor consumers against the repercussions of downward movements in food supplies. Food aid in the form of emergency aid or food-for-work schemes can play an important role here, provided it is strictly focused on yield cycles. In practice, food aid may reinforce instability, since shipments arrive only after the next season -- of higher yields -- has begun. More generally, one cannot always exclude the possibility that governments are frequently tempted to use food aid even for nonemergency purposes, in spite of access to foreign exchange for commercial imports.

This latter suggestion leads to another lesson to be learned from the papers: the moral hazard problem. Wherever a sizeable and permanent subsidy support is implemented, there is a risk that the beneficiaries may reduce their own efforts to cope with the risk and to reduce its causes. This may happen at the producer level if a multiple-risk crop insurance scheme is subsidized, or at the consumer level if subsidized consumption credit leads to reduced savings. It may also happen at the government level if unconditioned access to food aid leads to reduced efforts for holding food or foreign exchange reserves.

Concerning the choices among alternative policy options, crucial questions to be asked are

- What are the social benefits of the respective policies?
- Do the social benefits exceed the social costs?

Unfortunately, the papers contribute little to the answers to these questions. Further research is clearly necessary.

Individuals as well as countries may be in urgent need of public, including international, policy action in the event of major shortfalls in food production. Yet, in order to reduce the probability of such need, priority should be given to policies that tend to reduce the chances of such shortfalls and -- insofar as this cannot be achieved sufficiently -- to policies that strengthen the institutional structures for self-help rather than external help.

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29 Report of the Working Group on Public Policy*

John R. Tarrant

GOVERNMENT POLICY AND INCREASED VARIABILITY IN CEREAL PRODUCTION

As earlier working groups found, the evidence presented in the papers is not conclusive. However, in centrally planned economies (especially in the U.S.S.R.) inflexibilities in input distribution and in quota allocation reduces the ability of farmers to adjust to local (and changing) circumstances, and variability has increased. On the other hand, expansion into contrasting (albeit marginal) conditions in Soviet "newlands" has increased regional compensation effects and has helped to stabilize production. Also, a policy of encouraging private plot production (which now accounts for about 40 percent of total Soviet food production) exists when national production is poor, but the plots are discouraged, or not allowed at all, when national production is high. This is an important stabilization policy. A similar situation has arisen in Syria; as planning became more strictly enforced, variability increased.

GOVERNMENT POLICIES TO REDUCE VARIABILITY IN CEREAL PRODUCTION

The group considered the following six policy interventions to be appropriate for reducing yield risks:

1. Breeding for biological stress (pests, disease, and so on) is likely to be successful and cost effective. However, breeding for physical stress (like drought) is more difficult, less certain in result, and more doubtfully cost effective. We do not know what the biological and social trade-offs are in increasing yield response in poor environments compared to seeking higher yields in favorable environments.
2. Returns from tillage and other land management practices are potentially large in reducing yield variances, but the costs are likely to be high.
3. If fertilizer (especially phosphate) supplies are stable, then yield and production stability is likely to be increased.

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*The group consisted of Vishva Bindlish, Hartwig de Haen, Nazmi Demir, T. Engelhardt, Hung P. Nguyen, Victor Nyanteng, Martin L. Parry, David E. Sahn, John R. Tarrant, Winfried von Urff, Thomas S. Walker (chairman), Adolf Weber, and Donald Winkelmann.

Regularity of supply is vital. Despite transport and distribution difficulties and foreign exchange costs, the group believes that fertilizer imports are likely to be more cost effective than cereal imports.

4. Infrastructure and marketing improvements will improve food availability and stability.
5. Regular irrigation is vitally important. Area and yield covariance may increase with increased irrigation.
6. Improvements in farmers' knowledge about technologies and market prices can be expected to reduce production variability from year to year.

In common with almost every feature of economic development, these policies will make regions within a country behave more alike, thereby increasing production covariances between regions, even as they reduce variances within regions. This battle between reduced variances and increased covariances will lead to increased instability in national food supplies in some cases, especially where area covariances are a major component of the overall production variance. In other cases, like Mexico, where spatial contrasts are vast and yield variances dominate, the suggested policy directions are likely to reduce annual variability more than the increase in covariances.

In some cases, policies deliberately designed to reduce regional covariance effects are required, for example, expanding production in regions known to compensate one another in terms of production upsurges or downswings.

GOVERNMENT POLICIES TO REDUCE THE CONSEQUENCES OF VARIABILITY IN CEREAL PRODUCTION

The group considered the following six policies:

1. Stabilization through trade and buffer stocks would reduce the variability among countries. A landlocked country at or near self-sufficiency with foreign exchange shortages, for example, might favor buffer stocks. Other (perhaps most) countries would be better advised to rely on trade. One factor pushing countries toward buffer stocks is the experience of 1972-75. The work of the International Institute for Applied Systems Analysis on perturbating world food production and trade models by climate variability (especially coincidental climatic induced downturns for all major producers) may provide some evidence of the probabilities of such events and therefore of the costs and benefits of buffer stocks.
2. Food-for-work or employment guarantee schemes can be effective in dealing with downside variability, given good management and wages below local minimum wages. Careful consideration must also be given to who the beneficiaries are.
3. Promotion of savings can be facilitated by the development of a diversified banking system in which there is a close working relationship between the costs of borrowing and the returns to savings.
4. Food subsidies, to be cost effective, need to be targeted carefully, and the subsidy should be flexible in relation to variations in the supply and price of food. Food subsidies can

be most effective in protecting the needs of the urban poor against downside variability. It may be possible to use differentiated food products to help the targeting.

5. Consumption credit is not likely to work because of repayment difficulties.
6. Crop insurance is not a viable approach.

30 Approaches to Reducing Yield Variability: A Synthesis

Winfried von Urff

From the workshop discussions the following tentative conclusions can be drawn:

1. There is evidence that agricultural and other policy measures have increased variability in total cereal production. Even in an ideal setting where obvious mistakes such as abrupt changes in administered prices and production promotion measures can be avoided, government actions tend to increase interregional and interfarm covariance of yields.
2. Measures to promote irrigation, extension, price stabilization, and market information reduce yield variance for the individual farm and give higher levels of production on average. The final outcome with respect to aggregate variability depends on whether or not this reduction in variance is compensated or overcompensated by increases in interregional and interfarm covariances.
3. Any form of government planning that leads to restrictions or that limits the flexibility of individual farmers in adapting to changing situations is bound to lead to more variability, thus exacerbating the problem.
4. High variability in yields and in total cereal production is undesirable for the following reasons:

- Farmers may adopt risk reducing strategies, which imply less than optimal resource use and therefore reduced efficiency in crop production.
- Yield variability leads to unstable farm incomes, particularly in open economies where low yields are not automatically compensated by high prices.
- Consumer welfare is made unstable and thereby reduced, particularly in closed economies where the effect of yield variations on available quantities and prices tends to be high.
- Low-income groups are particularly vulnerable to reductions in real income originating from high food prices, whereas high-income groups suffer less and the real income of farmers with surpluses may increase.
- Variations in total cereal production may destabilize the entire economy, because variations in real private incomes lead to employment and investment repercussions and to variations in the intersectoral terms of exchange, tax revenue, and foreign exchange earnings.

5. Plant breeders may make some contribution to reducing variability, but this should not be overestimated. What plant breeders

can do is improve resistance against biotic yield reducers, such as pests and diseases. This is certainly an important task. However, they can do little to overcome physical constraints, particularly drought. Efforts in that direction rarely meet with success. In addition, they are costly, so that the question of cost effectiveness must be raised. There are some doubts as to whether it is justifiable to allocate large portions of scarce funds to such efforts when more promising avenues to higher and more stable production are available.

6. Breeding for high-input conditions is a reasonable strategy where the availability of the respective inputs, in particular fertilizer, pesticides, and insecticides, can be guaranteed at the village level, and at the time when they are needed. In addition, prices must be such that even low-income farmers can afford to buy these inputs. Under these conditions, the adoption of input responsive varieties will reduce yield variances for individual farms, but large-scale adoption will increase interfarm covariance.
7. Where assured input supplies cannot be fulfilled, an increased dependence on these inputs will increase the variability problem.
8. Even if breeders do their best to reduce yield variability, a considerable degree of variability will inevitably remain. It is the responsibility of policy makers and administrators to cope with these fluctuations.
9. The following means are at the disposal of policy makers to counter variability:

- foreign trade (including the IMF Compensatory Finance Facility);
- buffer stocks;
- crop insurance schemes;
- encouragement of rural savings;
- food aid, particularly food-for-work schemes; and
- consumer subsidies.

10. From an economist's point of view, the best way of compensating a country's fluctuations in cereal production is through foreign trade. However, there remains the problem of world price fluctuations. The foreign trade solution presupposes that a repetition of the events of 1973, when world market prices for cereals soared to three times their original values in less than 12 months, is not likely to recur. For small land-locked countries at the fringe of self-sufficiency, the foreign trade solution may be questioned because of the wide margin between export and import prices. Buffer stocks offer more security but normally lead to higher costs. To become more effective certain preconditions, such as the availability of technical infrastructure and improvements in storage capacity and storage methods, must be fulfilled. In general, unavoidable fluctuations in a country's cereal production should be compensated as much as possible through trade policy, providing that the risks entailed are not too high. Remaining fluctuations in food supplies should be buffered with domestic food stocks.

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Abstracts of Workshop Papers

I. YIELD VARIABILITY AND MODERN CULTIVARS: A SINGLE-FARM CASE STUDY

Jock R. Anderson and C. J. Findlay

Yield data for a commercial wheat-growing farm in southern Australia have been carefully maintained for the 21 seasons 1964-84 and are used here to investigate possible changes in variability from the first (11-year) subperiod to the second (10-year) subperiod. The two subperiods are dominated, respectively, by tall and short cultivars. While variability does seem to have increased when judged by variance and coefficient of variation, a more general and theoretically acceptable measure of risk based on concepts of stochastic dominance suggests that yields, while higher on average, are not more risky with the new cultivars.

2. VARIABILITY OF WHEAT YIELDS IN THE UNITED KINGDOM: ANALYSIS, FUTURE PROSPECTS, AND IMPLICATIONS FOR PLANT BREEDING STRATEGIES

Roger B. Austin and Michael H. Arnold

In the relatively stable climate of England the interannual standard deviation of national wheat yield has been relatively constant at about 0.2 tons per hectare during 1830-1980. As yields have doubled over the period, the standard deviation as a percentage of yield (the coefficient of variation of yield) has decreased. The interannual variation in yield at a given site varies with treatment (from 10 to 30 percent of the mean yield), lower values being obtained with good farming practice, which gives high yields. The field-to-field variation in yield has been and remains relatively constant at 14 to 19 percent of the mean yield.

We conclude that, given favorable economic circumstances in England, the interannual variation in yields, both at a given site and nationally, will decrease further. In more variable geographic regions, and in uncertain or less favorable economic circumstances, interannual variation in yield will be greater than in England at present. Until greater control of the environment is possible through greater inputs, plant breeders can make a cost effective contribution to reduced yield variation by focusing on stability as an essential criterion for selection.

3. AN ANALYSIS OF VARIABILITY IN INDIAN RICE YIELDS

Vishva Bindlish, Randolph Barker, and Timothy Mount

The relevant measure of production variability for a decision maker should be based on the difference between actual and expected production each year. Other workshop papers take trend production as the relevant expectation each year, but this need not take into account all the ex ante information available to decision makers at the time of making their forecasts.

In this paper, Indian rice production data by district are used to estimate production expectations models for both farmers and government. The former takes into account available rainfall data early in the season and the use of irrigation, high-yield varieties, and fertilizer. The government's expectations are specified as a distributed lag function of previous years' production. Production variability is then calculated for pre- and post-HYV periods with each of the two expectations models, and the results contrasted with those obtained from a standard trend model.

The results show that the measured variability and its change between the two periods is greatly affected by the expectations model assumed. Whereas the trend model predicts an increase in the variability of rice production after the introduction of HYVs, the results from farmers' and the government's expectations models suggest the opposite. The estimated variability is also markedly smaller for the farmers' expectations model, which is a direct reflection of the amount of input related information embodied in the model. This paper highlights the need for researchers to carefully define the expectations around which variability is evaluated and the need for government officials to endeavor to gather timely information on farmers' use of crop areas and inputs.

4. RICE PRODUCTION VARIABILITY: THE ROLE OF PEST RESISTANT VARIETIES AND OTHER INPUTS

Gerald A. Carlson

This paper surveys the biological and economic literature to indicate that there have been reductions in production variability seemingly associated with the use of pesticides. However, there are biological theories and case examples where intensive production using high levels of fertilizer, modern varieties, irrigation, and pesticides can be unstable.

Analysis of time-series data for rice in 14 countries shows there are countries where relative yield and production variability have increased. At the same time, other countries were able to secure greater production stability. Higher rice variability was found in Taiwan, Nepal, and Malaysia, with small percentage increases in South Korea, India, and Japan.

Farmers may devote resources to decrease variability of output; many of these resources are only qualitatively different from the usual production inputs. Farmers might generally accept higher income variability in return for sufficiently higher mean income.

Statistical evidence is presented to show that country-level coefficients of variation for production and yield are reduced with greater use of pest resistant rice varieties and with more extensive irrigation. Labor-intensive rice production and the production areas and time periods of larger farms were found to have lower relative variability about trend production. The effect of more intensive nitrogen use is unclear, but one data set shows statistically higher production variability with higher nitrogen use per hectare. Holding input use constant, there was not higher relative yield variability on average in the 1970s than in the 1960s for this sample of 14 rice countries. They produce about 90 percent of world rice production but have about a 25 percent higher rice production variability than the rest of the Asian countries.

Rice production variability is not exclusively found in either poor or wealthy countries of Asia. Some of the countries with the highest yields have been experiencing increases in production variability. At least one country (South Korea) has reduced its use of nitrogen fertilizer and modern varieties in the past few years. The traditional varieties are sometimes preferred for their cold tolerance and taste.

Most cereal farmers rely on labor, mechanical, and genetic approaches to pest control. Relatively higher pesticide-to-wheat price ratios since 1976 may predispose little increase in pesticide use for wheat. However, the constantly falling prices of pesticides relative to the prices of rice is probably encouraging more pesticide use in many rice producing countries. Poor data on price and

quantity for pesticides at both the aggregate level and microlevel hinder analysis in this area.

Subsidized fertilizer prices, credit linked to use of modern varieties, and price supports for rice have increased rice production dramatically in the past two decades. Now there are large stocks of domestic rice in countries such as Indonesia, which has traditionally been the largest rice importer. Rice farmers are experiencing depressed prices. At the same time, there is more variability in rice production in some areas. Increased use of irrigation and pest resistant varieties seem to be helping countries cope with instability in the production system. More attention to the combined effect of input use on stability and mean output is needed.

5. MODERN RICE VARIETIES AS A POSSIBLE FACTOR IN PRODUCTION VARIABILITY

W. Ronnie Coffman and T. R. Hargrove

High-yielding semidwarf varieties of rice and wheat have spread more rapidly and extensively than any other technological change in the history of Third World agriculture. Farmers' adoption of a relatively few improved varieties has increased Asian rice production tremendously but has narrowed genetic diversity of cultivated varieties. Most popular semidwarf rice varieties have similar cytoplasm, and virtually all have the same dwarfing gene. The common ancestry of modern rice varieties does not necessarily imply that they increase production variability.

Varietal characteristics affecting yield stability include agronomic characteristics (photoperiodism, growth duration, height, tillering, and grain dormancy), pest resistance (diseases, insects, weeds), and stress tolerance (drought, flood, adverse soils, adverse temperatures). Breeders have shortened and fixed the growth duration of modern rice varieties to maximize production per unit area of land and time under favorable conditions, eliminating the stabilizing effects of photoperiod sensitivity but bringing on staggered maturity, which might spread risk and contribute to stability. The short stature of modern rice varieties is not optimal under stress conditions such as drought, and it decreases their ability to cope with other adversities such as floods and weed growth.

Modern varieties are resistant to certain major pests, but they were developed in a short time on experiment stations, where the biological environment was affected by the use and misuse of pesticides. They may not have a spectrum of pest resistance comparable to that of traditional types in specific agroecologic locations. This situation could contribute to increased production variability but could be offset by the International Rice Testing Program, which allows breeders to test cultivars under a large number of environments in a very short time.

Modern varieties, combined with government subsidies for insecticides, made insecticide application profitable for farmers. The broad-spectrum insecticides initially recommended, and still on the market and subsidized in many developing countries, devastated the natural enemies of the brown planthopper and caused a resurgence of the pest, contributing to production variability in several Asian countries.

Modern rice varieties are less tolerant of drought and more vulnerable to flooding than are traditional types. Lack of low-temperature tolerance has contributed to production variability in limited areas, such as Korea.

Rice breeders seek to combine traits that give traditional varieties their production stability under unfavorable conditions. A

few modern varieties with resistance to agroecologic stress, inherited from traditional parents, have been released for farmers' cultivation.

With traditional rice varieties, production may be more stable, but unrealistically low. Without modern rice varieties, Asia would starve or be a beggar to the industrialized countries for food. Rice scientists have an obligation to diversify the genetic base of improved varieties and to transfer traits that give traditional varieties their production stability into a new range of improved rices for areas bypassed by the green revolution.

6. POSSIBLE GENETIC CAUSES OF INCREASED VARIABILITY IN U.S. MAIZE YIELDS

Donald N. Duvick

Year-to-year variation in average U.S. maize yields has been greater in the past 15 years (1970-84) than in the preceding 20 years. Climatic variation, particularly summertime rainfall and temperature, is probably the chief cause of annual variation in maize yields. Clusters of drought years, for example, occurred in the first decade of this century and also in the 1930s, the 1950s, and the past 15 years. But additional factors may amplify or decrease effects of weather. Of particular interest is the possibility that increased genetic uniformity may be a cause of increased annual variation in U.S. maize yields.

Changes in other cultural practices may also be important. Noteworthy changes in U.S. maize culture in the past 15 to 20 years are the countrywide movement to use ample amounts of nitrogen fertilizer, high-density planting, early planting (synchronous across the U.S. corn belt, where the greatest part of U.S. maize is produced), and planting of widely grown single cross hybrids. These changes, properly integrated, all give rise to higher grain yields.

There has been no decrease in genetic diversity, using as a measure of diversity the numbers of widely used inbred lines in use as parents of commercial hybrids over the past 30 years. Newer hybrids are better able to withstand unfavorable growing conditions, outyielding older hybrids when rainfall or soil fertility are limiting. But they also give even greater yields compared to the old hybrids in highly favorable years, thus giving the possibility of greater year-to-year variance in yields. It appears that, although the adoption of modern cultural practices, including superior hybrids, has raised the long-term yield average for U.S. maize, it may also serve to amplify the spread between high-yield and low-yield years.

7. TRENDS IN YIELD INCREASE AND YIELD VARIABILITY OF WINTER WHEAT AND SPRING BARLEY IN BAVARIA, 1950-84

G. Fischbeck

Calculations of 26 ten-year moving averages between 1950 and 1984 were used to calculate changes in the mean and variability of yield, area, total production, and prices of winter wheat and spring barley, the major cereal crops in the state of Bavaria. While average yield increases for winter wheat were maintained at high but slowly decreasing rates throughout the 35-year period, less intensive yield increase for spring barley ceased during the past decade.

A tendency for increased yield variability was observed for both crops in the early phases of yield increase. A change in trend in the 1970s brought yield variability for both crops to values lower than those observed in the 1950s.

Yield data from field trials indicate decreasing superiority and even inferiority of modern cultivars in low-input systems. Higher values obtained for modern cultivars of both crops are caused mainly by differences in yield potential, which need improved growing conditions for realization.

8. YIELD STABILITY AND MODERN RICE TECHNOLOGY

John C. Flinn and D. P. Garrity

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

Adaptability and stability in modern varieties are correlated, although breeding for location specificity will contribute further to yield stability. Second-generation modern varieties have greater pest resistance than traditional varieties. Varietal resistance coupled with judicious use of pesticides will increase yield stability. Modern varieties are more fertilizer responsive than traditional varieties, and yield variances increase as N rates increase. Farm-level data show that improved agronomic practices in aggregate may result in an increase in the negative skewness of yield distributions. Therefore, modern variety technology need not place farmers in a less favorable risk situation.

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

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

9. INTERAREA MAIZE YIELD CORRELATIONS AS INFLUENCED BY TECHNOLOGY

James B. French and J. C. Headley

This paper tests the hypothesis that interarea yield correlations have increased in the United States since the introduction of modern maize technologies. Maize yields by crop reporting districts were analyzed for two periods, representing low and high technology (1932-46 and 1967-81, respectively). The interarea correlations were derived after removing trend and the effects of weather. Little evidence was found for any increased interarea covariance associated with technology. Climatic factors were found to be principally responsible for positive yield correlations, with not much evidence of significant increase over time.

10. CHANGING PATTERNS OF VARIABILITY AND FUTURE STRATEGIES FOR CEREAL PRODUCTION IN INDIA K. S. Gill

This paper analyzes changes in the mean and variability of area, yield, and production of important cereals in India at the national, state, district, and block levels. The comparisons are made between two time periods corresponding to pre- and postmodern technology eras.

At the national level, the variance of production and yield of rice, wheat, maize, and barley increased significantly between the two periods. Within states, yields displayed a systematic tendency toward greater variance for all the important cereals. However, for agriculturally developed Punjab State, the variance of yield for wheat and rice declined between the two periods. At the district level within Punjab, the coefficient of variation of wheat yields declined sharply, and this pattern was similarly pronounced within different blocks in Ludhiana district. The results suggest that the higher the level of agricultural development, the lower the variability of yields within a region.

Several factors account for changing patterns of variability in cereal yields. The key factors being rapid adoption of semidwarf, high-yielding varieties, extensive use of fertilizers, and increased use of insecticides, weed killers, and farm machinery. Furthermore, government policies for promoting production through the supply of inputs, credit facilities, and improved infrastructure, have played an important role in increasing cereal production. As a result, cropping patterns have also become oriented in favor of cereals and against chickpeas and pearl millet in Punjab. Changes in the pathogen, pest, and weed flora, depletion of soil nutrients resulting in micronutrient deficiency, and energy constraints are the other consequences of this technology.

Future strategies to stabilize yields and increase production must focus attention on upgrading the yield potential of cereals (particularly maize, pearl millet, sorghum, and barley); developing varieties resistant to multiple diseases and pests; developing early maturing and short-duration varieties suitable for rotation; developing hybrid varieties of rice and wheat; developing varieties with wide adaptability to overcome the risk of uncontrollable environments; maintaining soil health; and developing efficient on-farm water-use technology.

In addition, the government must assure timely and adequate supply of inputs and credit, remunerative procurement prices, appropriate market facilities, and so on. Formulation of appropriate strategies to overcome the bottlenecks at the microlevel (the village) is very important for increasing and stabilizing cereal production.

11. CHANGES IN YIELD STABILITY OF WHEAT, BARLEY, AND TOTAL CEREALS IN THE EUROPEAN COMMUNITY, GERMANY, AND SCHLESWIG-HOLSTEIN

H. Hanus and L. Rizos

Yield and yield stability were analyzed for wheat, barley, and total cereals at three levels of aggregation: the European Community, the Federal Republic of Germany, and the German state of Schleswig-Holstein. The analysis was conducted for the years 1953 to 1984.

For all the crops and regions studied, a progressive trend in mean yields was observed, and the increase in yield was generally larger the higher the initial yield within a region. After the data were corrected for trend and weather, the only region showing a significant correlation between the absolute size of the residuals and time was Schleswig-Holstein. However, since this result held for total cereals and not for the two major individual cereals of wheat and barley, changes in area variability are most likely the source of the increase. Considering the strong trends in mean yields over time, the relative variability of yields has declined for all crops and regions.

12. INFLUENCE OF NITROGEN FERTILIZER AND FUNGICIDE TREATMENTS ON YIELD AND YIELD VARIABILITY OF WHEAT AND BARLEY

H. Hanus and P. Schoop

Yields of wheat and barley increase with increasing nitrogen applications, but the increments of yields depend on the total amount of nitrogen used and on fungicide treatments. When diseases were not controlled by fungicides, maximum yield was lower and was reached at lower nitrogen levels. The yield from fungicide treatment increased with increasing nitrogen. The variability of yields was generally less when fungicides were used and yields were higher. Variability was nearly constant until maximum yield was reached, after which it increased strongly. Applications at the beginning of growth reduced the variability, while applications at jointing or ear emergence increased the variability.

13. CHANGING PATTERNS OF VARIABILITY IN EGYPTIAN CEREAL PRODUCTION

Peter B. R. Hazell, Hung P. Nguyen, M. Rechache, and M. T. Zaied

Total cereal production increased substantially in Egypt between the periods 1955-69 and 1970-84. At the same time, the stability of cereal production improved. During the period 1955-69, the probability of a shortfall in total cereal production of 5 percent or more below trend was 0.21. This probability declined to only 0.03 in the period 1970-84.

Area and yield increases were both important sources of growth in Egypt's cereal production. Yield increases were most important for wheat, whereas area increases were the predominant source of growth for summer rice and summer maize.

Most of the reduction in the variability in production is attributable to a decline in area variability within crops and regions and, between regions, to a shift toward offsetting patterns of variation in yields and in areas sown to individual cereals. Changes in yield variability within crops and regions were not particularly important.

Although these findings differ somewhat by individual cereals, the general finding is that changes in patterns of area variability are the primary source of Egypt's increased stability in food production. This stability may have little to do with recent improvements in irrigation, varieties, and other agricultural technologies, but may simply reflect the higher variability generated in the first period of the analysis by the land reforms of the 1960s and the more rigidly enforced quotas for allocating land to crops at that time.

14. A NOTE ON CHANGING PATTERNS OF VARIABILITY IN CEREAL PRICES

Peter B. R. Hazell

World cereal prices have become much more variable since the early 1970s, and this has led to corresponding increases in the variability of domestic farm-gate prices in some of the major cereal exporting countries. However, many countries have been successful in buffering their domestic prices from the increased volatility of world markets, and some have even been able to reduce the variability of domestic prices.

There is a surprising lack of collinearity between many domestic cereal prices and world cereal prices. It would seem that countries that buffer their domestic market prices do so in ways that also shield their farmers from directional changes in world market prices. There does not appear to have been any significant change in these patterns of collinearity since the early 1970s.

On the other hand, there has been a dramatic increase in the collinearity of world cereal prices between crops, and this has been reflected in an increase in the correlation of domestic farm-gate prices between crops, both within and between countries.

15. VARIABILITY IN MAIZE AND WHEAT YIELDS AS INFLUENCED BY TECHNOLOGY AND WEATHER IN THE UNITED STATES, 1931-81

J. C. Headley and James B. French

Yields of maize and winter wheat from crop reporting districts in the United States were analyzed for two periods representing low and high technology (1932-46 and 1967-81, respectively). The variability of the yields after removing trend and the effects of weather and area was estimated. Absolute variance has increased with technology for both crops, although for winter wheat the increase is attributed to observed weather influences. In a majority of districts, the coefficient of variation declined for both crops. A majority of districts exhibited nonskewed distributions for both crops, suggesting that variance can be used as the basic measure of risk.

16. NEW AGRICULTURAL TECHNOLOGY FOR IMPROVED FOOD SECURITY AND STABILITY

H. K. Jain, M. Dagg, and T. A. Taylor

Many developing countries in the past 15 to 20 years, in the wake of increasing population pressures and mounting food deficits, have taken major policy decisions to transform their traditional agriculture. The discovery of new plant genes, leading to a higher harvest index and better response to high fertility and improved agronomic management, has contributed greatly to the development of this new technology. The technology has already had considerable impact, and some developing countries in recent years have recorded higher cereal production than the rest of the world.

The new technology, however, is also a potential source of variability in the production and productivity of agriculture in many of these countries. Its sensitivity to agronomic management and its genetic uniformity, creating favorable conditions for disease and pest epidemics, are a source of this variability. Also, adoption by farmers with varying resources and the phased nature of the production programs planned by the governments create another potential for variability.

But with all these limitations, the modernization process now being introduced should emerge as a major source of greater food security and also greater stability of agricultural production and productivity. The trends in cereal production in India over a 35-year period, analyzed here, support this conclusion.

17. SOURCES OF YIELD VARIATION IN MILLET AND THEIR RESEARCH IMPLICATION

John McIntire and L. K. Fussell

Analysis of farm data from a rainfed production system in Niger shows high variance of millet yield with traditional technologies. Significant yield variation was associated with year, village, and treatment. Chemical fertilizers and improved cultivars were analyzed for their effects on variance. Fertilizers contributed significantly to increased absolute variance with the local cultivar, but relative variation was sometimes reduced because of an increase in mean yield. Improved cultivars did not reduce absolute or relative variance with chemical fertilization above that normally applied by farmers.

Variance partitioning of millet yield provided a good approximation of the sample variance of yields in 13 of 18 cases. It shows that the average contribution of heading (tillering) variation was nearly 50 percent of the total variation across treatments, sites, and years. Density variation was generally second to heading variation in contribution to total variation. Analysis of interaction terms showed that density was nearly always negatively correlated with the other terms, suggesting that increases in mean density would not necessarily increase mean yield or yield variance.

The partitioning results show that changes in cropping practices, such as fertilizers and densities, could increase mean yield but would either raise variance absolutely or relatively. Efforts to reduce millet yield variations should therefore concentrate on reducing tillering variations. However, since such variation is an important component of the plant's ability to raise yield in response to its environment, it may be difficult to achieve a stable cultivar under farmers' conditions without sacrificing some mean yield.

18. A NOTE ON EFFECT OF VARIETAL IMPROVEMENT AND INTERCROPPING ON VARIABILITY OF CEREAL YIELDS

M. Mruthyunjaya and Dayanatha Jha

This paper presents some evidence from India on yield variability under alternative technological situations. This evidence suggests that higher yields (under improved technological situations) do not seem to be associated with greater variability. For both varietal and crop mixture options there was no clear evidence of distinctive risk regimes. These results suggest two important conclusions. First, there is a need to continue the search for factors responsible for increased variability, and second, evaluation techniques used by agrobiological scientists appear to have served well in the context of yield-environment relationships.

19. AGRICULTURAL PLANNING POLICY AND THE VARIABILITY OF SYRIAN CEREAL PRODUCTION SINCE 1970

Hung P. Nguyen

During the 1971-81 period, the variability of cereal production in Syria, as measured by the coefficient of variation around trend, increased significantly. A variance decomposition procedure shows that higher yield correlations within and between wheat and barley are a major contributor to this increased variability. Greater yield variability for wheat, which may be partly due to technological change, also played a role in this increase. Agricultural planning policy may account for the increasingly synchronized pattern of yield variations.

20. SOURCES OF INCREASED INSTABILITY IN SOVIET GRAIN PRODUCTION DURING THE 1970s Hung P. Nguyen

During the 1970s, the instability of grain production of the Soviet Union, as measured by the coefficient of variation around trend, increased significantly. Using a variance decomposition procedure to identify the important sources of change in the variance of total grain production, it is shown that higher correlations between yields and between area and yield, especially those between different crops, are a major contributor to this increased instability. Greater yield variability, which may be partly due to technological change, also played a role in this increase. Changes in agricultural policies affecting input allocation behavior may account for the increasingly synchronized pattern of yield and area-yield variations.

21. YIELD STABILITY OF WHEAT AT THE REGIONAL LEVEL: A COMPARISON OF NINE COUNTRIES

Hung P. Nguyen

This paper focuses on yield variability measured in given biological environments over time. A simple biological model was used to derive some hypotheses about the effects of modern agricultural technology, such as high-yield varieties (HYVs), on the stability and skewness of yields at the regional level. Data on fluctuations in wheat yields around trend for 132 regions in nine countries were used to test the hypothesis.

The results point to the greater probability of receiving below-average yields for wheat in many regions where the adoption of HYVs and more intensive cultivation has occurred. Homogenizing the plants' environment and narrowing the genetic base may have the destabilizing effect of synchronizing yields not only between regions but also between crops. To a large extent, economic and policy factors have become part of the plants' environment. The problem of yield stability at the regional level, therefore, requires an integrated strategy toward biological, technological, and political-economic factors.

22. CONTRIBUTION OF GENETIC IMPROVEMENT TO INCREASES IN WHEAT YIELDS AND VARIANCE OF PRODUCTIVITY IN THE GREAT PLAINS

C. James Peterson, V. A. Johnson, J. W. Schmidt, and R. F. Mumm

Wheat yield data from hard red winter wheat cultivars in the Southern and Northern Regional Performance Nurseries (SRPN and NRPN) of the Great Plains from 1959 to 1984 were examined. A linear increase in mean yield was indicated, averaging 56 kilograms per hectare per year in each nursery. A combination of improvements in cultivars, production practices, and increased fertilization contributed to yield gains. Genetic improvement and breeding contributions to increased yield accounted for 55 percent of the total yield gain in the SRPN from 1959 to 1984 and 40 percent of the yield gain in the NRPN from 1966 to 1984.

Mean squares associated with genotype-environment interactions have increased linearly in both the SRPN and NRPN. Breeding and development of improved cultivars have contributed to increased yield variability over environments in the nurseries. Recent cultivars appear to be less stable over wide ranges in environmental conditions and to have narrower adaptation. These cultivars have increased capacity to respond to favorable environments and to increased production inputs. Little genetic improvement in yield of cultivars under marginal or highly stressed environments is indicated. Differences in production between favorable and less-favorable environments have widened.

23. YIELD STABILITY IN BREAD WHEAT

W. H. Pfeiffer and H. J. Braun

Data from experimental variety trials in CIMMYT's international wheat testing system were analyzed for grain yield and yield stability. The results demonstrate that high-yield varieties have at least the same yield stability as local varieties, but on a higher yield plateau. They are also more responsive to favorable environments and the use of modern inputs.

24. YIELD STABILITY OF CIMMYT MAIZE GERMPLASM IN INTERNATIONAL AND ON-FARM TRIALS

H. N. Pham, S. R. Waddington, and J. Crossa

Data from experimental variety trials in CIMMYT's international maize testing system and from on-farm trials comparing improved with local maize varieties were analyzed for grain yield and yield stability. Results of international trials (containing varieties developed from different cycles of improvement of four tropical maize populations) indicate that at every cycle some varieties not only gave high yields but were stable over a range of environments. In the on-farm variety trials grown under farmers' level of inputs and management, improved varieties gave higher mean grain yields. There was little difference in stability between the two types across all environments sampled, though improved materials were more responsive to the better environments. On-farm trials comparing local varieties and practices with improved varieties and more advanced practices indicate that the latter combination was the most economically viable.

25. FARM RISKS: A STUDY OF A MIXED FARMING SYSTEM IN HIGHLAND ETHIOPIA

Gil Rodriguez and F. Anderson

Risks have always formed a part of the costs incurred by farmers. For small subsistence farmers confronted with limited technological options and having few assets, risk costs are especially high.

This paper uses a representative farm model of a traditional smallholding in the high-risk Debre Brehan area of Ethiopia to address two objectives:

- The risk reducing role of livestock enterprises in an integrated traditional crop-livestock system; and
- The impact of changes in livestock technologies within a farm-firm subsistence environment.

The stochastic aspects of the farm enterprises are represented by variations in crop gross revenue and milk output. Three farm scenarios were simulated:

- Using traditional draft ox either in singles or pairs;
- Using an improved single-ox technology, which yields less manure than a traditional ox pair but is more power efficient in such activities as land preparation; and
- Owning a cross-bred cow, which requires more labor and feed but yields a larger mean milk output with a very high coefficient of variation relative to that of the local cow breed.

The major empirical results of the model are

- Within the traditional mixed farming system, and given various assumptions about the level of risk aversion, the mean net farm income corresponding to the various optimal farm plans of the traditional single-ox option are higher than that of the ox pair. Although the standard deviation of net farm income is smaller under the ox pair, the high mean net farm income of the single ox is sufficient compensation for the greater income variation arising from it.
- The mean net farm income under the improved single-ox technology is greater than the traditional ox pair. However, it has a slightly lower income than the traditional single-ox model due to the higher feed costs. The standard deviation of net farm income is lower for the improved single ox relative to the traditional single-ox option.
- Human labor is expensive for the period October through January and at all levels of risk aversion if the farmer owns a cross-bred cow. The cropping pattern shifts in favor of barley and horsebeans during the short-rains period, a period known for its substantial rainfall variability. However, the change in the crop mix induced by the cross-bred cow indicates that the incremental risk costs are completely remunerated by the reduction in labor costs.

26. AREA, YIELD, AND INCOME VARIABILITY IN DIVERSION IRRIGATION SYSTEMS IN THE PHILIPPINES: A SIMULATION ANALYSIS

Mark W. Rosegrant

The variability in area, yield, production, and income for rainfed and irrigated rice in the Philippines was compared, and the effect on variability of different water distribution rules and qualities of canal maintenance was assessed. The analysis used an irrigation system simulation model that permits assessment of seasonal and crop-year area, yield, production, and income for diversion irrigation systems and for rainfed conditions, using 20 years of rainfall and streamflow data.

The results show that irrigation more than doubles crop-year rice production and farm income. However, because of the dependence of diversion irrigation systems on highly variable dry season streamflow, irrigated dry season production and income are much more variable than wet season rainfed production and income. On a crop-year basis, production and income variability is as high or higher under irrigated conditions than under rainfed conditions. Reform of the management of irrigation systems can reduce disparities among farmers within the system but does not induce large reductions in systemwide variability. Investments in irrigation system infrastructure and management are not substitutes for other policies, such as the use of buffer stock or import management, to offset the adverse effects of production instability.

27. EFFECT OF FERTILIZER USE ON THE VARIABILITY OF BARLEY YIELDS IN DRY AREAS Kutlu Somel

This paper attempts to measure the effect of fertilizer use (nitrogen and phosphorus) on the variability of barley yields in dry areas. Two sets of data were used to measure variability of yields. These data come from multiple, site-multiple, season-multiple, researcher managed trials conducted mostly on farmers' fields. The evidence quite clearly indicates that fertilizer use reduces variability in barley yields under rainfed conditions in dry areas. Furthermore, substantial gains in yields are possible, along with reductions in variability.

Research on this important crop of the drier regions of western Asia and North Africa indicates that improved cultural practices, with emphasis on fertilizer use, improves the efficient use of the most critical limiting factor, water. Fertilizer use improves water-use efficiency without increasing water use. Increased root growth and early plant establishment allow increased transpiration and reduce evaporative losses from the soil surface. Furthermore, maturity is advanced, enabling plants to avoid stresses from the drought that invariably occurs at the end of a season. These stresses are the principal factors that reduce the variability of yields.

28. CHANGING PATTERNS OF CEREAL PRODUCTION VARIABILITY IN CHINA DURING THE PEOPLE'S REPUBLIC PERIOD

Bruce Stone and Tong Zhong

Between the 1950s and the 1979-83 period, food crop production in the People's Republic of China increased by 98 percent. This increase was especially great in absolute terms for the three leading crops characterized by significant technical change (rice, wheat, and corn), of which China is now the world's largest or second largest producer. Before most of this technical change, good harvests and bad harvests tended to average out among provinces, such that during 1952-57 national food crop production variances were typically quite low. Although still not high relative to many countries, these variances have increased significantly: 26 percent for rice, 121 percent for wheat, 186 percent for other food crops, and 286 percent for all food crops combined. China's importance in world food production and its high and highly variable recent participation in international grain trade make these variances of particular concern.

A variance decomposition procedure to identify important sources of change in the variance of total food crop production shows that by far the greatest contribution to increased variance were increases in interprovincial production (and especially yield) covariances. The proportions explained by changes in interprovincial covariances were high even relative to those of other countries (for which similar results have appeared): 88 percent for rice, 85 percent for wheat, 73 percent for other food crops, and 91 percent for all food crops taken together. Hypotheses for explaining this phenomenon include increased provincial responsiveness to central policy, increased market involvement, and especially the interaction of centralized policy with supply of modern agricultural inputs now critical to yield levels.

29. AN ANALYSIS OF VARIABILITY IN SOVIET GRAIN PRODUCTION

John R. Tarrant

The Soviet Union has at least three contrasting production regions, and in most years high production in one of these regions compensates for low production in others. This compensation, a result of contrasting weather conditions, is of great importance in stabilizing overall Soviet production. But as production trends in these different regions are markedly different, these regional compensation effects will reduce through time. Thus annual variability in Soviet grain production can be expected to increase unless the rates of increase in the production of contributing regions can be brought into line. This will have to be achieved by accelerating the growth rates in regions that are not growing fast -- especially in Kazakhstan and Siberia. Unless and until this can be achieved, Soviet production will become increasingly variable, as will import requirements, with consequential destabilizing effects on world trade.

30. HIGH-YIELD VARIETIES AND VARIABILITY IN SORGHUM AND PEARL MILLET PRODUCTION IN INDIA

Thomas S. Walker

The following questions relating to coarse grain production variability in India were addressed: (a) Has production variability in the major sorghum and pearl millet growing regions increased over time? (b) Has the change in production variability been directly caused by changes in means and variances of area and yield within regions or by their covariances across regions? (c) Has the diffusion of high-yield varieties (HYVs) positively influenced or conditioned the direct cause found in (b)?

A statistical decomposition analysis revealed that (a) variability in sorghum and pearl millet production increased both absolutely and relatively between the periods before and after the green revolution (1956/57 to 1967/68 and 1968/69 to 1979/80); (b) increased production variance stemmed overwhelmingly from increased yield covariances among the sorghum and pearl millet production regions; and (c) changes in HYV adoption, irrigated area, and increased rainfall covariance are positively associated with, if not partially responsible for, more covariate yields over time.

A mix of trade and storage policies can effectively offset most if not all the variability costs of increasing yield covariance. If these policies are not forthcoming, investing in crop research to maintain and enhance resistance to yield reducers and to broaden genetic variability will have additional stability benefits over and above returns to increased production.

31. YIELD AND HOUSEHOLD INCOME VARIABILITY IN INDIA'S SEMIARID TROPICS Thomas S. Walker

The potential for enhanced yield stability to translate into reduced variability in income was quantified with household panel data from three villages in India's semiarid tropics (SAT). Risk benefits were estimated under a scenario of perfect (one-at-a-time) yield stabilization for the common crops in each village. Although the coefficients of variation for mean household income for the producers of these crops ranged from 0.33 to 0.47, the risk benefits from perfect yield stabilization were negligible.

Perfect yield stabilization did not buy much in the way of risk benefits because most farm households rely on several crops and on multiple income sources, particularly earnings in the local labor market. Diversified cropping patterns and area variability, characteristics of dryland agriculture, also severely erode the effectiveness of policies or technologies that work through yield to reduce variability in household income and consumption.

These results support the argument that little economic value should be attached to the supposed risk reducing attributes of improved varietal technologies for resource-poor households in India's SAT. Such technologies should be evaluated with regard to their effect on mean yield or output levels, equity, and nutrition.

32. YIELD VARIABILITY AND MODERN CULTIVARS: THE CASE OF WHEAT IN NEW SOUTH WALES

G. H. Wan, A. J. Cowie, Jock R. Anderson, and John L. Dillon

Data on the production and yield of wheat in New South Wales, Australia, for the 39 seasons 1945/46 to 1983/84 were used to investigate changes in variability from a 29-year subperiod, 1946-74, to an 8-year subperiod, 1977-84. The subperiods were dominated, respectively, by tall (traditional) and short (modern) cultivars. Yield and production variabilities seem to have increased from already high (internationally speaking) levels with the introduction of modern cultivars when judged by both variance and coefficient of variation.

33. PATTERNS OF GRAIN YIELD VARIABILITY IN WORLD AGRICULTURE

Adolf Weber

Variability was measured by the index analogous to a coefficient of variation developed by Cuddy and Della Valle, which eliminates the effects of trends on the measurements. Country data on production, yields, and areas were the basis of statistical analysis.

The geographical presentation confirms that adjacent countries of similar size tend to have similar grain production variabilities. These variabilities are shaped more by the climate than by the economic or political system. Countries with substantial irrigated areas show the lowest degree of production and yield variability. Production variability is the highest in the semiarid countries of Africa, in countries of the Near East, and in Australia. In a global perspective, Europe and both Americas are relatively stable.

Various countries have distinguishably different grain yields. Those with high yields have comparatively higher yield increases and a decreasing index of yield variability. National and international breeding programs have, therefore, to assess carefully their research priorities relative to the increase and the stability of yields.

34. YIELD VARIABILITY AND YIELD POTENTIAL OF DRYLAND BARLEY IN SYRIA, 1980

Heinrich C. Weltzien and Monika Zahlouta*

Barley is the most important dryland crop in Syria. Yields reported by official statistics are rather low and varied between 110 and 1,200 kilograms per hectare from 1960 to 1978. In many fields, spots with improved growth were observed. This growth was clearly related to underground ant nests and indicated a much higher yield potential than previously assumed. A survey was conducted throughout Syria to compare the grain yields of these improved spots with yields from surrounding check areas. A total of 245 samples were taken from 82 locations. Yields at improved spots were generally greater by 100 percent or more than check yields. The variability between locations was considerable. Yields ranged from 5.0 to 8.0 metric tons per hectare in the spots to 0.5 and 4.0 in the check areas. Major yield factors responsible for the increase were kernel weight and the number of ears per square meter. Straw yield increases were even more pronounced. No correlation between rainfall data and yield was found.

There is strong experimental evidence that nutrient deficiencies frequently overrule water deficiency. Nutrient analysis from ant nest soil indicates high amounts of phosphate and nitrogen. Fertilizer experiments support the nutrient hypothesis. We conclude that improved soil fertility will increase barley yields through better water-use efficiency in Syria.

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*This paper is based on work conducted at the International Center for Agricultural Research in the Dry Areas, Aleppo, Syria.

35. VARIABILITY IN YIELD OF PEARL MILLET VARIETIES AND HYBRIDS IN INDIA AND PAKISTAN

John R. Witcombe

In the International Pearl Millet Adaptation Trial, both hybrids and varieties as entries have been grown multilocationally in India and Pakistan. The grain yield data over five years were analyzed in a number of ways to examine the stability of the entries.

A regression analysis indicates that the breeders' procedure for selecting the high-yielding entries across environments is correct, as they include entries that perform well in poor environments. Selecting entries on predicted performance in the low-yielding environment appears to be a less reliable procedure.

The hybrids are generally higher yielding than the varieties but are less stable. The most important source of genotype x environment interaction in the regression analysis was the deviation from the regressions (S^2_d values), rather than variation between the regressions. The varieties were superior to the hybrids in this respect, having lower than average S^2_d values. However, a constrained mean-variance analysis showed that the high-yielding genotype was always preferred among the risk-efficient entries. Similarly, a first-degree stochastic efficiency analysis indicates that the hybrids, despite their inferior stability in a regression analysis, are more risk efficient than the varieties.

One variety, ICMV 81111, from an advanced cycle composite, combined both high yield and stability. Its advantage over hybrids in contributing to crop yield stability is discussed.

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